Review of 2002 Stock Assessment for

Large Coastal Sharks

DOC/NOAA/NOS/NMFS/OAR

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Independent Reviewer #1

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I. Executive Summary of Findings and Recommendations

My review of the 2002 assessment of large coastal sharks suggests that a state-of-the-art was performed using the best scientific information available. Alternative datasets were constructed for catch to represent the uncertainties in the data. Several indices of abundance were compiled and used in the assessment with two weighting systems. Six alternative stock assessment models were evaluated, and five of these were used in the stock assessment document. Alternative harvest policies from no catch to 150% of the year 2000 catch were contrasted, and management implications were discussed.

The stock assessment results show that there is great uncertainty in estimates of abundance, fishing mortality, and management parameters such as MSY. This difficulty can be traced to and high variability, uncertainty, and conflicting information in the data. The stock assessment wisely uses Bayesian analyses to provide an objective, albeit uncertain, assessment of stock status.

The stock assessment concludes that the condition of sandbar and blacktip sharks is good. Using "inference by subtraction", it concludes that there is no evidence that some species in the LCS complex may be in a poor condition. The declines in some of the indices of abundance since the 1970s and 1980s mean that these results from the assessment of the LCS complex may actually be valid. The problem is that the stock assessment did not examine individual species to see where the problems may lie. Whether there is sufficient information on which to take management action depends on the level of risk one is willing to accept. There is neither positive proof of an effect on the complex nor positive proof of no effect. It should be noted that many shark species have low productivity and are long-lived, so that failure to take action could result in long-term depletion of some species.

Improvements to the assessment can be made in the future. Further investigation of indices should be undertaken. Assessments should be done for more species or species groups in the LCS complex. Further investigation of age and age-sex-area models should occur. Investigation of alternative and robust harvest policies in contrast to the current constant-catch policy should occur in the future.

II. Introduction

My perception of Large Coastal Shark (LCS) Management Background

The 1998 assessment of large coastal sharks off the east coast of the United States was controversial. The shark workshop involved some different participants than previous ones, and the main modeling effort was sponsored and undertaken by those aligned with conservation organizations. Previous models were not entertained or presented. Consequently, litigation ensued which led to court intervention in LCS management to this day. Two different sets of peer reviews were undertaken after the workshop, one conducted by Natural Resources Consultants (NRC, 5 reviews) and the other by the Center of Independent Experts (CIE, 3 reviews). These reviews pointed out problems with the assessment, including inability to fit CPUE indices, inadequate exploration of alternatives, lack of estimation convergence, and inappropriateness of some components of the assessment.

In June 2002, the next shark workshop occurred. Alternatives for catch data, CPUE indices, and assessment models were considered. The workshop report was finalized in August. Analysts apparently worked through the summer on the stock assessment, and in September, NMFS released a detailed stock assessment document based on the workshop recommendations.

My Assignment

I understand that my assignment is to review the 2002 workshop report and stock assessment document for their scientific rigor and credibility. In addition, I am to address whether the 2002 assessment addressed the problems found in the review of the 1998 assessment. In so doing, I am to answer six questions, which are reproduced in part IV.

III. Review Methodology (Reviewer Activities)

In conducting my review, I read the wealth of information made available by NMFS on LCS (part V). I also read some other relevant literature related to assessment models (part V). I summarized the results of my review as answers to the six questions posed in the Statement of Work. Given the shortness of time for the review, I did not attempt to obtain or analyze any data, nor did I attempt to run any assessment models on LCS. I focused my attention primarily on assessment methodology, which corresponds to my area of expertise. Because I am unfamiliar with detailed biology of the shark species and do not live anywhere near the southeastern United States, I did not attempt to make detailed comments about data collection and reliability. Rather, I concentrated on whether practices in this assessment are within norms of what is done in other places.

IV. Review Results

Question 1

How the appropriateness of specific modeling approach(es) was (were) determined for assessing large coastal sharks, a long-lived species (or species complex), including consideration of alternative modeling approaches and the modeling approaches employed in prior shark evaluation workshops.

Summary of Findings and Conclusions

Six alternative models were considered in the assessment from a simple MLE model used in 1996, to the Bayesian surplus production model used in 1998, to four more complex and biologically realistic models. The most complex of these, an age-sex-area model, was not used in the stock assessment, presumably because it was too complex to use in a short time period. To my mind, the processes used in the LCS assessment were consistent and rational, and the results were presented without bias or subjectivity. Parameter estimation techniques were thoroughly documented for the models. Fits of the models to data were carefully examined. Model results are sensitive to the choice of model, aspects of parameter estimation, and different data sets for both catch and CPUE. Consequently, estimates of abundance and fishing mortality are highly uncertain. In addition, estimates of the management parameters MSY and the abundance corresponding to MSY are highly uncertain.

Expanded Explanation/Analysis

The report Improving Fish Stock Assessments (NRC, 1998) described the ingredients of an excellent stock assessment. There are four major parts of such an assessment:

1. Stock definition: There should be consideration of stock structure in spatial terms and the migratory character of the population should be defined.
2. Data: Removals and indices of abundance should be thoroughly documented; age- and length-structure information should be included

if possible, as well as environmental data and fishery information (from participants in the fishery).

3. Model: Determination of key population parameters should be described, the statistical formulation should be documented, uncertainty should be evaluated and retrospective evaluation should be undertaken. Alternative model structures should be considered.
4. Policy evaluation: Alternative hypotheses for the states of nature should be included, alternative actions should be evaluated, performance indicators for risk and fishery objectives should be described, and presentation of results should provide a good basis for decision-making.

Overall, I think that the 2002 shark assessment has addressed most of these considerations. With respect to stock definition, the assessment describes the underlying life history and migratory characteristics of the species, as far as they are known. To accommodate the fact that some portion of the shark population moves to Mexico during parts of the year, the baseline data scenario includes estimates of Mexican catches. One model by Apostolaki et al. (SB-02-1), described below, is a two-area model to deal with Mexico. Section 4.4 of the Workshop report describes tagging and other information. While the documents report information by individual species, species-specific information is not given much attention in the workshop report or stock assessment document (see Question 6).

With respect to data, an admirably exhaustive description of the removal data and indices of abundance is made in the workshop report and supporting papers. At the workshop, the Catch Working Group evaluated and constructed the datasets for removals. The CPUE Working Group compiled and evaluated indices of abundance. It must be recognized that some of the data sources for removals are not of high quality due to lack of real information. The assessment has attempted to address this problem by constructing alternative removal datasets. Similarly, the quality of the indices of abundance varies from dataset to dataset. Some of the series are very short, and others have very high estimates of variance. Given the contradictory nature of some of the indices, this further suggests that some of the indices are biased as indicators of population condition.

With respect to models, The Methods Working Group evaluated six alternative models, which is a high number with respect to typical stock assessments. The choice of an optimal model is a critical issue in this assessment and involves a particularly difficult tradeoff between biological realism in more complex models versus simplicity and parsimony for parameter estimation in simpler models.

Bayesian models have a particular advantage in the situation of dealing with data that are fairly uninformative, as is the case with LCS, as shown by McAllister et al. (SB-02-41). The reason for this is that likelihood methods can frequently produce unrealistic estimates of population parameters, whereas Bayesian methods can utilize informative priors to keep solutions away from bad places. However, such informative priors must be chosen with care and can strongly influence the outcome of the assessment. Therefore how such priors are chosen must be thoroughly documented and justified, which was done in the stock assessment document.

A description of each model (from simplest to most complex) follows, along with my subjective evaluation. Table 9 of the workshop report provides additional details about some of the models.

1. Maximum likelihood method (SB-02-4): This model was used in some assessments before 1998. It is a density-independent method (i.e., reproduction is proportional to spawning stock) that contains no age structure, no spawner-recruit relationship, deterministic abundance (i.e., no random variability), and a single "lumped" parameter for population dynamics. Parameter estimation is accomplished through the time-honored maximum likelihood technique and is not a Bayesian method. Its use in the past seems predicated on matching the complexity of the model to the amount of data available. The contention was that the method could provide useful information for time series as short as 4 years long. To my mind, this model is unacceptable, except for the crudest of assessments. It only allows exponentially increasing or decreasing trends in abundance and cannot cope with the variability induced by an age-structured population. It may have been sufficient for the original assessments when little data or other information had been compiled, but I view it as overly simplistic for current needs. It should not be used for making projections, because the model is unrealistic.
2. Bayesian surplus production model (SB-02-25,26,41): This model was the only one used in 1998. It is a density-dependent method that contains no age structure, a parabolic-shaped, logistic spawner-recruit relationship, deterministic abundance (i.e., no random variability), and two parameters for population dynamics (essentially instrinsic rate of population growth r, and carrying capacity K) (Quinn and Deriso 1999, chapter 2). Parameter estimation is accomplished through the Bayesian method, in which prior distributions are set for unknown parameters, these prior distributions are combined with the likelihood of the data, and resulting posterior distributions summarize the new state of knowledge about the population. Bayesian methods are inherently useful for presenting uncertainty and making projections, because these posterior distributions can be constructed for almost any desired quantity, include future catch and abundance. This application makes use the SIR algorithm for doing multi-variable integration.
3. Bayesian surplus production model with state-space implementation: This model is essentially the same as Model 2, except that stochasticity (randomness) in the population process is incorporated. Thus, both observation and process errors are included in the modeling. This model derives from important work by Meyer and Millar (1999a, b) and represents a state-of-the art application of modern assessment methodology. This application makes use the Gibbs sampling algorithm for doing multi-variable integration.

   I find both Models 2 and 3 to be less satisfying than the next set of models, because I do not think that the surplus production model adequately represents the dynamics of LCS. Surplus production models assume that an immediate density-dependent impact is made in the population’s dynamics by a change in abundance. This is because the recruitment function has no time lag in its response. Therefore a reduction in reproductive potential of adults would occur immediately in the model, whereas in a real age-structured population, it would take several years. Consequently, if recruitment had been favorable in recent years due to good environmental conditions, this would not be reflected in the model's dynamics, and vice versa. Finally, the parabolic shape of the Schaefer model may not properly reflect the dynamics of shark populations. These long-lived species with low fecundity are more likely to have a different productivity function, in which maximum productivity is shifted to a higher abundance than one-half of the carrying capacity in the Schaefer model.

4. Bayesian delay-difference model with state-space implementation (SB-02-11): This model is a density-dependent method that does contain age structure, an asymptotic Beverton-Holt spawner-recruit relationship, stochastic abundance, and parameters for population dynamics (growth, survival, recruitment) (Quinn and Deriso 1999, chapter 5). Parameter estimation is accomplished through the Bayesian method using Gibbs sampling, similar to Model 3. The beauty of this model is that is essentially deals with two components of the population (juveniles and adults) in a simplified setting that does not require age-structured data. Thus it can work in the same situations for which surplus production models are applied. In addition, the population parameters are more intuitive and can be used to calculate other population parameters of interest such as maximum sustainable yield and carrying capacity.
5. Bayesian age-structured model with state-space implementation (SB-02-5, 31): This model is a density-dependent method that is fully age-structured, with an asymptotic Beverton-Holt spawner-recruit relationship, stochastic abundance, and parameters for population dynamics (growth, survival, recruitment, selectivity) (Quinn and Deriso 1999, chapter 8). As such, it is the first model that offers the opportunity to utilize age-structured data and indices of abundance. Parameter estimation is accomplished through the Bayesian method using Gibbs sampling, similar to Models 3 and 4. The model has an accounting mechanism by which each individual age is tracked through the life of a year-class. This creates the complication of needing to specify the selectivity properties of each fishery that catches sharks. The critical question is whether the complexity of the model is too great for the quality of information available. Age-structured models are the *de rigueur* approach utilized for assessment around the world.
6. Bayesian age-sex-area-structured model (SB-02-1): This model is the apotheosis of models used in stock assessment. Few assessments around the world deal with both sex-specific and area-specific population parameters in addition to age structure. Parameter estimation is accomplished through the Bayesian method using the SIR algorithm. From the workshop Report (p.36): "The authors concluded that the age-based model is preferable to less sophisticated models in that it can account for fisheries with different size selectivity, fish migration, and age-specific management measures, but it requires more detailed information, such as selectivity data."

At the 2002 workshop, a methods working group evaluated these models. The working group concluded that a variety of models should be subjected to a full analysis in the stock assessment to be done over the summer. The stock assessment document contains model runs from the first five models. The most complex age-sex-area model (Model 6) was not presented in the stock assessment document, presumably because it was too complex to use in a short time period. I could not find the reason given in the stock assessment document.

To my mind, the development of new models and Bayesian applications is a welcome development in the 2002 assessment. These new models are contemporary and state-of-the-art applications of the most current assessment techniques (Quinn and Deriso 1999). The report Improving Fish Stock Assessments (NRC 1998) also welcomed the development of such methods.

The move to Bayesian analyses also comes with a set of new problems. Convergence of the multivariable integration techniques for constructing posterior distributions must be assessed, and there are several methods for doing so (Su and Adkison 2001, Adkison and Su 2001). The presence of outliers and misspecification of priors can have a big effect on outcomes (Chen et al. 2000). Perceptions and weighting of data can also have a big influence on assessment results (Merritt and Quinn 2000). Consequently, different modeling approaches can have different outcomes, and the proper way to average across models is not yet known (Adkison 2002).

The accuracy and precision of the assessments of any one stock cannot be known with certainty. What can be ascertained is whether consistent and rationale processes were used to arrive at model specifications and choices. To my mind, the processes used in the LCS assessments were consistent and rationale and the results were presented without bias or subjectivity. Parameter estimation techniques were thoroughly documented for the models. Fits of the models to data were carefully examined.

(Parenthetically, I have one criticism of the presentation of methods in the stock assessment document. Each model should have a full description of data variables, model parameters, objective functions, and equations that describe all processes. It is not sufficient to reference existing literature for the model's specifications.)

Model results are sensitive to the choice of model, aspects of parameter estimation, and different data sets for both catch and CPUE (as shown in Figures 71, 73, and 76 for LCS, sandbar shark, and blacktip shark, respectively). Consequently, estimates of abundance and fishing mortality are highly uncertain. In addition, estimates of the management parameters MSY and the abundance corresponding to MSY are highly uncertain (even though they are shown without any measures of uncertainty in those figures).

Recommendations for Improved Future Stock Assessments

1. The stock assessment workshop held in June 2002 appeared to me to be extremely productive. The stock assessment that followed represented an

incredible amount of work in a very short time period. Further validation of the modeling should be undertaken. This would involve reconvening the workshop and allowing participants to comment on choice of prior distributions and plausibility of outcomes.
2. Additional convergence diagnostics should be examined, along the lines of Su and Adkison (2001).
3. Bayesian model averaging may be a method for synthesizing results across different models (within a set of hierarchical models, Adkison 2002).
4. Further exploration of age-structured and age-sex-area models would be useful.

Question 2

> How the availability and quality of alternative data sets was considered, including recent catch, catch rates, trends in stock status, and other biological parameters (i.e., how the data series were estimated, how they were weighted for the analysis, and how they were applied as age-specific indices of abundance).

Summary of Findings and Conclusions

The workshop participants and stock assessment scientists did an excellent job of considering alternative datasets. At the workshop, the Catch Working Group developed two datasets (updated and baseline). The latter included bycatch in the menhaden fishery and Mexican catches (as well as they could be determined). The stock assessment document also used an alternative catch scenario, which attempted to reconstruct historical catches, in line with the recommendation of one of the CIE reviewers. The CPUE Working Group compiled and evaluated indices of abundance. In the assessment, indices were weighted in two ways: (1) equal weighting, and (2) weighted by the inverse of variance. The assessment also examined runs in which only fishery-dependent or only fishery-independent indices were used, as well as runs with all indices. Age-specific indices were identified and utilized in the age-structured models.

Expanded Explanation/Analysis

The preceding summary paragraph is sufficient to answer Question 2. This section will considered some additional issues related to indices of abundance and data weighting.

The number of indices of abundance is impressive but also disconcerting. Many of the indices cover a short time period (as short as 2 years), pertain only to a local area, may be affected by catchability changes, or have other problems. Shark scientists have done an admirable job in attempting to assess the variability in these indices. As recognized by the workshop participants, variability is not the only component for selecting an index. Other considerations include bias, length of series, area to which the index applies, and applicability as an overall index. An analytical hierarchy process (Merritt and Quinn 2000) might be useful in further paring down the number of indices used in the stock assessment model. In the current modeling, particular indices may drive the assessment results, but that would be hard to discern with so many indices. Alternatively, it may be possible to construct some omnibus indices that are based on area-weighting of indices from particular areas (Quinn and Deriso 1999, section 1.3).

Weighting indices by inverse variance is a long-recognized desirable technique in statistics and fisheries (Merritt and Quinn 2000). As such, it should be considered more desirable *a priori* than equal weighting. The stock assessment results differed greatly with the two weighting methods. And some of the results with inverse weighting were completely implausible. Therefore, further investigation of optimal weighting systems needs to be conducted in the future.

Recommendations for Improved Future Stock Assessments

1. Develop a process for winnowing out the important and useful indices of abundance to be used in stock assessment models.
2. Consider developing omnibus indices.
3. Continue to investigate alternative weighting systems.

Question 2A

> Whether the best available scientific data (at the time of the 2002 SEW Report) were used (including consideration of the CIE and NRC reports that reviewed and gave recommendations regarding data used in the 1998 SEW Report).

Summary of Findings and Conclusions

In my reading of the Workshop Report, the stock assessment document, and the auxiliary documents, I came to the conclusion that the best available scientific data was being used. The current stock assessment workshop report and document addressed the major issues raised in the CIE and NRC reports.

Expanded Explanation/Analysis

A sensitivity analysis was conducted to address the reviews of the 1998 workshop report (SB02-14). Sensitivity tests were conducted with respect to the catch series used, the CPUE series used, weights assigned to the CPUE series, the form of the stock assessment model, the importance function used in Bayesian integration with the SIR method, the specification of prior distributions, and the start of the fishery (1969 versus 1974). Further sensitivity analyses were conducted in the stock assessment document (see page 9). The results were most sensitive to the choice and weighting of CPUE series and the importance function used. (In the 1998 assessment, the importance function used was too narrow, so that larger abundance values were under-sampled. Consequently, the estimates of abundance were too low. This problem was corrected in the 2002 assessment.) Prior distributions also had a major impact on the outcomes. Nevertheless, the stock assessment document took great care to explain and justify the priors chosen.

Recommendations for Improved Future Stock Assessments

1. Sensitivity trials should continue in future assessments.
2. Retrospective analyses (NRC 1998), in which one year of data at a time is

left out, should be conducted to explore the stability of the outcomes of the models.

Question 3

> How the selected modeling approach(es) was (were) applied to the data chosen for the analyses, including: how information was handled or applied relating to whether each of the large coastal shark species under consideration represent open or closed populations, and how discard mortality was accounted for in the stock assessment and whether options were identified to account for dead discard mortality in setting a landings quota based on the assessment.

Summary of Findings and Conclusions

The stock assessment attempted to use a variety of datasets for catch and CPUE in the modeling approaches. To account for the Mexican component of the population, the baseline scenario used in all models included estimates of Mexican catches. Only the age-sex-area model explicitly accounted for the U.S. and Mexican areas. The catch data included estimates of discard in the menhaden fishery and were used in all models. Options to account for discard mortality in setting a landings quota were not given, for reasons described on page 59 of the stock assessment document. Essentially, reducing the TAC may increase dead discards and not reduce fishing mortality. A solution to this problem has not been found.

Expanded Explanation/Analysis

My comments regarding modeling are found in Question 1.

Recommendations for Improved Future Stock Assessments

See Question 1.

Question 4

> How the reliability of projections was evaluated based on the above three considerations.

Summary of Findings and Conclusions

The projections were carried out according to standard Bayesian practice. Consequently the reliability of the projections is inherent in the specification of the model. The issue of uncertainty in the MSY level does not seem to have been addressed in the projections. Future work to improve projections would be desirable.

Expanded Explanation/Analysis

Projections were undertaken for most models, except the MLE method, because its density-independence assumption means that reliable projections would not be obtained over the 10 to 30 year time periods used. For the other methods, the

Bayesian methodology allows populations to be projected into the future with uncertainty incorporated for various catch scenarios from 0 to 150% of the current catch. Essentially, the projections are samples from the probability distributions of the input parameters and data and result in posterior distributions of outcomes specified by the analysts. Consequently the reliability of the projections is inherent in the specification of the model. Any mis-specification in the model or its data would carry over into the projections.

For each future time period considered, the probabilities of abundance exceeding the current level and exceeding the calculated MSY level were determined. These probabilities were then averaged over the "main scenarios" for the LCS complex (Figure 72, sandbar shark (Figure 74), and blacktip shark (Figure 77). The results suggest that there is a good chance that the LCS complex will be below the MSY level unless catch is reduced, but that there is a good chance that sandbar and blacktip sharks will be above the MSY level with current catch.

The issue of uncertainty in the MSY level does not seem to have been addressed in the projections. The stock assessment tends to treat the MSY level as a constant, where in reality it is an estimate with potentially high uncertainty (see Question 5). This is a hard question that has not been addressed much in stock assessments around the world. One approach is to use probability distributions to summarize the uncertainty in MSY using standard Bayesian methods. Another approach has been to relate MSY to environmental conditions and then undertake projections of the environment along with the population. A third approach is called Management Strategy evaluation (Cooke 1999), in which simulation testing of harvest strategies is conducted with the goal of obtaining a harvest policy robust to alternative states of nature that may be occurring. The constant catch policy may not be a very robust or efficient strategy because it applies to all population levels. Strategies that adapt to the size of the population may perform better, as elaborated in Question 5.

Recommendations for Improved Future Stock Assessments

1. Address the uncertainty in MSY in greater detail, using one or more of the methods described in the previous paragraph.
2. Evaluate Management Strategy Evaluation as a tool to compare alternative harvest policies.

Question 5

> How the effects of a range of catch scenarios, including the effects of current regulations on stock trajectories were evaluated.

Summary of Findings and Conclusions

Catch scenarios included: 0%, 50%, 80%, 100%, 120%, and 150% of year 2000 catch. The MLE model is not useful for projections, because it is a density independent model, which only allows exponential behavior. For the other models, NMFS employed standard Bayesian methodology to project the population forward in time 10, 20 and 30 years. NMFS summarized the results in terms of expected trends and probability distributions of the outcomes. The projection methodology used by NMFS was contemporary and comparable to what is done in other places.

Expanded Explanation/Analysis

Each model expresses population abundance at a given time period as a function of past abundances and population parameters estimated from the data. In order to do projections, one uses those parameters and abundances to forecast into the future. The only thing that is not specified at that point is the values of catch to be taken in the future. Those values are specified by the range of management policies to be evaluated. In this case, the assessment has relied on constant catch policies from no fishing to 150% of the year 2000 catch.

Several alternative scenarios for policy evaluation could also be evaluated. In many parts of the world, there is a preference for policies based on constant fishing mortality or harvest rate. These policies adapt to the level of abundance by curtailing catch when abundance is low or increasing catch when abundance is high, because catch is approximately equal to fishing mortality times abundance. More contemporary policies make further adjustments to fishing mortality at low population sizes. For example, the North Pacific Fishery Management Council linearly decreases fishing mortality as biomass drops below the target level. This results in a quadratic decrease in catch as biomass decreases.

Secondly, there are alternative policies based on per recruit or spawning potential ratios. For example, an F40% policy is one in which the fishing mortality is determined which does not allow the population biomass per recruit to drop below 40% of the unfished level. This fishing mortality is often below the level that produces MSY, and hence, is conservative. Furthermore, it requires far less information than is required to determine MSY with confidence, as it depends only on natural mortality, selectivity, and average weight of adults by age class. In order to determine MSY, one must know the spawner-recruit relationship, and that does not seem to have been well determined or validated in the LCS assessments.

Recommendations for Improved Future Stock Assessments

1. Consider alternative harvest policies, such as constant fishing mortality or abundance-based policies.
2. Consider whether per recruit harvest policies may be more stable and useful than those based on MSY.
3. Justify the form of the spawner-recruit relationship used by showing spawner-recruit plots, along with pertinent data for validation. In other words, are there data that can substantiate the shape and extent of the spawner-recruit curve?

Question 6

> Whether candidates for prohibited species status were considered, including whether the species on the existing prohibited species list are appropriate.

Summary of Findings and Conclusions

There was nothing in the stock assessment document that addressed this issue directly. The document does call for additional protection for species in the LCS complex other than sandbar and blacktip sharks. Alternative assessment approaches should be found for other species in the complex in the future.

I found the results for the sandbar and blacktip sharks to be more compelling that for the LCS complex. It is not clear that the assessment models applied to the LCS complex result in reliable estimates of MSY and its corresponding abundance, because pooling is done over many species with different life histories. Because the status of sandbar and blacktip shark populations is relatively good, inference by subtraction is used to conclude that the condition of the other species in the complex is poor.

Further analysis is needed to determine whether this conclusion is valid by examining data on a species by species basis. Whether the conclusions from the LCS complex assessment provide sufficient information on which to take management action depends on the level of risk one is willing to accept. It should be noted that many shark species have low productivity and are long-lived, so that failure to take action could result in long-term depletion of some species.

Expanded Explanation/Analysis

There is a summary of shark biological information in the 2002 workshop report (pages 2 to 6) but not much about the condition of individual species in the LCS complex. There is also little information about individual stocks in the 2002 stock assessment document.

The modeling philosophy with respect to the condition of individual species is to fit models to the LCS complex, sandbar shark, and blacktip shark. The models for the LCS complex are constructed to show the overall condition of this species complex. Sandbar and blacktip sharks make up the bulk of the catch of the complex, and sufficient information is available to perform individual assessments of these species. As noted in the 2002 workshop report (page 56), the workshop group would like to conduct additional assessments of dusky, hammerhead, sand tiger, silky, spinner, and bull sharks in the future.

The stock assessment results suggest that the LCS complex is below MSY and that current catches are too high (Figure 71). In contrast, sandbar and dusky sharks appear to be above the MSY level, with catches above or below the MSY level (Figures 73, 76) depending on the assessment model. The stock assessment authors make the "inference by subtraction" that the other species in the complex must be below the MSY level and that overfishing must then be occurring.

This "inference by subtraction" is troubling. The bulk of the catch is from sandbar and blacktip sharks, but information on the catches of individual species is available (SB-02-15). There are no species-specific indices of abundance in the stock assessment document to show which species might be impacted. But there are indices of abundance for some individual species, such as mako, dusky, blue, hammerhead, and tiger sharks (SB-02-6,7,12).

Furthermore, the authors do not describe a mechanism by which these other species would be differentially impacted. Is it that the productivity of these other species is lower? Or would it be due to higher availability or catchability? Or could it just be some artifact of the modeling? How do the data by individual species support the assessment results obtained for the complex?

Finally, it is not clear that MSY for the complex is well determined by pooling all these species with different life histories. If one presumed that each species had its own productivity relationship, then the overall productivity relationship for the complex would be a complicated weighting of the individual relationships. This overall relationship could change dramatically depending on the composition of individual species in the complex, which could also change over time. The assessment models (from surplus production to age-structured) all assume fairly simple productivity relationships, and thus, the MSY estimate for the complex may be poorly determined and even biased. Further analysis is needed to determine whether this conclusion is valid by examining data on a species by species basis.

All the same, it cannot be said that there is no evidence that some species in the LCS complex may be in a poor condition. The declines in some of the indices of abundance since the 1970s and 1980s mean that the results from the assessment of the LCS complex may actually be valid. Whether this is sufficient information on which to take management action depends on the level of risk one is willing to accept. There is neither positive proof of an effect on the complex nor positive proof of no effect. It should be noted that many shark species have low productivity and are long-lived, so that failure to take action could result in long-term depletion of some species.

Recommendations for Improved Future Stock Assessments

1. Include pertinent information in the stock assessment document about the species found in the LCS complex.
2. Develop indices of abundance for species groups with similar life histories. The paper by Cortes (SB-02-13) may be helpful in classifying species groups and in trend analysis in point 4 below.
3. Investigate species misidentification in greater depth.
4. Conduct additional analyses of the trends of these species groups.
5. Develop stock assessment models for these species groups analogous to those for sandbar and blacktip sharks.

I. Bibliography of Materials Reviewed

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