Review of Atlantic large coastal sharks assessment

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1 Executive Summary

A review of the assessment of Atlantic coastal sharks and resulting management recommendations was conducted under contract to the Center for Independent Experts (CIE), University of Miami. The review focused primarily on the data, assessment, and management recommendations for large coastal sharks presented in the "1998 Report of the Shark Evaluation Workshop" (SEW-1998) and addressed the specific issues identified in the CIE *Statement of Work*.

This review confirms that the Atlantic large coastal shark stock is currently depleted and that reductions in fishing mortality rates are required for the stock to rebuild to higher productivity levels. However, specific conclusions regarding the relative status of the sandbar and blacktip shark species are overstated in the 1998 stock assessment report. The analytical stock assessments for these species, in particular the blacktip shark assessment, are less reliable than the assessment for the large coastal shark stock aggregate.

The Bayesian approach and stock production model employed for the 1998 stock assessment are consistent with contemporary fisheries stock assessment methodology. The Bayesian approach is appropriate for the large coastal sharks assessment, and inclusion of Bayesian priors in the 1998 assessment reduced uncertainty in parameter and stock status estimates relative to previous assessments. Stock production models are the most commonly used analytical method for fisheries stock assessment when the data available are limited to catch and abundance index data, as in the large coastal shark assessment.

Reliability of a stock assessment may be compromised if the assumptions of the methodology are violated. A key assumption of stock production models, that the catch and CPUE data reflect a closed population, is not appropriate for the large coastal shark species, which migrate outside the U.S. fishery zone where they are susceptible to non-U.S. fisheries. To adhere to the closed population assumption, the blacktip assessment included catch estimates of sharks taken in Mexican waters. The large coastal sharks aggregate and sandbar shark assessments did not account for catch outside the U.S. region; this will bias parameter estimates. However, a sensitivity analysis, conducted for this review, suggests that under-estimation of catch is not likely to affect the conclusion that the large coastal sharks aggregate is currently depleted.

Analysis of the sensitivity of model results to alternative priors, model assumptions, and data series is a useful diagnostic tool for examining the reliability of stock assessment results. The only sensitivity evaluated in the 1998 large coastal shark stock assessment was to under-reported catch; the assessment would be improved considerably with additional sensitivity analyses. Results from an alternative stock production model implementation, made for this review, suggest that model parameter estimates are sensitive to the specific form of the model structural assumptions.

The 1998 stock assessment reflects significant efforts since 1992 to increase the quality and quantity of data for Atlantic large coastal sharks. Time series of catch estimates have been refined, although there is still considerable uncertainty in the earlier estimates because of unreported catch. Numerous abundance index (CPUE) data series have been compiled; further effort is needed to evaluate the reliability of the different series. Size structure data are available for some components of the catch and some CPUE series, but have not been compiled for use in the stock assessment. Incorporation of size- or stage-based data may significantly improve the stock assessment.

2 Introduction

This report presents results of a review of the assessment of Atlantic coastal sharks and resulting management recommendations, work that was conducted under contract to the Center for Independent Experts (CIE), University of Miami. A set of 43 documents that were used in recent NMFS assessments of large coastal shark stocks were provided by CIE and form the basis of the material evaluated for this review (Appendix A). A further 7 documents, which present information on specific details of the assessment, were requested from the CIE and included in the material evaluated (Appendix A). Finally, a position paper prepared by the Atlantic Shark Industry was provided by the CIE and considered for this review (Appendix A).

This review focuses primarily on the data, assessment, and management recommendations for large coastal sharks presented in the "1998 Report of the Shark Evaluation Workshop" (SEW-1998), and addresses the specific issues identified in the CIE *Statement of Work* (Appendix B). The areas addressed in this review are: the development of the large coastal sharks assessment, in particular analytical models used in the assessments (Section 3); the information available for the 1998 assessment (Section 4); the 1998 stock assessment analyses and stock projections (Section 5) and the resulting scientific advice (Section 6); some recommendations for further development of the large coastal sharks stock assessment (Section 7); comments on the *Atlantic Shark Industry Position Statement* (Section 8) and finally summarizes my response to the specific statement (Section 9) and specific issues (Section 10) identified in the CIE *Statement of Work*. Although some information, in particular catch trends and abundance indices, is provided for the small coastal shark and pelagic shark species groups, no analysis of these data is presented in the review documents, so these species groups are not considered in this review.

The work activities conducted to fulfill this contract include:

- Review of the documents listed in Appendix A.
- Implementation of a Bayesian stock production model and analyses of the shark data series (Appendix C).
- Preparation of this report.

This work was conducted between March 1, 2001 and September 27, 2001.

3 Development of Large Coastal Shark Assessments, 1992-1998

3.1 Overview

Development of the assessment of Atlantic large coastal shark stocks is described in an annual series of documents, beginning with the 1992 Atlantic Coastal Shark Fishery Analysis Review (SEW-1992). The series documents considerable efforts to improve the data and knowledge bases for assessing large coastal sharks, both through compilation of existing data and new sampling programs. Major initiatives included: improving the estimates of total catch and species composition of the catch; developing catch-per-unit-effort abundance indices (CPUE) both from existing data sources and from new sampling programs; and developing programs to assess juvenile shark nursery areas. These initiatives resulted in a significant increase in the quantity of data and improvements to the quality of data available for the stock assessments.

The first assessment of the Atlantic large coastal shark stock was conducted in 1992 using a simple likelihood model. The data available were very limited, and in the case of recreational catch estimates, highly inaccurate. After the 1992 stock assessment, major changes to the analytical procedures were implemented for the 1996 and 1998 assessments. The interim assessments focused largely on the development of data bases and analyses of CPUE trends.

3.2 Analytical Assessment Models

3.2.1 Likelihood Model

The analytical model used for the 1992 assessment of large coastal sharks, which was termed the *likelihood model*, was used in slightly different form for the 1996 assessment. Parameters estimated in the analysis are: initial stock abundance; the rate(s) of natural population change (encompassing natural mortality, recruitment, migration, and catch under-reporting), and fishery-specific catchability parameters. The model is fitted to time series of catch in numbers and average weight of fish in the catch, and uses time-series of effort data to predict catch (SB-III-14).

There are a number of problems with this approach, in particular the assumptions regarding model error structure and model over-parameterization (few data observations per estimated parameter). The model structure assumes that all error (lack of fit) is observation error attributable to the enumerated catch estimates and the estimates of the average weight of sharks in the catch. The relationship between catch and fishing effort is assumed to be error free, although clearly this is not true and error in this relationship is likely much greater than in the estimates of catch. The effect of assuming that variability in the catch and average weight estimates are the only sources of model error is that parameter uncertainty will be greatly under-estimated.

With maximum likelihood estimation, the number of estimable parameters is equal to the number of minimum sufficient statistics in the data (essentially, the number of independent data observations). The accuracy and precision of parameter estimates are related to the accuracy and precision of the data observations. Assuming that data observations are unbiased estimates of the quantities they represent, parameter precision may be increased with more data observations per estimated parameter. For the shark analyses done with this model, the number of independent data observations per parameter is small, and there are issues with data accuracy, in particular the commercial fishery yield estimates and the effort data (section 4.1.2). Model parameter estimates from this method will be uncertain and probably unreliable, in particular when the model is fitted to only a few years of data. In that case the parameter estimates will likely reflect noise in the data rather than the quantities they represent.

3.2.2 Production Model

Analyses using a production model were conducted for both the 1996 and 1998 stock assessments. The structure of the population dynamics model was the same for both assessments, but aspects of the model implementations including the methods for estimating parameters and parameter uncertainty were different. Only the 1996 model implementation and resulting analyses are discussed here; the 1998 application is discussed in a later section.

For the 1996 stock assessment, least-squares estimation was used to fit the production model to two alternative CPUE series (SB-IV-31). Analyses were conducted for the large coastal shark aggregate group. Results indicated that the intrinsic rate of increase (r) was approximately 0.26, the 1996 stock size was approximately 62% of the optimum level (the level which produces maximum sustainable catch, *MSC*) and current fishing mortality rates were approximately twice the rate that would produce *MSC*.

The estimate of r is substantially higher than estimates of the potential annual increase of the shark species obtained from life-history analysis (SB-IV-31). Given that the CPUE time series is essentially a "one-way" trip (i.e., it has only a decreasing time trend), it is unlikely to be informative about model parameters (Hilborn and Walters, 1992). The effect of over-estimating the intrinsic rate of increase parameter is that stock projections will be over-optimistic.

Uncertainty estimates for parameter estimates were obtained using a bootstrap method that re-sampled residuals from the model fit. This bootstrap approach assumes there is no remaining pattern in the residuals, or if a pattern exists that the residuals to be re-sampled have been de-trended prior to the bootstrap operation. There is no obvious pattern in the observed residuals, so this bootstrap approach is likely to produce reasonable results. The bootstrap results indicated large uncertainty in parameter values (e.g., a CV of 0.8 on 1996 stock size), such that it was not possible to reject a hypothesis of no change in stock abundance over the time-series. This level of uncertainty is consistent with the expectation that the catch and CPUE data will be largely uninformative with respect to parameter estimates, given that abundance indices exhibit only a downward trend.

3.2.3 Age-structured Model

A third analytical model, based on age-structured population dynamics, was proposed as a potential tool for assessing Atlantic coastal shark stocks, and preliminary results were presented to the 1998 stock assessment workshop (SB-IV-21). The major advantage of an age-structured model is that it can account for the delay between increases in spawning stock abundance and subsequent recruitment to the adult stock. A disadvantage is that more parameters are needed to drive the model, so either additional data or additional assumptions are required.

The model described in SB-IV-21 is a multi-species (sandbar, blacktip, and "other") age-structured model that assumes a functional stock-recruitment relationship. The model, as described, is over-parameterized relative to the available data, so numerous parameters such as the age- and species-specific fishery selectivity parameters were fixed in the assessments that are presented.

The development of an age-structured model for large coastal sharks is a logical step in the evolution of this assessment. However, this should occur in conjunction with the establishment of age- or size-based databases to provide additional information related to the additional parameters required for this type of model. The potential for developing size- or stage-based CPUE series is discussed later in this review. Also, there is already a reasonable amount of data (e.g. SB-III-5, SB-IV-2, SB-IV-22) related to the size distribution of landings, in particular for recent years, which can be used to estimate fishery-specific size selectivity.

The implementation of a multi-species model seems inappropriate at this time, because there is unlikely to be enough information in the data from which to estimate the requisite parameters. Rather, a single-species approach is more likely to improve the assessment in the short term. A simpler approach to modeling the recruitment function is likely more appropriate for the shark stocks where recruitment is more directly related to adult abundance. For example, juvenile survival and age-at-maturity could be parameterized as functions of adult abundance.

4 Review of Information Available for the 1998 Assessment

The principal data used in the analytical assessments of large coastal shark stocks are catch and abundance (CPUE) time series. Ancillary information in the form of life history characteristics is used in demographic analyses to estimate intrinsic rates of stock increase. Although size composition information is available for some of the catch and CPUE series, this has not been incorporated in the analyses.

4.1 Catch Data

Catch estimates for the aggregate large coastal sharks species group are compiled from a variety of sources for the 1981-1997 period. The major components of the catch series are estimates of commercial fishery landings, recreational fishery landings, and commercial fishery discards (mortalities). Additionally, separate time series for sandbar and blacktip sharks are estimated, with the blacktip series including estimates of catch from Mexico. The quality of the catch estimates varies for the different sources, and considerable effort has gone into using all possible sources of information in compiling the data series.

4.1.1 Recreational Fishery Landings

Recreational landings are estimated from the U.S. Marine Recreational Fishing Statistics Survey (MRFSS), the Texas Parks and Wildlife Recreational Fishing Survey (TXPWD) and the NMFS Headboat Survey (HBOAT). Information on species composition, and to a limited degree, size composition, is obtained for all surveys, which should result in relatively accurate statistics for the recreational landings. Details of the procedures for estimating catches were not provided, and hence cannot be evaluated. However, summary statistics provided in SB-IV-25 (p. 18), suggest that the number of sharks enumerated through the MRFSS intercept survey may be inadequate for accurate estimates of species- and stratum-specific catches. An anomalous 1993 landings estimate[1] (SB-III-5) may result from limited and biased intercept data.

4.1.2 Commercial Landings

Estimation of commercial fishery landings is the most problematic component of the catch data series. Prior to 1993, commercial landings statistics under-estimate the actual landings because of non-reporting of landings and the practice of finning (removing fins and discarding carcasses at sea). Additionally, estimates of the average weight of landed sharks, used to convert biomass to numbers of sharks landed, may be inaccurate because of limited size-sampling in the earlier years. Recent estimates of commercial landings for the large coastal sharks aggregate are relatively accurate because of reporting requirements, a ban on finning, and better data on average shark weights from observer programs.

Estimates of sandbar and blacktip shark commercial fishery landings for the period prior to 1996 are based on strata-specific (region and gear) estimates of their proportion in the total landings. The estimates of these proportions are based on very limited data, and hence are generally assumed to be invariant over the time series (Appendix III, SB-IV-31). Thus the species-specific landings estimates may not reflect temporal changes in species composition and are likely to be less accurate than the aggregate large coastal sharks landings estimates. Recent (since 1996) estimates of species-specific landings are relatively accurate because of increased reporting of species data in the landings records (rather than reporting as "unclassified" sharks) and inclusion of data from observer programs.

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[1] The 1983 catch estimate generated through the survey programs (SB-III-5) is the highest in the time series and 80% higher than the estimate for the previous year. The high estimate is the result of extremely high estimates of sandbar shark landings in the mid-Atlantic (MAB) and south Atlantic states (SA). The data contributing to these estimates should be checked to see if they are biased by the intercept survey conducted that year. The average and variance for the 1983 sandbar weight data suggest that some very large sandbar sharks were sampled that year. This anomalous catch estimate also affects the 1983 CPUE estimates of large coastal sharks and sandbar sharks.

4.1.3 Mexican Catch

For blacktip shark, an estimate of the Mexican catch of sharks that had emigrated from the U.S. harvestable stock was included in the catch time series. The estimates were based on: 1) the 1994 species composition of Mexican shark catch (SB-IV-8); 2) the 1994 estimates of Mexican Gulf of Mexico total landings of small, “cazon” sharks; and 3) assumptions about emigration from U.S. to Mexican territorial waters and the time trend in Mexican catches. Although the validity of the assumptions can’t be evaluated, the estimation is a reasonable first step in accounting for Mexican removals from the U.S. harvestable stock.

4.2 CPUE Series

For the 1998 stock assessment, 76 CPUE series are compiled for Atlantic sharks, 58 of which relate to either the large coastal shark aggregate or individual large coastal shark species. The CPUE series include both fisheries-based and fisheries-independent indices. The series also differ in their spatial and temporal coverage and the time span they cover. The documents reviewed reflect little discussion of the quality of different indices or their likelihood of reflecting changes in population abundance. Consideration should be given to removing indices that are likely to reflect only local scale population changes and ones that are likely to be influenced by changes in fishing patterns (e.g., changes in targeted species).

The CPUE series also differ in the component of the shark stocks reflected by the index. Some indices reflect primarily juvenile shark abundance while others reflect primarily sub-adult and adult life stages. For the CPUE series where detailed size structure data are available, stage-based indices should be developed.

Specific comments for particular CPUE series follow:

<u>Crooke LL:</u> This series is developed from an individual fisherman’s logbook records. The spatial coverage is highly local, and records were kept only for successful sets (SB-IV-39). As such, this series is not likely to reflect abundance trends for the large coastal sharks aggregate.

<u>Hudson, Jax, Port Salerno, Tampa Bay:</u> These series are developed from shark tournament data records and likely reflect local and short-term abundances. The series tend to be highly variable. The series are potentially valuable because they begin in the 1970s, where there are little other data. A suggestion for using these data is to fit a trend line to the observations from the four series and to use the resulting annual estimates as a CPUE series.

<u>Virginia LL:</u> This fishery-independent index is the longest (1976-1997) and probably one of the most consistent of the series. It represents local (Chesapeake Bight area) but good temporal coverage and has detailed biological information (species and size data).

There appear to have been some changes in the sampling program over the time series, involving the number of hooks per set, number of sets per depth stratum, and number of sets per season; the method of standardization to account for these changes is not documented. Separate juvenile and non-juvenile sandbar shark abundance indices could be developed from this time series. This approach would address the concern raised in SB-IV-13: that the recent increase in the abundance index reflects an increase in juvenile sandbar sharks, not an increase in the older population.

Branson, NC#: These fishery-based indices both cover narrow geographic ranges and are based on a small number of trips sampled each year. They are likely of limited value as abundance trend indicators because of their narrow scope.

SCLL: This index, although a short and local time series, is based on year-round fishery-independent longline catch rates. Species composition and other biological information are collected, so it should be possible to develop juvenile and non-juvenile catch rate series.

Pelagic logbook: Although fishery-based, this CPUE index has broad geographical and temporal coverage. Changes in targeting of sharks may, however, influence the series and should be investigated.

SHARK Observer: Detailed information on species and size composition should allow the development of stage-based indices from the Shark Observer database.

MRFSS,HBOAT,TX: The recreational fishery CPUE series has broad geographical coverage, but could be influenced by changes in species targeting. The blacktip shark CPUE series increases over a period where all other indices decline. The possibility of changes in targeting should be investigated. Also note that the anomalous 1983 catch (section 4.1.1) effects the 1983 sandbar and large coast sharks aggregate CPUE indices.

4.3 Life History Data

Life table analyses have been conducted for both the sandbar and blacktip shark to estimate intrinsic rates of increase. The data required for these analyses are: 1) age-at-maturity, 2) fecundity, and 3) age-specific survivorship. Because of uncertainty in the values of these parameters, in particular the age-at-maturity and survivorship values, stochastic simulations were conducted that sampled across the range of possible values. The resulting distributions of the intrinsic rate of increase should adequately reflect the current uncertainty in this life history characteristic.

4.4 Stock Structure

Data from recaptures of tagged large coastal sharks provide a basis for exploring potential stock structure of these species. Ideally, stock structure considerations would be based on estimates of migration rates into and out of U.S. territorial waters. However, the tag-recapture data cannot be used to estimates these rates because of the following considerations:

- the release locations for tagged sharks are primarily in U.S. territorial waters, with only limited releases outside this area for a few species (SB-III-31);

- the probability that fishermen will return tags is likely to differ between U.S. and non-U.S. fishermen; and

- estimates of exploitation rates for both U.S. and non-U.S. fisheries are not available.

Although migration rates cannot be estimated from the tag-recapture data, the patterns of tag recoveries provide information on the direction and magnitude of migration of individual sharks, and they indicate the fisheries to which U.S.-tagged shark are susceptible. Recovery patterns indicate large-scale migrations for sandbar, dusky and tiger sharks - there are significant recoveries of sharks that were tagged along the Atlantic U.S. coast from Mexican territorial waters (sandbar and dusky sharks) and from the Caribbean Sea (tiger sharks) (SB-III-31). The tag release and recovery data show smaller-scale migrations for blacktip sharks. All blacktip shark recoveries in Mexican waters were from sharks tagged along the Texas coast. The release and recovery patterns for blacktip sharks suggests three to four relatively separate production units through the northwestern Atlantic and Gulf of Mexico.

5 Review of the 1998 Assessment

5.1 CPUE Trend Analyses

Analyses of recent trends in the catch rate (CPUE) data series involved fitting linear trend lines to the individual data series (1990-1997 and 1993-1997) and fitting a general linear model (GLM) to the combined data series. These are useful approaches to assess recent trends to which more complex stock-dynamic based models may not respond. However, the CPUE indices may differ in how well they reflect stock abundance: some may reflect some species better than others. Consideration should be given to which indices are used, particularly for the GLM analysis. Trends may be obscured if highly variable data, mostly reflecting sampling variability, are combined with data that have a better defined signal.

Additionally, some CPUE series reflect largely juvenile and others largely adult abundance. Separate catch rate series should be developed for the different life stages, and CPUE trend analysis should be conducted for the life stage groups.

5.2 Stage-based Model Analyses

Two separate analyses were conducted to evaluate the impact of fishing sandbar sharks at different life history stages (SB-IV-4, SB-IV-9). Both analyses used a stage-based approach and they varied levels of fishing mortality at different life history stages, but they differed in other aspects of the analyses.

The major conclusion from these analyses is that the younger life history stages are more sensitive to fishing pressure. That is, the adult component of the stocks can sustain higher levels of exploitation when fishing mortality on juvenile and sub-adult sharks is reduced or eliminated.

5.3 Production Model Analyses

5.3.1 Model Structural Assumptions

Stock production or "biomass-dynamic" models have a long history of use in fisheries stock assessments, and are the most commonly used models when the data available are limited to series of annual catch and abundance (CPUE) indices (Hilborn and Walters 1992, Quinn and Deriso 1999). Although different forms of the stock dynamics equations can be used in stock production analyses, in general the assumptions implicit in the equations remain the same. The key assumptions are that:

- the abundance indices are proportional to stock abundance;
- the population responds immediately to changes in exploitation rates; and
- the catch and abundance index data reflect the entire population or production unit, or at least a consistent component of the population (e.g. adult component).

An additional assumption of stock production models, which can be modified through different formulation of the dynamics equations, is the level of stock abundance at which the maximum sustainable catch (*MSC*) is attained. For the shark stock assessments *MSC* was assumed to be produced at 50% of the carrying capacity (K) of the stocks. While the actual level could be higher given the life history characteristics of these stocks (long-lived, slow-growing, and with low fecundity), this assumption is not likely to have a significant effect on the results.

The shark stock assessments may be most affected by the assumption that the data reflect a closed population. If the catch data do not reflect all removals from the production unit, parameter estimates from the stock production model analyses will be biased. The bias will be to under-estimate the intrinsic rate of increase (r) and the carrying capacity parameters (K). Stock projections may also be biased; however, the direction of this bias is less clear - they will depend on catch levels in both the region included in the analysis and the region not accounted for. Simulation analyses could be conducted to evaluate alternative situations.

Because stock production models have no age-structured dynamics, they assume that a population responds immediately to changes in exploitation rates. That is, they cannot account for lags between birth and subsequent recruitment to the adult stock. With species such as the Atlantic large coastal sharks, where the age-at-maturity is high, stock projections based on stock production dynamics may be over-estimate the stock's initial response to decreased exploitation rates. Age-structured analytical approaches account for these recruitment lags and allow estimation of the abundance of mature fish. Mature fish abundance is a more useful measure than total abundance for assessing conservation concerns. However, age-structured models generally require age-structured data; such data are not yet available for the shark stock assessments.

5.3.2 Bayesian Implementation

Bayesian analysis, a now-common approach for analyzing fisheries stock assessment data (McAllister *et al.* 1994, Punt and Hilborn 1997), is used to implement the shark stock production model. In a Bayesian approach, a prior probability distribution, which represents the state of knowledge prior to the analysis of the data, is assumed for some or all model parameters. The prior probability is combined with the likelihood of the data to form a posterior distribution that represents the state of knowledge after analyzing the data.

There are several advantages to using Bayesian methods for fisheries stock assessments. First, incorporating prior knowledge in the analysis can decrease the uncertainty (variance) of parameter estimates and reduce the probability associated with “unlikely” or biologically unreasonable solutions. Second, these methods provide a natural way to incorporate uncertainty in the stock projections and to estimate the risks associated with alternative management actions. Finally, the posterior distributions are easy to comprehend and therefore a useful way to convey uncertainty to fisheries managers.

A major disadvantage of Bayesian methodology is that results of stock assessments can be highly sensitive to the choice of priors. Often little is known about the appropriate distributions for the priors, yet they can have a major influence on the results when there is little information in the data.

In general, the choices of priors for the shark stock assessments appear to be reasonable. A relatively uninformative prior, uniform in log space, is assumed for the carrying capacity parameter (K). The prior for stock abundance in 1974 implies an assumption that initial abundance was close to carrying capacity. The prior for the 1974 to 1980 catch level, lognormal with an expected value equal to the average recruitment for the 1981-1997 time period, seems high, given that the commercial fishery was relatively small prior to 1985 (SEW-1992). However, there may be additional information, not in the stock assessment reports, on which this prior is based. Finally, the lognormal distributions assumed for the intrinsic rate of increase parameters (r) have expected values based on life-history analyses. The similarity in estimates of the r parameter for the sandbar and blacktip shark does not intuitively seem correct, given that age-at-maturity and longevity for the blacktip shark is less than half that of the sandbar shark (SB-IV-31, SB-IV-1), however the values are consistent with life history analyses (section 4.3).

Assumptions made about the distributional form of the proportionality constants (q_I) and the variance (σ_I^2) of the CPUE observations cannot be evaluated because they are not documented in the 1998 shark assessment. The assumptions regarding these parameters adopted in SB-IV-26 do not appear to be the assumptions used in the 1998 assessment analyses report (see Section 5.3.5 and Appendix C). Stock assessment reports should provide sufficient information about both the data and the analytical methodology employed, or reference to such documentation, so that it is possible for the analyses to be replicated.

5.3.3 Results

Stock production model analyses were conducted for the sandbar shark, the blacktip shark, and a large coastal sharks aggregate group. Results are presented for model fits to a *baseline* catch time series and an *alternative* catch time series that adjusts for under-reporting of commercial landings prior to 1994.

A useful diagnostic for examining the reliability of stock assessment results is the pattern of residuals from the model fit. Trends in residual patterns indicate inconsistency between model structure and the data observations, which could result in unreliable parameter estimates. The residuals for the shark analyses (the differences between the CPUE data and the expected values of population abundance from Bayesian analysis) indicate a certain lack of fit in recent years for the sandbar shark and large coastal shark aggregate, with mostly positive residuals for the most recent three years. Over the longer period of the analyses there are no trends in the residuals, so the lack of fit for the final years is not likely to affect parameter values.

The most dominant feature in the residuals for the blacktip shark analyses is the complete lack of fit to the *Early Rec.* CPUE series. This index shows a steady increase over its duration (1981-1992) while the predicted stock abundance is in continuous decline. It would be useful to examine this CPUE series to see if changes in species targeting may be influencing the index.

Analysis of the sensitivity of model results to alternative priors, model assumptions, and data series is another useful diagnostic tool for examining the reliability of stock assessment parameter estimates. If results are strongly influenced by changes that are specified within a range that is considered reasonable, then any specific result is suspect.

The only sensitivity reported for the 1998 shark stock assessments was examination of the *alternative* catch time series, which increased the estimated catch by up to 50% in some years. For the large coastal sharks aggregate and the blacktip shark analyses, estimates of *K* increased while other key parameters (*r,* depletion) changed little with the higher catch levels. With the *alternative* catch series, the parameter estimates for the sandbar shark analysis changed considerably: in particular, the expected value of *r* increased from 0.10 to 0.21.

Directional changes to a catch time series (i.e. all increases or decreases) will certainly result in changes in parameter values estimated with a stock production model. While the sensitivity analysis to the catch time series is appropriate for the Atlantic shark stocks, given the known under-reporting, additional sensitivity analyses would be useful to assess parameter reliability. In particular, sensitivities to model priors, sub-sets of the CPUE series, and alternative weightings of the CPUE series would be valuable.

5.3.4 Projections

Stock projections are conducted by sampling the joint posterior distributions of parameter values and simulating these forward for up to 30 years at fixed catch levels. Forward simulations are deterministic in that stock production parameters are assumed to be invariant and implementation of the specified catch level is without error. Hence the measures of uncertainty for stock projections are directly related to the uncertainty of stock productivity parameters and current abundance. The true uncertainty is under-estimated because natural stochastic process is not addressed.

Projection catch levels are fixed at proportions of the estimated 1995 catch. This is appropriate, because it allows evaluation relative to the current management target, which is a 50% reduction in catch from the 1995 level. Decision tables (Punt and Hilborn, 1997) that present the probability of various outcomes conditioned on the uncertainty in the intrinsic rate of increase parameter (*r*) and future quota levels, are presented for 10, 20, and 30 year time horizons. The outcomes include; measures of stock risk (probability of extinction and probability that abundance is less than 20% of carrying capacity), a measure of fishery impact (expectation of average annual catch), and a measure of stock and fishery performance (probability that abundance is equal to or greater than the level that maximizes production).

5.3.5 Alternative Analyses

I coded an implementation of the stock production model described in SB-IV-26 so that I could investigate the sensitivity of model parameter estimates to different CPUE series and to different assumptions regarding prior distributions (Appendix C). Using this implementation, results presented in SB-IV-26 were replicated.

When the same model was fit to the data presented in the 1998 stock assessment workshop report (SEW-1998), results presented in that report could not be replicated. Clearly there had been some changes in the methodology, but these had not been documented. It is essential that stock assessment reports provide sufficient information about both the data and the analytical methodology employed, or reference to such documentation, that it is possible for the analyses to be replicated (NRC 1998). This is important to ensure the credibility of the stock assessment.

Because the stock production analyses presented in the 1998 stock assessment report could not be replicated, comparison of those results with mine from the alternative implementation are informative: they show how changes in the model formulation, albeit unknown changes, can affect the assessment. Model parameter estimates did not differ substantially for the large coastal sharks aggregate or sandbar shark analyses, but differences were greater for the blacktip shark analyses (Appendix C). Sensitivity of model results to: 1) fitting to alternative CPUE series, 2) alternative constraints for the carrying capacity (*K*) parameter, 3) an alternative prior for the intrinsic rate of increase (r) parameter for the sandbar shark analysis, and 4) fitting to an alternative catch time-series, are presented in Appendix C.

Results from the alternative implementation of the Bayesian stock production model and sensitivity assessment support several conclusions:

- The specific form of model structural assumptions employed in an analysis can significantly affect parameter estimates. The differences in results from the alternative implementation of the Bayesian stock production model from those reported in the 1998 shark stock assessment analysis probably result from differences in assumptions regarding the error structure of the data, differences in the assumptions regarding the distribution of the proportionality constants (q_I) and index variance (σ_I^2) parameters, or differences in the constraints for the carrying capacity parameter (*K*).

- The measures of both parameter uncertainty and stock projection uncertainty reported in the 1998 stock assessment workshop report are conditioned on the model structure, and as such they under-estimate the total uncertainty.

- The uncertainty in the blacktip shark stock parameter estimates is greater than the uncertainty for the sandbar shark and the large coastal sharks aggregate. This likely results from fewer and shorter CPUE series for this stock.

- The conclusion that large coastal shark stocks are currently depleted is supported by the alternative analyses.

6 Review of the Scientific Conclusions and Management Recommendations

This section reviews the scientific conclusions and management recommendations presented in the 1998 shark assessment document. The scientific conclusions relate to assessment of stock status and harvest levels that ensure stock rebuilding. The main recommendations for fisheries management, aside from harvest levels, are about species-specific management and minimum size limits.

6.1 Stock Status

The stock production model used to assess the sandbar, blacktip, and large coastal sharks aggregate assumes that the data reflect a closed population. If some removals from the population are not accounted for in the catch time series, model parameter estimates, stock trajectories and projections will be unreliable.

The blacktip shark catch series included estimates of sharks taken in Mexican fisheries that would otherwise have been available to U.S. fisheries. While this is an appropriate step towards meeting the "closed" population assumption, further analysis of stock structure is needed for this species. Patterns of tag recoveries for blacktip shark released in U.S. waters are suggestive of three to four separate production units in the U.S. Atlantic and Gulf of Mexico (SB-III-31). These are areas among which there appears to be little movement. If these areas represent relatively discreet production units, analyses of the combined data may obscure local abundance trends.

Patterns of tag recoveries for sandbar and other large coastal shark species also indicate substantial movement from U.S. to non-U.S. waters. Not accounting for the catch of these species outside of U.S. fisheries may bias the assessment results.

6.1.1 Recent Trends

The assessment concludes that the evidence is equivocal regarding recent (since 1991) trends in shark abundance and that hence it is not possible to determine if stocks have begun rebuilding or are being further depleted. This conclusion is consistent with analyses of trends in the recent CPUE data series. The CPUE trend analyses might be improved by removal of data series that are less likely to reflect population abundance (e.g. fishery-based indices where changes in species targeting may influence trends). Additionally, development of stage-based abundance indices might reduce the variability of the indices and improve the ability to detect trends.

6.1.2 Catch Levels to Achieve Rebuilding

The 1998 shark stock assessment document concludes that: "… there is a need for substantial reductions in catches of the large coastal species, exclusive of sandbar and blacktip. For sandbar, analyses indicate that small reductions are needed to assure recovery. For blacktip, large reductions in catches may be needed, but it is unclear whether reductions in the U.S. alone would achieve the intended goals."

While I would agree with a general conclusion that the analyses support the need for reductions in catches for the large coastal sharks aggregate, I think conclusions related to individual species are not warranted.

One of the implicit assumptions in the statement quoted is that the large coastal aggregate analyses are representative of the large coastal shark species other than sandbar and blacktip. This assumption is unlikely. The shark catch is dominated by sandbar and blacktip, with these two species comprising between 72% and 96% of the total U.S. catch between 1986 and 1997 (Tables 2-5, SEW-1998). The CPUE series also reflect the dominance of sandbar and blacktip shark, although to a lesser degree than the catch. Thus the analyses based on the large coastal sharks aggregate data will probably reflect the sandbar and blacktip stocks to a greater extent than other large coastal shark species.

Result from the Bayesian stock assessments and projections for the sandbar and blacktip sharks are probably less reliable that the assessment of the large coastal sharks aggregate. The reasons for this are:

- There is greater uncertainty in the sandbar and blacktip pre-1994 catch estimates because of very limited data on species composition of the catch.

- The assessments for these two species, in particular blacktip, were more sensitive to changes in model implementation (Appendix C); in turn this suggests that results from the assessment are less reliable.

- The CPUE series for the individual species cover a shorter time span.

Note that the statements quoted above, making conclusions about reductions in catch levels, refer to reductions from the 1995 level. The Bayesian model stock projections were based on catch levels specified relative to 50% of the 1995 catch, which was the current quota level. Hence the projections took into account the expected effect of the current management regulations.

6.2 Species-Specific Management

The document recommends that effort should be made to manage large coastal shark species separately. The reason for this is that individual species respond differently to management, such that an acceptable level of exploitation for one stock may result in overfishing of others. Given the range of life history patterns for the different shark species in the large coastal aggregate, the recommendation to work towards managing species or species groups separately is appropriate

6.3 Minimum Size Limits

The document makes specific recommendations regarding minimum size limits. These are: commercial and recreational size limits for ridgeback sharks (e.g. sandbar), and recreational size limits for non-ridgeback sharks (e.g. blacktip). A non-ridgeback limit is not proposed for the commercial fishery because blacktip shark do not show a clear size-depth segregation, so minimum size limits could result in significant bycatch mortality of small sharks.

The minimum size limit recommendations are consistent with results presented in the shark assessment documents.

7 Recommendations

The following list summarizes recommendations to improve data collection, data analysis, and the stock assessment methodology to improve the quality of the large coastal sharks assessments.

1. Improve the quality of the CPUE data series by:
   - eliminating less reliable series
   - combining shark tournament series through GLM or similar analysis
   - investigating outliers in series

2. Develop stage-specific CPUE indices for series where size structure data are available.

3. Compile existing size composition data from fisheries so they can be used in the assessment.

4. Continue development of an age-structured model for assessment of large coastal shark species.

5. For analytical assessments, conduct sensitivity analyses to priors, data weighting, and model structure assumptions; report sensitivity analyses so that reliability of results can be assessed.

6. Update and analyze the tag release-recovery data for large coastal sharks. Investigate whether shark tag and recapture data are available from other regions of the Atlantic.

7. Continue to improve estimates of Mexican blacktip shark catches and attempt estimation for other large coastal shark species. If estimation is not feasible, conduct simulation studies to investigate the potential impacts of not accounting for all removals on shark stock assessments and projections.

8. Evaluate the adequacy of the recreational fishery intercept surveys for estimation of species composition.

9. Document all analytical methodology used in the shark assessments such that analyses are reproducible by other workers.

8 Comments on Atlantic Shark Industry Position Statement

The document *Atlantic Shark Industry Position Statement* was received after I had conducted my review of the NMFS Atlantic Shark assessment documents. A number of the issues raised in the industry position paper are discussed in preceding sections of this report. My comments here address issues raised in the position paper that I believe are pertinent with respect to the 1998 large coastal sharks stock assessment and management recommendations.

8.1 Modeling Approach

The *Atlantic Shark Industry Position Statement* identifies the following concerns with the modeling approach adopted for the 1998 shark stock assessment:

- analyses using alternate analytical models were not conducted
- modeling shows a lack of fit to the most recent CPUE data
- the production model does not account for open population structure
- modeling used an inappropriate intrinsic rate of increase (*r)* prior

I believe that the Bayesian production model used for the 1998 large coastal sharks stock assessment was an appropriate model given the data and information available for the assessment. This modeling approach was a considerable improvement over methods that had been previously used (Sections 3.2.1, 3.2.2), reducing the uncertainty in parameter estimates. The age-structured production model, which the industry position statement suggests as a more appropriate analytical method, was insufficiently developed at the time of the 1998 stock assessment for reliable use (Section 3.2.3). While age-based assessment methods are an appropriate direction for the shark assessments, these should be developed in conjunction with age-based index and catch data, which are not currently available (Section 4.2).

The *Atlantic Shark Industry Position Statement* suggests that the lack of fit between the most recent (post-1993) CPUE indices and the model-reconstructed abundance trends implies that the Bayesian production model was not the best available assessment method. As stated previously, I believe that the Bayesian production model was an appropriate model and alternate better methods (and data) were not available for the 1998 assessment.

The *Atlantic Shark Industry Position Statement* also suggests that the lack of fit between the most recent CPUE indices and model abundance trends indicates that the then-current catch levels were not excessive. There is no clear overall trend in the post-1993 CPUE indices, with some indices showing increasing trends and others showing declining trends. Because of the high uncertainty in the individual CPUE values and the inconsistencies among the CPUE series, the GLM analyses show that it is not possible to determine the trend in the recent data (Section 4.1, SEW-1998). The assessment model results reflect the high uncertainty inherent in the CPUE series. A continued decline in stock abundance provides the most consistent fit to the CPUE and catch data series, leading to the conclusion that the then-current catch was above the sustainable level.

An assumption of the production model used for the 1998 shark stock assessment is that the data reflect the entire (i.e. closed) population, an assumption which, given tag recovery observations, is clearly violated (Section 4.4). Violation of the closed population assumption causes the catch time-series to underestimate the total removals from the stock, and possibly causes the model to under-estimate productivity. If a relatively consistent proportion of the stock resides in US waters, the observed CPUE series should reflect the overall population trend. To investigate the potential impact of underestimating catch over the time-series, I conducted a sensitivity analysis that is discussed in Section 8.3. The results suggest that violation of the closed population assumption is not likely to qualitatively affect the stock assessment conclusions.

The *Atlantic Shark Industry Position Statement* suggests that sandbar shark demographic characteristics are inappropriate to represent the ridgeback shark aggregate and that blacktip shark demographics are inappropriate to represent the non-ridgeback shark aggregate, because some other shark species in these groups have higher productivity. I disagree with this point: sandbar and blacktip shark represent about 80% of the total large coastal sharks catch and consequently their productivity will dominate the fishery dynamics.

8.2 Catch Estimates

The industry position paper suggests that the pre-1993 estimates of the LCS commercial catch underestimate the true catch, even in the analyses where these values were increased from reported levels (Table 3, SEW 1998). While it is unlikely that there is any information that would allow more accurate estimation of the catch in the earlier years, a sensitivity analysis to evaluate the potential impact of higher pre-1993 catches can be run. I conducted such an analysis (Appendix C), and results are discussed later (Section 8.3).

The *Atlantic Shark Industry Position Statement* suggests that inappropriate average weight estimates, taken from 1988 to 1991, are used and may bias the catch estimates. The average weights used for these years are anomalous (Table 1, SB-III-6), in that they are considerably lower than estimates for years prior to and after this period. This anomaly should be investigated to determine if commercial fishing practices were different during this period such that smaller sharks were targeted or landed, or whether the lower average weights are the results of small and non-random sampling of the catch. Although average weight estimates that are more consistent with other years would significantly change the estimates of the number of fish landed during the 1988-1991 period (25%-40%), this is not likely to have a major effect on the stock assessment. In particular, the effect would be a reduction in the estimated catch for these four years whereas major concerns appear to be that the catch estimates over this period underestimate the true catch.

8.3 Sensitivity Analyses

The *Atlantic Shark Industry Position Statement* states that the absence of sensitivity analyses related to the CPUE indices is a point of concern. They suggest that additional analyses using subsets of the CPUE series and alternative weighting schemes should be conducted as part of the stock assessment procedure. I agree with this point: this type of sensitivity analysis is useful to determine the reliability of the stock assessment (Section 5.3.3). Additionally, I concur with the industry position that the VIMS CPUE index should be standardized to account for changes that occurred in the survey design (Section 4.2). However, note that the sensitivity analysis that I conducted using alternate CPUE series did not alter the conclusion that the large coastal shark stock is depleted (Section 5.3.5, Appendix C).

I conducted a sensitivity analysis of the large coastal sharks aggregate data, using the Bayesian production model, to address two concerns identified in the industry position paper:

1. that the alternate catch history used for the 1998 stock assessment (Table 3, SEW-1988) underestimates true catch, and
2. that catches of the Atlantic large coastal shark population that occur outside the US zone are not accounted for in the analysis.

For this sensitivity analysis the catch estimates were increased over the time-series (Appendix C). The level of increase was *ad hoc*, however the main point is to evaluate changes to model parameter estimates rather than to provide an alternative stock assessment. The principal differences, when fitting to the alternate catch time-series, were higher values for the carrying capacity (*K*) and the maximum sustainable catch (*MSC*) parameters (Appendix C). Although the estimate for the level of stock depletion was somewhat less pessimistic, the conclusion that stock abundance is currently (as of 1998) below the target level and that the 1997 catch exceeded the *MSC* level is not changed.

9 Specific Statement

Responses to Section B of the CIE *Statement of Work* (Appendix A).

Each reviewer's report will include a specific statement on whether or not the assessments and scientific information behind them supports the conclusions of the stock assessment. If the reviewer concludes that only some conclusions are supported by the assessment and others are not, the review should point out which ones are supported, which ones are not, and why. If the model(s) used are inappropriate, the reviewer should suggest better alternatives and explain why they are more suitable for assessing large coast shark stocks. If the assessments did not consider fully all the relevant data, the reviewer should point out which data sets were treated inappropriately (either by exclusion or by weighting too heavily) and if possible suggest how more appropriate treatment of the data sets might have affected assessment results and conclusions. The *reviewer should include a listing of changes that should be included in future assessments of these stocks.*

I find that the scientific conclusions and scientific management recommendations contained in the 1998 SEW Report are based on scientifically reasonable uses of appropriate fisheries stock assessment techniques and the best available (at the time of the 1998 SEW Report) biological and fishery information relating to large coastal sharks. Specifically:

- Conclusions about the large coastal shark aggregate are supported, but with reservations including:
    - catch data do not include all removals (open population)
    - CPUE indices are noisy - this may influence ability to detect recent trends
    - stock rebuilding could take longer than projected because of considerable lag between birth and maturation

- Conclusion that sandbar and blacktip are depleted relative to MSC levels is supported but species-specific assessments are less reliable than the large coastal aggregate assessment.

- Models and data used in assessment are appropriate.

- Recommendations on data and models are presented in sections 4, 5, and 7.

10 Summary Statements

The following statements summarize conclusions about the specific issues identified in Section A of the CIE *Statement of Work* (Appendix A).

The review, which shall analyze background material and an analytical model to assess the status of Atlantic coastal shark stocks, shall address the following issues:

1. *Review the analytical model(s) used to assess the status of large shark stocks in Atlantic coastal waters, including the modeling approaches used in recent prior shark evaluation workshops. Consider, inter alia:*

- *The reliability of estimates of current abundance, recent trends, and demographic structure (including uncertainties);*

Current abundance estimates for the large coastal sharks aggregate are reliable (conditional on model assumptions) although uncertainty is under-estimated. Estimates for sandbar and blacktip shark are less reliable than those for the large coastal sharks aggregate (sections 5.3.3. and 5.3.5).

Recent trends are correctly identified as equivocal in the assessment (section 6.1.1) and could be improved by developing stage-based abundance indices (section 4.2).

Present uncertainty about life history characteristics is reflected in demographic analyses (sections 4.3 and 5.2).

- *The reliability of population projections from the assessment results;*

Projections from the Bayesian assessment are appropriately made, but they under-estimate the total uncertainty because no natural stochastic processes are simulated. (section 5.3.4)

- *The appropriateness of the weighting of the various indices of abundance for the different ages and species/stocks of shark;*

The weighting and estimation assumptions used to fit abundance indices are not documented (section 5.3.5 and Appendix C).

The assessment would benefit from indices developed for population stages of shark (section 4.2). The separate single-species landings data are less reliable than the large coastal shark aggregate data (section 4.1.2) and the conclusions should therefore be given less weight than those based on the large coastal shark aggregate data (section 6.1.2)

- *The appropriateness of the Bayesian methods used in evaluating population status;*

The Bayesian methods are appropriate (section 5.3.2).

- *The appropriateness of the non-age-structured methods used to estimate status of shark populations;*

Non-age-structured methods have limitations (section 5.3.1); their chief disadvantages are that lags in productivity are not accounted for and that detailed biological structure cannot be addressed by the model.

2. *Review the quantity and quality of data available for assessment of status of the large coast shark stocks, particularly the data from the MRFSS, and how the data were used in assessment of the large coastal shark stocks.*

The data are reviewed in section 4.

Stock production model analyses based on an *alternative* catch series are appropriate, given under-reporting of catch prior to 1994 (section 4.1.2. and 5.3.3). The CPUE indices differ in their potential to reflect abundance changes and less reliable indices should be eliminated from the analyses (sections 4.2 and 5.1).

Detailed information on the MRFSS data was not provided for the review. However, inference from a summary table suggests that sampling through the intercept program may be inadequate for accurate species-composition resolution (section 4.1.1).

3. Review the support for and consequences of assumptions made about whether the shark stocks represent open or closed populations.

Consequences of the assumption of closed populations are described in sections 5.3.1 and 6.1. Information about population structure is reviewed in sections 4.1.3, 4.4 and 6.1.

4. Consider the degree to which the scientific conclusions and management recommendations in the assessment documents are supported by the analytical results, and if alternative conclusions would be equally consistent with the analytical results.

Conclusions and recommendations are discussed in sections 6.

The conclusions that the large coastal shark aggregate is depleted and that reductions in fishing mortality rates are required for stock rebuilding are supported by analytical results; however, conclusions regarding the status of sandbar and blacktip shark are overstated (sections 5.3.5 and 6.1.2).

5. Consider the degree to which the assessment methods and the advice on management:

- *took account of effects of current management regulations on population trajectories*

This is discussed in section 6.1.2 - the assessment addressed adequately the effects of current management regulations on population trajectories.

- *took account of the risks to the resource of maintaining status quo management versus the costs to industry of immediate reductions in permitted landings of large coastal sharks before evaluation of recent new management regulations could be evaluated fully.*

Assessment did not include bio-economic analyses to evaluate costs to industry, however, performance measures (expectation for average catch, probability of stock extinction, probability that abundance is less than 20% of carrying capacity) at alternative catch projection levels should allow managers to evaluate these trade-offs (section 5.3.4).

11 References

Hilborn, R., and C.J. Walters. 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics & Uncertainty. Chapman and Hall, New York. xv + 570 p.

McAllister, M.K., E.K. Pikitch, A.E. Punt and R. Hilborn. 1994. A Bayesian approach to stock assessment and harvest decisions using the sampling/importance resampling algorithm. *Canadian Journal of Fisheries and Aquatic Sciences 51*: 2673-2687.

National Research Council. 1998. Improving Fish Stock Assessments. National Academy Press, Washington DC. 177 p.

Punt, A.E., and Hilborn, R. 1997. Fisheries stock assessment and decision analysis: the Bayesian approach. *Reviews in Fish Biology and Fisheries 7*:35-63.

Quinn, T.J. II, and R.B. Deriso. 1999. Quantitative Fish Dynamics. Oxford University Press, New York. xv + 542 p.

APPENDIX A: List of Documents

List of documents provided in the CIE review material:

SB-IV-1. Branstetter, S. and G. Burgess. Gulf and South Atlantic Fisheries Development Foundation and University of Florida. Commercial shark fishery observer program 1996.

SB-IV-2. Branstetter, S. and G. Burgess. Gulf and South Atlantic Fisheries Development Foundation and University of Florida. Commercial shark fishery observer program 1997-1998.

SB-IV-3. Branstetter, S. and G. Burgess. Gulf and South Atlantic Fisheries Development Foundation and University of Florida. Monitoring the large coastal shark stock of the western Gulf of Mexico.

SB-IV-4. Brewster-Geisz, K.K., and T. J. Miller. Management of the sandbar shark (*Carcharhinus plumbeus*): implications of a stage-based model.

SB-IV-5. Brown, C.A. Standardized catch rates of four shark species in the Virginia-Massachusetts (U.S.) rod and reel fishery, 1986-1997.

SB-IV-6. Carlson, J.K. An index of abundance for coastal species of sharks from the northeast Gulf of Mexico: 1966-1997.

SB-IV-7. Carlson, J.K. Occurrence of neonate and juvenile sandbar sharks, *Carcharhinus plumbeus*, from the northeastern Gulf of Mexico.

SB-IV-8. Castillo, J.L., J.F. Marquez, M.C. Rodriquez de la Cruz, E. Cortes, and A. Cid del Prado. The Mexican artisanal shark fishery in the Gulf of Mexico: toward a regulated fishery.

SB-IV-9. Cortes, E. A stochastic stage-based population model of the sandbar shark in the western North Atlantic.

SB-IV-10. Cortes, E. and G. Scott. Rates of increase per generation for large coastal species of sharks from the U.S. Atlantic Ocean and Gulf of Mexico.

SB-IV-11. Cramer, J. Large pelagic logbook catch rates for sharks.

SB-IV-12. Scott, G.P., J. Bennett, B. Slater, and P. Phares. Recent recreational and commercial catches of sharks along the US east and Gulf of Mexico coasts.

SB-IV-13. Musick, J.A., J. Gelsleichter, R.D. Grubbs, and K. Goldman. A delineation of shark nursery grounds in Chesapeake Bay and an assessment of abundance of shark stocks (Parts 1,2,3, and Annual Progress Report for 1996-97).

SB-IV-14. Trent, L., D.E. Parshley, and J.K. Carlson. 1977. Catch and bycatch in the shark drift gillnet fishery off Georgia and East Florida.

SB-IV-15. Trent, L., S. Prescott, J.K. Carlson, and B. Heinisch. Relative abundance and size of juvenile and small adult sharks in St. Andrew Sound in northwest Florida.

SB-IV-16. Trent, L. Comparison of longline methods to estimate juvenile shark abundance indices in shallow coastal areas of northwest Florida.

SB-IV-17. Poffenberger, J. Shark logbook data.

SB-IV-18. Schirripa, M.J. Analysis of shark catch rates from the Gulf of Mexico reef fish logbooks: 1998.

SB-IV-19. O'Boyle, R.N., G.M. Fowler, P.C.F. Hurley, and M.A. Showell. Update on the status of NAFO SA 3-6 Porbeagle shark (*Lamna nasus*).

SB-IV-20. NAFO Subarea 3-6 Porbeagle shark. DFO Science Stock Status Report B3-09 (1998).

SB-IV-21. Powers, J.E. Options for age-structured production models for large coastal sharks.

SB-IV-22. Cramer, J., A. Bartolino, and G.P. Scott. Estimates of recent shark bycatch by U.S. vessels fishing for Atlantic tuna and tuna-like species.

SB-IV-23. Hoey, J.J. and G.P. Scott. Standardized catch rates for pelagic and large coastal sharks based on research survey, logbook, and observer data from the western North Atlantic.

SB-IV-24. Merson, R.R., and H.L. Pratt, Jr. Nursery and pupping grounds of the sandbar shark, *Carcharhinus plumbeus*, in Delaware Bay.

SB-IV-25. Babcock, E.A., and E.K. Pikitch. The effect of bag limits on shark mortality in the U.S. Atlantic recreational fishery.

SB-IV-26. McAllister, M.K. and E. K. Pikitch. A Bayesian approach to assessment of sharks: fitting a production model to large coastal shark data.

SB-IV-27. McAllister, M.K. and E. K. Pikitch. Evaluating the potential for recovery of large coastal sharks: a Bayesian decision analysis.

SB-IV-28. Hueter, R.E., and C.A. Manire. Distribution, relative abundance, and migration of sharks in coastal nursery areas of the Gulf of Mexico (5 documents included).

SB-IV-29. Grace, M. and T. Henwood. Assessment of the distribution and abundance of coastal sharks in the U.S. Gulf of Mexico and Eastern Seaboard, 1995 and 1996.

SB-IV-30. Henwood, T. Mississippi Laboratories groundfish surveys: 1972- 1997.

SB-IV-31. N.M.F.S. 1996 Report of the Shark Evaluation Workshop.

SB-IV-32. N.M.F.S. 1977 Shark Evaluation Annual Report.

SB-IV-33. Cramer, J. and H. M. Adams. Pelagic Longline bycatch.

SB-IV-34. Jones, L.M. A preliminary report on historical and recent longline shark catches.

SB-IV-35. Jones, L., M. Grace, and T. Cody: Shark nursery areas in the major bay systems of Texas.

SB-IV-36. Bonofil, R. Status of shark resources in the southern Gulf of Mexico and Caribbean; implications for management.

SB-IV-37. Marin, R. Aspectos biologicos de los tiburones capturados en las coastas de Tamaulipas y Veracruz, Mexico.

SB-IV-38. Rodriquez de la Cruz, M.C., Castillo, J.L, and J.F. Marquez. Evaluacion de la pesqueria de tiburon del Golfo de Mexico.

SB-IV-39. N.M.F.S. 1994 Report of the Shark Evaluation Workshop.

SB-IV-40. N.M.F.S. 1995 Shark Evaluation Annual Report.

SB-IV-41. Pikitch, E., M. McAllister, and B. Babcock. Preliminary large coast shark assessment results.

No number, but labeled SEW-1992 for this review. Appendix II, Final Report. Report of the Atlantic Coastal Shark Fishery Analysis Review, September 30, 1992.

No number, but labeled SEW-1998 for this review. NMFS. 1988 Report of the Shark Evaluation Workshop.

Atlantic Shark Industry Position Statement. January 10, 2001.

Additional documents requested from CIE for this review:

SB-III-5. Scott, G., P., J. Phares and B. Slater. Recreational catch, average size and effort information for sharks in US Atlantic and Gulf of Mexico waters.

SB-III-6. Poffenberger, J. Commercial shark landings.

SB-III-9. Ulrich, G.F. Fishery independent monitoring of large coastal sharks in South Carolina (1993-95). Grant No. NA47FI0347-01 Final Report.

SB-III-13. Hester, F. Landings and effort from a specific dealer.

SB-III-19. Scott, G.P. and J.K. Lacey. Updated charterboat catch rate information for sharks through 1995.

SB-III-14. Parrack, M.L. A simple likelihood method of estimating fish abundance.

SB-III-31. Kohler, N. Summary of tag and recapture data for 33 species of sharks.

APPENDIX B: Statement of Work

CENTER FOR INDEPENDENT EXPERTS STATEMENT OF WORK

Consulting Agreement Between the University of Miami and Vivian Haist

March 1, 2001

A. General

The review, which shall analyze background material and an analytical model to assess the status of Atlantic coastal shark stocks, shall address the following issues:

1. Review the analytical model(s) used to assess the status of large shark stocks in Atlantic coastal waters, including the modeling approaches used in recent prior shark evaluation workshops. Consider, *inter alia*:
- The reliability of estimates of current abundance, recent trends, and demographic structure (including uncertainties);
- The reliability of population projections from the assessment results;
- The appropriateness of the weighting of the various indices of abundance for the different ages and species/stocks of shark;
- The appropriateness of the Bayesian methods used in evaluating population status;
- The appropriateness of the non-age-structured methods used to estimate status of shark populations;

2. Review the quantity and quality of data available for assessment of status of the large coast shark stocks, particularly the data from the MRFSS, and how the data were used in assessment of the large coastal shark stocks.

3. Review the support for and consequences of assumptions made about whether the shark stocks represent open or closed populations.

4. Consider the degree to which the scientific conclusions and management recommendations in the assessment documents are supported by the analytical results, and if alternative conclusions would be equally consistent with the analytical results.

5. Consider the degree to which the assessment methods and the advice on management:
- took account of effects of current management regulations on population trajectories
- took account of the risks to the resource of maintaining status quo management versus the costs to industry of immediate reductions in permitted landings of large coastal sharks before evaluation of recent new management regulations could be evaluated fully.

B. Specific Products and Deadlines

Reviewers may communicate among themselves as they choose. However, each reviewer will prepare an independent report addressing each of the Terms of Reference. No consensus opinion among reviewers is required.

Each reviewer's report will include a specific statement on whether or not the assessments and scientific information behind them supports the conclusions of the stock assessment. If the reviewer concludes that only some conclusions are supported by the assessment and others are not, the review should point out which ones are supported, which ones are not, and why. If the model(s) used are inappropriate, the reviewer should suggest better alternatives and explain why they are more suitable for assessing large coast shark stocks. If the assessments did not consider fully all the relevant data, the reviewer should point out which data sets were treated inappropriately (either by exclusion or by weighting too heavily) and if possible suggest how more appropriate treatment of the data sets might have affected assessment results and conclusions. The reviewer should include a listing of changes that should be included in future assessments of these stocks.

A set of 41 documents used in recent NMFS assessments of large coastal shark stocks will be provided to each reviewer. The documents are intended to provide full information on the background of these recent assessments and scientific advice . Reviewers are not asked to provide a detailed critique of the individual documents. Rather review should consider the information and knowledge base as a whole. as it relates to the assessments and advice based on them. In doing so, reviewers may find it helpful to reference individual documents, and are welcome to consider additional documentation as appropriate.

The reviewer's duties shall not exceed a maximum total of three weeks- several days for document review and several days to produce a written report of the findings. The consultant may perform all review, analysis, and writing duties out of the consultant's primary location, as no travel is required.

The itemized tasks of the consultant include:

1. Reading and analyzing the relevant documents provided to the consultant;

2. No later than April 27, 2001, submitting a written report of findings, analysis, and conclusions (refer to Annex 1 [attached] for report generation guidelines). The report should be addressed to the "UM Independent System for Peer Reviews, " and sent to Manoj Shivlani, UM/RSMAS, 4600 Rickenbacker Causeway, Miami, FL 33149 (or via email to mshivlani@rsmas.miami.edu) and to Dr. Jake Rice, DFO, Canada (via email to RICEJ@DFO-MPO.GC.CA).

Signed________________________ Date_____________

APPENDIX C: Alternative Assessment Results

I implemented the stock production analysis described in document SB-IV-26 so that I could investigate the sensitivity of model parameter estimates to different CPUE series and weightings and to different assumptions about the prior distributions. The model code I developed followed the same stock dynamics and likelihood equations as described in SB-IV-26, and this alternative version also implemented a Sampling/Importance Resampling (SIR) algorithm to obtain posterior marginal distributions. The method proposed by Walters and Ludwig (1994) for integrating over the prior distributions of the CPUE index proportionality constants and variances, the q_j and $\sigma^2_{I_j}$ in SB-IV-26, was adopted. For convenience, results from analyses using this model implementation will be referred to as PR-ALT, results presented in SB-IV-26 will be referred to as PR-IV-26, and results presented in the 1998 stock assessment report (SEW-1988) will be referred to as PR-1998.

When I applied my model implementation to the catch and CPUE data series given in SB-IV-26, I obtained estimates of the means and CVs of the parameter marginal posterior distributions similar to those reported for the original analysis (Table A1). However, when I fitted the model to the data series presented in SEW-1998, I could not duplicate the results reported there (Tables A1-A3). The 1998 stock assessment report (SEW-1998) does not provide documentation of or reference to the specific methodology used; the only reference to the methodology is the general statement that "a Bayesian framework (as in SB-IV-21, SB-IV-26, SB-IV-27)" was used. Note that the analytical methods described in SB-IV-26 and SB-IV-27 are the same, but the model described in SB-IV-21 is different and not fully documented. I investigated a number of different formulations for the likelihood function, but could not generate results similar to those presented in SEW-1998. All results described here are from my model formulated as described in SB-IV-26.

Large Coastal Sharks

For the large coastal sharks aggregate, results from my model implementation were not substantially different from PR-1998 (Table A1). Estimates of the intrinsic rate of increase, (r), and the current level of stock depletion, (*N(98)/K*), were similar for the two analyses. I conducted an alternative analysis, fitting only 8 of the CPUE series. The series selected were ones for which sandbar and blacktip shark indices had been developed and used in those assessments. Although fitting to the alternative CPUE series decreased the expected value of the depletion slightly (0.16 versus 0.21), the expected value for the *r* parameter did not change. Fitting to similar CPUE series as used for the single-species assessments did not change the estimated intrinsic rate of increase parameter to values similar to those obtained for the sandbar or blacktip stock assessments.

Sandbar and Blacktip Shark Data

The differences in estimated parameter values between PR-ALT and PR-1998 are greater for the single stock analyses than for the large coastal aggregate analysis (Tables A2 and A3). The expected values of the marginal posterior distributions that I estimated were higher for all model parameters.

For the base case PR-ALT analyses, the upper limit for the carrying capacity (*K*) parameter had been fixed at 20,000. For the large coastal aggregate and sandbar shark analyses this limit did not appear to have much influence on the marginal posterior distribution for *K*, as there was little density in the region greater than 15,000. For the blacktip shark analysis there was substantial density in this region. Alternative analyses were therefore conducted for the sandbar and blacktip data series with an upper limit of 12,000 for *K*. This change had little impact on parameter estimates for the sandbar shark analysis (Table A2), but it substantially reduced the expected values of the carrying capacity (*K*) and current depletion (*N(98)/K*) for the blacktip shark analysis (Table A3).

This result demonstrates a common problem when using Bayesian analyses for fisheries stock assessments: when uninformative priors are used and there is little information in the data about absolute abundance, the marginal posterior distribution for abundance will have a long right-hand tail that reflects some, albeit low, density at high abundance levels. This non-zero density will continue out to infinite abundance unless constrained. Unfortunately, the form of the constraint will substantially influence the marginal posterior distributions.

Two additional alternative analyses were conducted. First, different CPUE series were fitted for both the sandbar and blacktip shark stocks. These changes had little effect on parameter estimates (Tables A2 and A3). Second, the sandbar shark data were fitted with a different prior for *r*. A lognormal prior with a mean of 0.07 and standard deviation of 0.7 was assumed. This change to the prior reduced the expected value for *r* to 0.072 (from 0.115), but had little effect on other parameters (Table A2).

Alternative Catch History

To address certain issues identified in the *Atlantic Shark Industry Position Statement* an alternative analysis was conducted for the large coastal sharks aggregate data using a modified catch history. The commercial landings for the period 1981 to 1993 were increased to a greater degree than in the SEW-1988 *alternative catch* analysis (doubled for 1981 to 1985, tripled for 1986 to 1992, and doubled for 1993). Additionally, a constant catch of 100 thousand was assumed for non-US fisheries. The resultant catch estimates are shown in Table A4.

The analysis using the alternative catch history increased the expected value of the carrying capacity parameter (*K:* 15,092 versus 9,565 for the base case analysis) and decreased the expected value of the intrinsic rate of increase parameter (0.06 versus

0.08). The estimate of stock depletion (*N(98)/K*) was less pessimistic regarding current stock status than was the base case analysis (0.27 versus 0.21). However, current abundance was still estimated to be below the target (*MSC*) level and current catch well above the *MSC* estimate.

Summary

The results presented here, comparing an alternative implementation of the Bayesian stock production model to results presented in the 1998 stock assessment report (SEW-1998), support several conclusions:

- The specific form of model structural assumptions employed in the shark assessments can significantly affect parameter estimates. The differences between my "*base case*" results and those obtained for the 1998 shark stock assessment (PR-ALT *vs* PR-1998) probably result from differences in assumptions about the error structure of the data, differences in the assumptions about the distribution of the proportionality constants (q_I) and index variance (σ_I^2) parameters, or differences in the constraints for the carrying capacity parameter (*K*).

- Estimates of both parameter uncertainty and stock projection uncertainty reported in SEW-1998 are conditioned on the model structure, and as such they under-estimate the total uncertainty.

- The uncertainty in the blacktip shark parameter estimates is greater than the uncertainty for the sandbar shark and the large coastal sharks aggregate. This likely results from fewer and shorter CPUE series for this stock.

- The conclusion that large coastal shark stocks are currently depleted is supported by the alternative analyses.

Table A1. Estimates of the Expected Value (EV) and the Coefficient of Variation (CV) of parameter marginal posterior distributions from alternative applications of Bayesian stock production model analyses. Results are from fits to the large coastal sharks aggregate data.

	PR-IV-26 base case[1]		**PR-ALT base case[2]**		**PR-1998 base case[3]**		**PR-ALT base case[4]**		**PR-ALT CPUE[5]**	
Parameter	**EV**	**CV**	**EV**	**CV**	**EV**	**CV**	**EV**	**CV**	**EV**	**CV**
K	10226	0.21	10046	0.22	9535	0.17	9565	0.22	10573	0.25
r	0.07	0.62	0.07	0.75	0.07	0.51	0.08	0.67	0.08	0.61
Co	309	0.44	310	0.45	284	0.39	305	0.43	590	0.51
N(98)	2964	0.32	2974	0.38	1385	0.25	1992	0.32	1636	0.30
N(98)/K	0.29	0.29	0.30	0.31	0.15	0.24	0.21	0.28	0.16	0.30
MSC	157	0.44	162	0.47	149	0.38	162	0.43	179	0.42

[1] Results reported in SB-IV-26.
[2] Results from my model implementation, with data and model structure as described in SB-IV-26.
[3] Results reported in SEW-1998.
[4] Results from my model implementation, with data as described in SEW-1998 and model structure as described in SB-IV-26.
[5] Results from my model implementation, with data as described in SEW-1998 and model structure as described in SB-IV-26. Only 8 of the CPUE series (*Shark Observer, SC LL, Va LL, Pelagic log, Early Rec, Late Rec, NMFS LL NE, and NMFS LL SE*) were fitted in the analysis and 1983 *Early Rec* data point was removed.

Table A2. Estimates of the Expected Value (EV) and the Coefficient of Variation (CV) of parameter marginal posterior distributions from alternative applications of Bayesian stock production model analyses. Results are from fits to the sandbar shark data.

	PR-1988 base case[1]		**PR-ALT base case[2]**		**PR-ALT 12 K limit[3]**		**PR-ALT CPUE[4]**		**PR-ALT *r* prior[5]**	
Parameter	**EV**	**CV**	**EV**	**CV**	**EV**	**CV**	**EV**	**CV**	**EV**	**CV**
K	3265	0.32	4031	0.49	3936	0.44	3719	0.43	4516	0.40
r	0.10	0.70	0.11	0.69	0.12	0.69	0.11	0.70	0.07	0.76
Co	170	0.54	226	0.61	227	0.60	196	0.58	223	0.58
N(98)	924	0.45	1347	0.82	1299	0.72	1319	0.72	1466	0.69
N(98)/K	0.29	0.39	0.34	0.45	0.34	0.43	0.36	0.41	0.33	0.44
MSC	71	0.55	96	0.56	97	0.56	87	0.52	70	0.60

[1] Results reported in SEW-1998.
[2] Results from my model implementation, with data as described in SEW-1998 and model structure as described in SB-IV-26.
[3] Results from my model implementation, with data as described in SEW-1998 and model structure as described in SB-IV-26. The maximum value for the *K* parameter was reduced to 12,000 from 20,000.
[4] Results from my model implementation, with data as described in SEW-1998, 12,000 maximum for *K* and model structure as described in SB-IV-26. The 1983 *Rec1* CPUE point was removed.
[5] Results from my model implementation, with data as described in SEW-1998, 12,000 maximum for *K,* and model structure as described in SB-IV-26. The prior for the *r* parameter was lognormal with expected value of 0.07 and standard deviation of 0.7.

Table A3. Estimates of the Expected Value (EV) and the Coefficient of Variation (CV) of parameter marginal posterior distributions from alternative applications of Bayesian stock production model analyses. Results are from fits to the blacktip shark data.

	PR-1998 base case[1]		PR-ALT base case[2]		PR-ALT 12 K limit[3]		PR-ALT CPUE[4]	
Parameter	**EV**	**CV**	**EV**	**CV**	**EV**	**CV**	**EV**	**CV**
K	5527	0.31	8411	0.53	6445	0.35	5984	0.35
r	0.12	0.70	0.14	0.80	0.14	0.81	0.13	0.80
Co	81	0.37	246	0.41	235	0.39	230	0.38
N(98)	1383	0.57	4222	0.84	2766	0.85	2074	0.94
N(98)/K	0.25	0.43	0.47	0.56	0.39	0.57	0.31	0.60
MSC	137	0.43	226	0.63	186	0.61	161	0.58

[1] Results reported in SEW-1998.
[2] Results from my model implementation, with data as described in SEW-1998 and model structure as described in SB-IV-26.
[3] Results from my model implementation, with data as described in SEW-1998 and model structure as described in SB-IV-26. The maximum value for the *K* parameter was reduced to 12,000 from 20,000.
[4] Results from my model implementation, with data as described in SEW-1998, maximum value for *K* of 12,000 and model structure as described in SB-IV-26. The *Gulf Logs* CPUE series was removed.

Table A4. Alternative catch history modified from Table 3 (SEW-1998). Commercial landings for the 1981-1985 period were increased by a factor or 2 and for the 1986-1992 period increased by a factor of 3 (from their Table 2 values, SEW-1998). The non-US catch estimate has been added (number of fish in thousands).

year	commercial.	Longline discards	Rec. catches	Unreported	Coastal discards	Non-US	Total
1981	32.4	10.0	265.0			100.0	407.4
1982	32.4	10.0	413.9			100.0	556.3
1983	35.0	10.0	324.6			100.0	469.6
1984	47.8	10.0	254.6			100.0	412.4
1985	44.4	10.0	366.1			100.0	520.5
1986	162.0	10.0	426.1	24.9		100.0	723.0
1987	314.1	9.7	314.4	70.3		100.0	808.5
1988	823.8	11.4	300.6	113.3		100.0	1349.1
1989	1053.0	10.5	221.1	96.3		100.0	1480.9
1990	802.8	8.0	213.2	52.1		100.0	1176.1
1991	600.6	7.5	293.3	11.3		100.0	1012.7
1992	645.6	20.9	304.9			100.0	1071.4
1993	338.8	7.3	249.0		25.4	100.0	720.5
1994	228.0	8.8	160.9		22.8	100.0	520.5
1995	222.4	6.1	183.4		22.2	100.0	534.1
1996	164.5	5.7	184.5		16.4	100.0	471.1
1997	98.4	5.6	161.9		9.8	100.0	375.7

Table A5. Estimates of the Expected Value (EV) and the Coefficient of Variation (CV) of parameter marginal posterior distributions from alternative applications of Bayesian stock production model analyses. Results are from fits to the large coastal sharks aggregate data.

	PR-ALT base case[1]		**PR-ALT Alt. Catch**[2]	
Parameter	**EV**	**CV**	**EV**	**CV**
K	9565	0.22	15092	0.14
r	0.08	0.67	0.06	0.55
Co	305	0.43	361	0.44
N(98)	1992	0.32	3986	0.29
N(98)/K	0.21	0.28	0.27	0.26
MSC	162	0.43	217	0.42

[1] Results from my *base case* model implementation as presented in Table A1.
[2] Results from my model implementation, with data and model structure as described in the *base case* except for the catch time-series where values presented in Table A4 were used.