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Chesapeake Bay Blue Crab Stock Assessment Review

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Executive Summary

The blue crab supports the most important commercial fishery in the Chesapeake Bay. Commercial landings have exceeded 100 million pounds historically (1993) with more recent average landings reaching approximately 72 million pounds. The total impact of the blue crab fishery to the Chesapeake region exceeds $200 million annually.

Sound management of this resource requires accurate information on the status and trends of the blue crab population and on the dynamics of the fisheries that exploit the stock. The NOAA Chesapeake Bay Office (NCBO) supported the development of a full blue crab stock assessment utilizing which was initiated in October 2003 and completed in 2005. This follows the stock assessment completed for the blue crab in 1997.

The review workshop for the Chesapeake Bay blue crab assessment took place in Annapolis, Maryland on August 9-11, 2005. The NOAA Chesapeake Bay Office provided the key documents prior to the Chesapeake Bay blue crab stock assessment review meeting as well as a CD with an extensive database of all the relevant data referred to in the stock assessment report and the assessment model. The objectives of the review were to evaluate the Chesapeake Bay blue crab stock assessment, including input data, assessment methods, and model results.

The 2005 stock assessment highlights a number of research areas where significant progress had been made on the 1997 stock assessment. A large number of research reports had been published that focused on issues relevant to the stock assessment or on related issues with the blue crab biology. These included: (a) natural mortality studies (Hewitt and Hoenig 2005, Lambert et al. 2005); (b) studies on growth dynamics (eg Bunnell and Miller in press, Miller and Smith 2003, Smith and Chang in press); (c) a time series analysis of catch that adjusted for changes in reporting methods (Fogarty and Miller 2004); (d) use of depletion experiments during the winter dredge survey (WDS) to estimate catchability which can be used to estimate absolute abundances (Volstad et al. 2000, Sharov et al. 2003); (e) assessment of WDS to quantify abundance and distribution (Jensen et al. in press a and b, Jensen and Miller in press); (f) reproduction issues such as sperm limitation (Hines et al. 2003); (g) the Virginia Institute of Marine Science (VIMS) survey provides a valuable index of mature females on the spawning grounds that has been combined with a survey of the megalopae to assess the stock-recruitment relationship (Lipcius and Stockhausen, 2002); (h) an assessment of spawning sanctuary and protected deepwater dispersal corridor used to improve the level of spawning stock (Lipcius et al. 2003); (i) a new stock assessment model that used data from a number of fishery-independent surveys to assess changes in abundance and exploitation; (j) individual-based approach to spawning potential per recruit (Bunnel and Miller in press); and (k) revised control rule based on exploitation fraction rather than the fishing mortality F that is dependent on the estimate of the natural mortality M being used.

The stock assessment modeling, which involves an extension of the Collie and Sissenwine (1983) model to include the multiple fishery-independent surveys, was appropriate given the information available and provides some interesting insights into the stock assessment. This model has addressed some significant issues such as revision of natural mortality estimates, growth model and harvest estimates. A significant change in the control rule has been the use of the exploitation fraction rather than F in the control rule. This avoids the need to estimate M to assess the exploitation.

The fishery-independent surveys continue to be valuable indicators of the relevant abundance of the blue crab year-classes which provides an indication of the annual recruitment index as well as abundance of mature and spawning females. The WDS appears to be particularly useful and the recruitment index has been shown to be reliable indicator of harvest. These surveys indicate that the spawning stock and recruitment have generally been below average in recent years which highlights concerns about recruitment overfishing that need further investigation through the stock-recruitment relationship. Efforts to protect the breeding stock have been undertaken in recent years through the marine protected area and corridor in the lower Chesapeake Bay and the impact of these closures on the spawning stock needs to be monitored.

Recommendations

Some areas for future research to improve the stock assessment and contribute to the improved management of the blue crab fishery are:

1) One of the fastest growth models used to obtain the average growth model used in the stock assessment model was undertaken in a pond mesocosm (Ju et al. 2001), which may not be representative of growth in the wild.

2) The significant contribution of cannibalism to natural mortality suggests than M could be inversely related to age/size due to reduced mortality with increasing size from cannibalism and predation and reduction in frequency of moulting. The impact of this assumption should be investigated in the stock assessment model using sensitivity analysis.

3) Cannibalism could contribute to a density-dependent effect on M if there were a significant difference in annual abundance of the year-classes. This could also be examined in the model using a sensitivity analysis.

4) The stock assessment report acknowledges the influence of annual variations in growth, recruitment timing and distribution that need to be evaluated further. The annual variability of the size threshold could have a significant effect on the relative abundance of age 0 and 1+ crabs which could influence the stock assessment model. An assessment of the sensitivity of the model to some annual differences in the size threshold is required.

5) Environmental factors can have a significant impact on the efficiency of the gear, and it would be useful to have an assessment of this issue and a summary of the key environmental indices during the surveys so that the potential biases in the indices are identified and whether that bias is likely to be positive or negative. If the relationship between the environmental factors and gear efficiency can be determined, then this relationship can be used to standardize the catch rates so that they better reflect the abundance of the year-classes.

6) A 3-year moving average of the annual indices of abundance can be used to assess the trends in the abundance indices and reduce the possible annual biases in the annual indices of abundance. This assumes that the biases due to the annual catchability variation and the use of constant-size thresholds between years is relatively random and hence will be reduced by averaging over a number of years.

7) The Maryland trawl survey has had an unbalanced design so a generalized linear model (GLM) analysis of the data can be undertaken to obtain an annual standardized index of abundance of the year-classes. This may provide a more robust indicator of year-class abundance.

8) The Virginia Institute of Marine Science (VIMS) survey provides a valuable index of mature females on the spawning grounds. This time series should continue to be monitored closely and be considered as one of the key biological reference points (BRPs) for this fishery.

9) The VIMS spawning stock index should continue to be used to evaluate the stock-recruitment relationship using the megalopae or the winter dredge survey (WDS) 0+ abundance as an index of recruitment. The impact of environmental conditions on recruitment should also be assessed.

10) Spawning sanctuary and protected deepwater dispersal corridor has been used to improve the level of spawning stock. The closures appear to be the best management option to enhance the level of the spawning stock and further research is required into improving the spatial and temporal spawning closures.

11) The WDS in December-March has proved valuable in enabling harvest prediction of the catch April to December with an R^2 of 0.85. The recruitment-catch relationship should be examined at different spatial scales such as the state level. This would enable each state to highlight to commercial and recreational fishers what the catch in the coming season is likely to be.

12) A comparison of fishery-independent surveys has been undertaken for some of the four surveys. It would be useful to examine coherence in all fishery-independent surveys, particularly the WDS. The abundance of the year classes for the WDS could be obtained for Virginia and Maryland separately to assess the relationship between the WDS and the trawl surveys for each state.

13) Recreational fishers using trotlines require a license, and the number of licenses sold each year should be monitored as an indicator of the trend in effort. A

random sample from this group could also be selected to undertake a phone/diary survey of their fishing activities during the year.

14) A cross check on the accuracy of the catch estimates is being examined in Maryland using dealers catch reporting and voluntary daily reporting of catch rates by selected cooperating fishers and observers on board commercial vessels. This work will provide valuable information on catch rates, length frequencies being obtained from the fishery and this monitoring should be continued and extended into Virginia.

15) With the implementation of the compulsory returns, the effort data needs to be examined. This is important in the assessment of nominal effort trend, catch rates and evaluation of issues such as pot saturation and latent effort. The fishery-independent spatial survey of effort of the trap fishery in Maryland should be continued to help interpret and validate the fishers' returns.

16) The latent effort in this fishery needs to be assessed in terms of numbers not fishing, number of part-time fishers, and periods of low fishing activities amongst full-time fishers, as this will affect any attempt to try and reduce fishing effort.

17) The inverse relationship between exploitation fraction and abundance which is suggestive of a depensatory behaviour. The factors operating in the fishery that could induce this behaviour should be examined. This could include a concentration of the stock during periods of lower abundance. The impact of variability on the abundance estimate may bias this relationship and this should be examined. A density-dependent effect on natural mortality could also have an impact on this relationship and should be investigated using sensitivity analysis.

18) A 3-year moving average of the exploitation and the abundance can be used as part of the control rules to assess the trends and avoid the annual fluctuations. The annual indicators of catch and abundance can be affected by the environmental factors that can have a positive or negative effect on catchability. Therefore an average over 3 years will avoid the short-term impact of catchability changes and assist in focusing the control rules of the significant trend in the fisheries.

19) A preliminary economic assessment of the fishery should be undertaken in conjunction with the stock assessment modelling to assess ways to improve the economic performance of the fishery. This should provide an assessment as to whether the number of pots being used can be reduced without much impact on the catch being taken. This may result in considerable cost savings with little or no loss of catch.

Background

The blue crab supports the most important commercial fishery in the Chesapeake Bay. Commercial landings have exceeded 100 million pounds historically (1993) with more recent average landings reaching approximately 72 million pounds. The total impact of the blue crab fishery to the Chesapeake region exceeds $200 million annually.

Sound management of this resource requires accurate information on the status and trends of the blue crab population and on the dynamics of the fisheries that exploit the stock. The NOAA Chesapeake Bay Office (NCBO) supported the development of a full blue crab stock assessment utilizing which was initiated in October 2003 and completed in 2005 (Miller et al. 2005). This follows the stock assessment completed for the blue crab in 1997 (Rugolo et al. 1997).

The terms of reference of the 2005 stock assessment were to: (i) assess and quantify the life history and vital rates of blue crab in the Chesapeake Bay that are relevant to an assessment of the stock, (ii) describe and quantify patterns in fishery-independent surveys of blue crab abundance, (iii) describe and quantify patterns in catch and effort by sector and region, (iv) develop and implement assessment models for the Chesapeake blue crab fisheries, and (v) re-evaluate, and where necessary, update control rules for Chesapeake Bay blue crab fishery.

Due to the political nature of any decision regarding fisheries in Chesapeake Bay, especially blue crab, an independent and expert review of the science was necessary for the management of this important fisheries resource. The Habitat Conservation Office requested that the Center for Independent Experts (CIE) of University of Miami conduct a review for the NOAA Chesapeake Bay Office's Blue Crab Stock Assessment.

Description of Review Activities

The review workshop for the Chesapeake Bay blue crab assessment took place in Annapolis, Maryland on August 9-11, 2005. The NOAA Chesapeake Bay Office provided the following documents prior to the Chesapeake Bay blue crab stock assessment review meeting:

- 2005 Chesapeake Bay blue crab assessment report;
- 1997 blue crab stock assessments;
- A CD was also provided with an extensive database of all the relevant data referred to in the stock assessment report and the assessment model as well as other relevant papers that were quoted in the report.

The objectives of the CIE Blue Crab Assessment Review Panel were to evaluate the Chesapeake Bay blue crab stock assessment, including input data, assessment methods, and model results. The terms of reference for the review were:

1) Evaluate the adequacy and appropriateness of all data used in the assessment, including the following:
    - Life history and vital rates of blue crab in Chesapeake Bay.
    - Patterns in fishery-independent surveys.
    - Patterns in catch and effort by sector and region.
2) Evaluate the adequacy, appropriateness, and application of the assessment models used for the Chesapeake Bay blue crab fisheries and characterize the uncertainty in the assessment.
3) Evaluate the scientific basis for the control rule for the Chesapeake Bay blue crab fishery.
4) Develop recommendations for future research for improving data collection and the Chesapeake Bay blue crab assessment.

The meeting was chaired by the chairman of the CIE team, Associate Professor Malcolm Haddon. Associate Professor Tom Miller, the project leader of the stock assessment team, presented the key aspects of the report on the first day. On the second day the panel asked detailed questions on some aspects of the stock assessment report and presentation. Miller was supported by other members of the team in answering questions and expanding on some aspects of the stock assessment. On the third day the CIE panel met and they reviewed the stock assessment and prepared to write their individual independent reports.

Summary of Findings

The findings of the review have been presented based according to the terms of reference set of the panel:

TOR 1: Evaluate the adequacy and appropriateness of all data used in the assessment, including the following:

- *Life history and vital rates of blue crab in Chesapeake Bay.*
- *Patterns in fishery-independent surveys.*
- *Patterns in catch and effort by sector and region.*

(a) Life history and vital rates of blue crab in Chesapeake Bay.

The life history and vital rates of the blue crab in Chesapeake Bay examined included stock structure, growth, reproduction, larvae, juveniles, adults, lifespan and natural mortality.

Evidence presented supported the case for a functionally separate Chesapeake Bay stock with limited exchange with neighboring stocks.

Growth was examined using two principal approaches: molt-process modeling and continuous growth modeling such as von Bertalanffy model. The study reviewed growth studies undertaken and used information from six empirical studies to develop an average growth model. These growth models had a generally slower growth than the model used by Rugolo et al. (1997). One of the fastest growth models included was undertaken in a pond mesocosm (Ju et al. 2001) which may not be representative of growth in the wild.

Issues associated with lifespan and natural mortality were extensively reviewed in the report and discussed thoroughly at the meeting. Lipofuscin and mark-recapture studies were considered which indicated a range of lifespan of 4 to 6 years. This was significantly lower than the 8 years adopted in the previous stock assessment based on a tag return. In assessing natural mortality a number of direct and indirect methods were examined to determine possible ranges of M. These methods generally suggested a higher value of M than that used in the 1997 stock assessment of 0.375. The range of M selected for stock assessment was 0.6 to 1.2 with 0.9 selected as the most likely level. These were consistent with the studies reviewed and provided a satisfactory justification for the increase in M compared with the previous assessment.

The issue of using one constant M for the whole stock over all sizes, ages, sex and years was discussed at the meeting. The significant contribution of cannibalism to natural mortality suggested than M should be inversely related age/size due to reduced mortality with increasing size from cannibalism and predation and reduction in frequency of moulting. Similarly, cannibalism could contribute to an annual variation in M if there was a significant difference in annual abundance of the year-classes. While there are no concrete estimates of variation in M for different sizes and density dependence, it would be useful to undertake some sensitivity analysis in the stock assessment modeling to assess the likely impact. For example, assuming an average M of 0.9, then one could consider using an estimate of M=1, 0.9, 0.8 for ages 1, 2, 3+ respectively in the stock assessment model.

(b) Patterns in fishery-independent surveys.

Information from four fishery-independent surveys, VIMS trawl survey, Calvert Cliffs pot survey, Maryland trawl survey, and winter dredge survey (WDS), was one of the strengths of the stock assessment and a key component of the stock assessment model. These surveys were different in spatial and temporal scale and fishing technique. These surveys have provided abundance indices for age 0 and 1+ based on spatial, temporal and size thresholds for three of the surveys. The size-threshold for the WDS was not shown.

An examination was undertaken of the correlation between abundance of age-0 crabs in year i and age 1+ crabs both within the same year, and in year i+1. A strong correlation between years was used as an indicator of effectively tracking cohorts. A correlation of age-0 and age 1+ in the same year may be an indicator that the threshold may be incorrect or indicate that environmental conditions during the survey may be biasing the catch rates of both year-classes.

The stock assessment report acknowledges the influence of annual variations in growth, recruitment timing and distribution that need to be evaluated further. The annual variability of the size threshold could have a significant effect on the relative abundance of age 0 and 1+ crabs which could influence the stock assessment model. An assessment of the sensitivity of the model to some annual differences in the size threshold is required.

Environmental factors can have a significant impact on the efficiency of the gear and it would be useful to have a discussion of this issue. The key environmental indices during the surveys should be summarized so that the potential biases in the indices are identified and whether that bias is likely to be positive or negative. If the relationship between the environmental factors and gear efficiency can be determined, then this relationship can be used to standardize the catch rates so that they better reflect the abundance of the year-classes.

A 3-year moving average of the annual indices of abundance can be used to assess the trends in the abundance indices and reduce the possible annual biases in the annual indices of abundance. This assumes that the biases in the annual catchability effects and the use of constant-size thresholds between years is relatively random and hence can be reduced by averaging over a number of years.

The VIMS survey is valuable as it is the longest time series (since 1955) and is focused near the mouth of the bay where the larvae are hatched and exit the bay in the summer and where the megalopae enter the bay. There have been some gear changes in the 1973 and 1979 and calibration methods have been used to adjust for these changes. The report indicates that the spring survey abundances are higher than those in the fall but then appears to use the survey indices in the fall for age-0 and 1+ abundances in the stock assessment.

The VIMS survey provides a valuable index of mature females on the spawning grounds from 1988 to 2004 that shows a significant decline (Lipcius and Stockhausen, 2002). This time series should continue to be monitored closely and be considered as one of the key BRPs for this fishery.

The time series of megalopae from Chesapeake Bay Program's monthly zooplankton monitoring program since 1985 was not directly used in the stock assessment but may provide an indicator of recruitment. Lipcius and Stockhausen (2002) indicated that the poor recruitment in 1991 resulted in the initial decline in spawning stock in 1992 and that subsequent poor recruitment may have been driven by the low spawning stock. Based on this assessment, a BRP of the spawning stock of about 3 crabs per tow should be considered as a limit reference point. Further work on the stock recruitment relationship should be undertaken. For example, the spawning stock from the VIMS survey could be related to the recruitment from the WDS that seems to provide a robust indicator of recruitment that reflects the variation in catch. In addition, it is important to assess the impact of environmental conditions on the recruitment as Lipcius and Stockhausen (2002) indicated that the decline in the 1991 recruitment was due to environmental conditions as the spawning stock was in good condition at the time. The impact of environmental conditions in the below-average recruitment of the last decade also needs to be assessed.

The Maryland trawl survey has been undertaken since 1977, however the coverage is not consistent temporally and spatially from year to year. To take into account the unbalanced design of the survey, a GLM analysis of the data can be undertaken to obtain an annual index of abundance of the year-classes. This may provide a more robust indicator of year-class abundance.

The WDS has been operating since 1989 and is an extensive survey of the whole Bay. This survey has also been used to estimate absolute abundances using catchability estimates obtained from depletion analysis (Volstad et al. 2000). This survey has also been used to assess the spatial variability in abundance and how this has changed over the years. It identified that the central mainstem of the Bay has experienced a strong decline for the last decade. This is an indication of the reduction in the spawning stock.

The WDS in December-March has proved valuable in enabling harvest prediction of the catch April to December with an R^2 of 0.85. This indicates that the survey is providing a reliable indicator of abundance. The strength of this relationship also indicates that if there has been any variation in effort over the last decade then this has not had a significant impact on catch. If trends in nominal effort can be obtained for this period it will provide some insights on the impact of effort on the catch taken. For example, if there has been a significant increase in effort with little impact on catch then it may be an indicator of gear saturation. It would also be useful to investigate the recruitment-catch relationship at different spatial scales such as the state level. This would enable each state to highlight to commercial and recreational fishers what the catch in the coming season is likely to be. These relationships may also provide some insight into spatial trends and migration.

A comparison of fishery-independent surveys has been undertaken using time series analysis for a number of time series which had a long time series (>30 years) and extensive periods in common. It would be useful to examine coherence in all fishery-independent surveys, particularly the WDS, before they are combined with equal weight. The abundance of the year classes for the WDS could be obtained for Virginia and Maryland separately to assess the relationship between the WDS and the trawl surveys for each state.

The surveys are stardardized (normalized) to Z-score and averaged across all the available surveys for the particular year to obtain an overall index of abundance. A GLM analysis of all the surveys can be undertaken to examine the coherence of the surveys and obtain an overall index of abundance

(c) Patterns in catch and effort by sector and region.

There have been significant improvements in the assessment of commercial catches through the introduction of compulsory reporting in the early 1990s and an extensive assessment of the impact of changes in the reporting systems (Fogarty and Miller 2004). However, there continues to be a need for caution in interpreting the catch data and examining ways to verify the catch time series. The complexity in the fishery includes full-time, part-time and non-fishing license holders, a number of different fishing methods, variation in minimum size for different types of crabs, different reporting systems for the states.

A cross check on the accuracy of the catch estimates is being examined in Maryland using dealers catch reporting and voluntary daily reporting of catch rates by selected cooperating fishers and observers on board commercial vessels. This work should continue to be encouraged and extended into Virginia.

Effort information has not been used in this current assessment as the research team did not believe the effort time series was sufficiently reliable. With the implementation of the compulsory returns this data needs to be examined again in the future. This is important in the assessment of nominal effort, catch rates and evaluation of issues such as pot saturation and latent effort. Some research has commenced into a fishery-independent spatial survey of effort of the trap fishery in Maryland. This needs to be continued to help interpret and validate the fishers' returns.

With the different fishing methods in use, a standardized index of nominal effort needs to be determined. This can be obtained using the catch rates from trap fishing and the total catch from all methods. There should also be a standardization of the way the data is collected across the states to enable a bay wide assessment. An understanding of any changes in fishing practices that may affect their fishing power should also be documented as it may be valuable in future assessments.

There is considerable latent effort in this fishery which needs to be assessed in terms of numbers not fishing at all, numbers of part-time fishers, and periods of low fishing activities amongst full-time fishers, as this will affect any attempt to try and reduce effective fishing effort and fishing mortality.

Recreational catch was not included in the stock assessment as it was not available annually. It was estimated for 2001 and 2002 as being about 5-9% of the total harvest. A sensitivity analysis was undertaken to assess the impact of this additional harvest. As recreational fishers using trotlines require a license it would be useful to monitor the licenses sold each year as an indicator of the trend in recreational effort. The catch and effort trend of this group may make a significant proportion of the total recreation catch. A random sample from this group could also be selected to undertake a phone/diary survey of their fishing activities during the year. The proportion of total recreational catch this group takes should be available from the surveys of the whole recreational fishery.

TOR 2: Evaluate the adequacy, appropriateness, and application of the assessment models used for the Chesapeake Bay blue crab fisheries and characterize the uncertainty in the assessment.

The stock assessment modeling involves an extension of the Collie and Sissenwine (1983) model to include the multiple surveys. This model was called the Catch-Multiple-Survey (CMS). The model is appropriate given the information available and provides some interesting insights into the stock assessment. This model has addressed some significant issues such as revision of natural mortality estimates, growth model and harvest estimates.

A key parameter of this model is the natural mortality. A thorough review of the value of M was undertaken as there was considerable controversy over the value of M used in the 1997 assessment. The reviews examined to determine the value of M all assumed value to be constant for over all ages. As cannibalism is a major cause of natural mortality, then M could be inversely related to age/size. The impact of possible variation in M according to age should be investigated using sensitivity analysis in the stock assessment modeling.

The research team highlights an inverse relationship between exploitation fraction (Catch/Abundance) and abundance which is suggestive that the crab fisheries behave in a depensatory manner. If this is the case then the factors operating in the fishery that could induce such a behaviour should be discussed. This could include a concentration of the stock during periods of lower abundance. The impact of variability on the abundance estimate may bias this relationship and this should be examined. A density-dependent effect on natural mortality could also have an impact on this relationship and should be investigated using sensitivity analysis.

TOR 3: Evaluate the scientific basis for the control rule for the Chesapeake Bay blue crab fishery.

The control rules examined focused on the level of exploitation to assess the level of overfishing and a stock abundance indicator to assess whether the stock was overfished. A significant change in the control rule has been the use of the exploitation fraction rather than F in the control rule. This avoids the need to estimate M to assess the exploitation. The abundance from the WDS is used as the stock abundance as this has been shown to be reliable indicator of harvest.

To focus on the trends in the exploitation and the abundance and avoid the annual fluctuations, a 3-year moving average of the indicators can be used as part of the control rules. The annual indicators of catch and abundance can be affected by the environmental factors that can have a positive or negative effect on catchability. Therefore, an average over 3 years will avoid the short-term impact of catchability changes and assist in focusing the control rules on the significant trend in the fisheries.

The stock assessment highlights a concern about the status of the breeding stock. The use of the stock abundance from the WDS is a reliable indicator of the overall stock status throughout the fishery; however, it does not necessarily provide an indicator of spawning stock. The stock assessment report provides an assessment of the spawning stock based on the VIMS survey of mature females on the spawning grounds since 1988 (Lipcius and Stockhausen, 2002). This indicator shows a significant decline that has been particularly low over 2000 to 2004. This time series should continue to be monitored closely and be considered as one of the key BRPs for this fishery.

TOR 4: Develop recommendations for future research for improving data collection and the Chesapeake Bay blue crab assessment.

A program started in Maryland in 2002 on voluntary daily reporting of catch and length frequency information by cooperating fishers and observers on board commercial vessels. The fishers participating in the program have been provided training to collect the required research information. This has proved valuable for verifying fishers catch rates, and obtaining annual length frequencies. This work should continue to be encouraged and extended into Virginia.

Future research on fishing effort should provide an understanding of number of days fished, number of pots being used, and number of pots being pulled daily, and daily catch rate. This should provide an assessment as to whether there is excessive effort in the fishery and possible gear saturation. A preliminary economic assessment of the fishery should be undertaken in conjunction with the stock assessment modelling to assess ways to improve the economic performance of the fishery. This should provide an assessment as to whether the number of pots being used can be reduced without much impact on the catch being taken. This may result in considerable cost savings with little or no loss of catch.

The low level of spawning stock and recruitment in the last 10 years suggests that research should continue on the stock-recruitment-environment relationship. Management options to improve the level of the spawning stock should be investigated. Given the high level of fishing effort as well as considerable level of latent effort in the fishery, it is unlikely that a sufficient reduction in fishing effort will be achieved in the short-term to generate a significant improvement in the spawning stock. Spawning sanctuary and protected deepwater dispersal corridor has been used to improve the level of spawning stock (Lipcius et al. 2003). The closures appear to be the best management option to enhance the level of the spawning stock and further research is required into improving the spatial and temporal spawning closures.

Conclusions

The information on the stock assessment provided to the reviewers before the meeting and the detailed presentation and subsequent discussion at the meeting in Annapolis provided reviewers with the basis to undertake the review.

The 2005 stock assessment highlights a number of research areas where significant progress had been made on the 1997 stock assessment. A large number of research reports had been published that focused on issues relevant to the stock assessment or on related issues with the blue crab biology. These included:

(a) natural mortality studies (Hewitt and Hoenig 2005, Lambert et al. 2005);

(b) studies on growth dynamics (eg Bunnell and Miller in press, Miller and Smith 2003, Smith and Chang in press);

(c) a time series analysis of catch that adjusted for changes in reporting methods (Fogarty and Miller 2004);

(d) use of depletion experiments during the winter dredge survey (WDS) to estimate catchability which can be used to estimate absolute abundances (Volstad et al. 2000, Sharov et al. 2003);

(e) assessment of WDS to quantify abundance and distribution (Jensen et al. in press a and b, Jensen and Miller in press);

(f) reproduction issues such as sperm limitation (Hines et al. 2003);

(g) the Virginia Institute of Marine Science (VIMS) survey provides a valuable index of mature females on the spawning grounds that has been combined with a survey of the megalopae to assess the stock-recruitment relationship (Lipcius and Stockhausen, 2002);

(h) an assessment of spawning sanctuary and protected deepwater dispersal corridor used to improve the level of spawning stock (Lipcius et al. 2003);

(i) a new stock assessment model that used data from a number of fishery-independent surveys to assess changes in abundance and exploitation;

(j) individual-based approach to spawning potential per recruit (Bunnel and Miller in press); and

(k) revised control rule based on exploitation fraction rather than the fishing mortality F that is dependent on the estimate of the natural mortality M being used.

The stock assessment modeling, which involves an extension of the Collie and Sissenwine (1983) model to include the multiple fishery-independent surveys, was appropriate given the information available, and it provides some interesting insights into the stock assessment. This model has addressed some significant issues such as revision of natural mortality estimates, growth model and harvest estimates. A significant change in the control rule has been the use of the exploitation fraction rather than F in the control rule. This avoids the need to estimate M to assess the exploitation.

The fishery-independent surveys continue to be valuable indicators of the relevant abundance of the blue crab year-classes which provides an indication of the annual recruitment index as well as abundance of mature and spawning females. The WDS appears to be particularly useful and the recruitment index has been shown to be reliable indicator of harvest. These surveys indicate that the spawning stock and recruitment have generally been below average in recent years which highlights concerns about recruitment overfishing that need further investigation through the stock-recruitment relationship. Efforts to protect the breeding stock have been undertaken in recent years through the marine protected area and corridor in the lower Chesapeake Bay and the impact of these closures on the spawning stock needs to be monitored.

Recommendations

Some areas for future research to improve the stock assessment and contribute to the improved management of the blue crab fishery are:

1) One of the fastest growth models used to obtain the average growth model used in the stock assessment model was undertaken in a pond mesocosm (Ju et al. 2001) which may not be representative of growth in the wild.

2) The significant contribution of cannibalism to natural mortality suggests than M could be inversely related age/size due to reduced mortality with increasing size from cannibalism and predation and reduction in frequency of moulting. The impact of this assumption should be investigated in the stock assessment model using sensitivity analysis.

3) Cannibalism could contribute to a density-dependent effect on M if there was a significant difference in annual abundance of the year-classes. This could also be examined in the model using a sensitivity analysis.

4) The stock assessment report acknowledges the influence of annual variations in growth, recruitment timing and distribution that need to be evaluated further. The annual variability of the size threshold could have a significant effect on the relative abundance of age 0 and 1+ crabs which could influence the stock assessment model. An assessment of the sensitivity of the model to some annual differences in the size threshold is required.

5) Environmental factors can have a significant impact on the efficiency of the gear and it would be useful to have a discussion of this issue and a summary of the key environmental indices during the surveys so that the potential biases in the indices are identified and whether that bias is likely to be positive or negative. If the relationship between the environmental factors and gear efficiency can be determined then this relationship can be used to standardize the catch rates so that they better reflect the abundance of the year-classes.

6) A 3-year moving average of the annual indices of abundance can be used to assess the trends in the abundance indices and reduce the possible annual biases in the annual indices of abundance. This assumes that the biases in the annual

catchability effects and the use of constant-size thresholds between years is relatively random and hence will be reduced by averaging over a number of years.

7) The Maryland trawl survey has had an unbalanced design so a GLM analysis of the data can be undertaken to obtain an annual index of abundance of the year-classes. This may provide a more robust indicator of year-class abundance.

8) The VIMS survey provides a valuable index of mature females on the spawning grounds. This time series should continue to be monitored closely and be considered as one of the key BRPs for this fishery.

9) The VIMS spawning stock index should be used to evaluate the stock-recruitment relationship using the megalopae or the WDS 0+ abundance as an index of recruitment. The impact of environmental conditions on recruitment should also be assessed.

10) Spawning sanctuary and protected deepwater dispersal corridor has been used to improve the level of spawning stock. The closures appear to be the best management option to enhance the level of the spawning stock and further research is required into improving the spatial and temporal spawning closures.

11) The WDS in December-March has proved valuable in enabling harvest prediction of the catch April to December with an R^2 of 0.85. The recruitment-catch relationship should be examined at different spatial scales such as the state level. This would enable each state to highlight to commercial and recreational fishers what the catch in the coming season is likely to be.

12) A comparison of fishery-independent surveys has been undertaken for some of the surveys. It would be useful to examine coherence in all fishery-independent surveys, particularly the WDS. The abundance of the year classes for the WDS could be obtained for Virginia and Maryland separately to assess the relationship between the WDS and the trawl surveys for each state.

13) Recreational fishers using trotlines require a license and the number of licenses sold each year should be monitored as an indicator of the trend in effort. A random sample from this group could also be selected to undertake a phone/diary survey of their fishing activities during the year.

14) A cross check on the accuracy of the catch estimates is being examined in Maryland using dealers catch reporting and voluntary daily reporting of catch rates by selected cooperating fishers and observers on board commercial vessels. This work should be continued and extended into Virginia.

15) With the implementation of the compulsory returns, the effort data needs to be examined. This is important in the assessment of nominal effort trend, catch rates and evaluation of issues such as pot saturation and latent effort. The fishery-independent spatial survey of effort of the trap fishery in Maryland should be continued to help interpret and validate the fishers' returns.

16) The latent effort in this fishery needs to be assessed in terms of numbers not fishing, number of part-time fishers, and periods of low fishing activities amongst full-time fishers, as this will affect any attempt to try and reduce fishing effort.

17) The possible inverse relationship of M and age should be investigated using sensitivity analysis in the stock assessment modeling.

18) The inverse relationship between exploitation fraction and abundance which is suggestive of a depensatory behaviour. The factors operating in the fishery that could induce such a behaviour should be examined. This could include a concentration of the stock during periods of lower abundance. The impact of variability on the abundance estimate may bias this relationship and this should be examined. A density-dependent effect on natural mortality could also have an impact on this relationship and should be investigated using sensitivity analysis.

19) A 3-year moving average of the exploitation and the abundance can be used as part of the control rules to assess the trends and avoid the annual fluctuations. The annual indicators of catch and abundance can be affected by the environmental factors that can have a positive or negative effect on catchability. Therefore an average over 3 years will avoid the short-term impact of catchability changes and assist in focusing the control rules of the significant trend in the fisheries.

20) The program in Maryland on voluntary daily reporting of catch and length frequency information by cooperating fishers and observers on board commercial vessels should be continued and extended into Virginia.

21) A preliminary economic assessment of the fishery should be undertaken in conjunction with the stock assessment modelling to assess ways to improve the economic performance of the fishery. This should provide an assessment as to whether the number of pots being used can be reduced without much impact on the catch being taken. This may result in considerable cost savings with little or no loss of catch.

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Appendix 1. BACKGROUND MATERIAL

Doc1: Miller, T.J., Martell, S.J.D., Bunnell, D.B., Davis, G., Fegley, L., Sharov, A., Bonzek, C., Hewitt, D., Hoenig, J. & Lipcius, R., 2005. *Stock Assessment of Blue Crab in Chesapeake Bay 2005.* Final Report (in draft). Technical Report Series No. TS-487-05, University of Maryland Center for Environmental Science. 163 pp.

Doc2: Rugolo, L., Knotts, K., Lange, A., Crecco, V., Terceiro, M., Bonzek, C., Stagg, C., O'Reilly, R. & Vaughan, D., 1997. *Stock Assessment of Chesapeake Bay Blue Crab (Callinectes sapidus).* National Oceanic and Atmospheric Administration. 267 pp.

Doc3: Bunnell, D.B. & Miller, T.J., in press. An individual-based modelling approach to per-recruit models: blue crabs *Callinectes sapidus* in the Chesapeake Bay. *Canadian Journal of Fisheries and Aquatic Science*.

Doc4: Hewitt, D.A. & Hoenig, J.M., in press. Comparison of two approaches for estimating natural mortality based on longevity. *Fishery Bulletin*.

Doc5: Jensen, O.P., Seppelt, R., Miller, T.J. & Bauer, L.J., in press. Winter distribution of blue crab (*Callinectes sapidus*) in Chesapeake Bay: application of a two-stage generalized additive model (GAM). *Marine Ecology Progress Series*.

Doc6: Jensen, O.P. & Miller, T.J., in press. Geostatistical analysis of blue crab (*Callinectes sapidus*) abundance and winter distribution patterns in Chesapeake Bay. *Transactions of the American Fisheries Society*.

Doc7: Jensen, O.P., Christman, M.C. & Miller, T.J., in press. Landscape-based geostatistics: a case study of the distribution of blue crab in Chesapeake Bay. *Environmetrics*.

Doc8: Fogarty, M.J. & Miller, T.J., 2004. Impact of a change in reporting systems in the Maryland blue crab fishery. *Fishery Research*, **68**, 37-43.

In support of Doc1 a data CD was provided, containing the assessment report (Doc1) and other documents (Docs3-7) in electronic form, spreadsheets containing most of the data and calculations contained in the report, output from statistical analyses, and AD Model Builder code and output for the assessment model.

Appendix 2 STATEMENT OF WORK

Consulting Agreement between the University of Miami and Dr. Nick Caputi

July 21, 2005

Background

The blue crab supports the most important commercial fishery in the Chesapeake Bay. Commercial landings have exceeded 100 million pounds historically (1993) with more recent average landings reaching approximately 72 million pounds. The total impact of the blue crab fishery to the Chesapeake region exceeds $200 million annually.

Sound management of this resource requires accurate information on the status and trends of the blue crab population and on the dynamics of the fisheries that exploit the stock. There have been two recent stock assessments completed for the blue crab (1997, 1998) and the NOAA Chesapeake Bay Office (NCBO) has produced annual 'Advisory Reports' for blue crab to assist resource managers in the decision making process. Seeing the need for an updated assessment, the NCBO supported the development of a full blue crab stock assessment utilizing FY2003 funds.

This assessment was initiated in October 2003. Due to the political nature of any decision regarding fisheries in Chesapeake Bay, especially blue crab, an independent and expert review of the science is necessary for management of this important fisheries resource. The Habitat Conservation Office is requesting that the Center for Independent Experts (CIE) conduct a review for the NOAA Chesapeake Bay Office's Blue Crab Stock Assessment.

The review workshop for the Chesapeake Bay blue crab assessment will take place in Annapolis, Maryland on August 9-11, 2005. The NOAA Chesapeake Bay Office will provide the following documents prior to the Chesapeake Bay blue crab stock assessment review meeting:

- 2005 Chesapeake Bay blue crab assessment report;
- 1997 and 1998 blue crab stock assessments;
- Annual blue crab advisory reports;
- Adopted management strategies establishing targets and thresholds;
- Chesapeake Bay Fishery Management Plan (1997); and
- Other key publications as necessary.

Objectives of the CIE Review

The Blue Crab Assessment Review Panel will evaluate the Chesapeake Bay blue crab stock assessment, including input data, assessment methods, and model results. The following are the main terms of reference for the review:

1) Evaluate the adequacy and appropriateness of all data used in the assessment, including the following:
   - Life history and vital rates of blue crab in Chesapeake Bay.
   - Patterns in fishery-independent surveys.
   - Patterns in catch and effort by sector and region.
2) Evaluate the adequacy, appropriateness, and application of the assessment models used for the Chesapeake Bay blue crab fisheries and characterize the uncertainty in the assessment.
3) Evaluate the scientific basis for the control rule for the Chesapeake Bay blue crab fishery.
4) Develop recommendations for future research for improving data collection and the Chesapeake Bay blue crab assessment.

The Assessment Review Panel's primary duty is to review the assessment presented. In the course of this review, the Chair may request a reasonable number of sensitivity runs, additional details of the existing assessments, or similar items from technical staff. However, the Review Panel is not authorized to conduct an alternative assessment or to request an alternative assessment from the technical staff present. The Review Panel should outline in its report any remedial measures that the Panel proposes to rectify shortcomings in the assessment.

Specific Activities and Responsibilities

The CIE shall provide a Chair and three Review Panelists to conduct the review of the Chesapeake Bay blue crab stock assessment.

Tasks

Each panelist's duties shall occupy a maximum of 14 workdays (i.e., a few days prior to the meeting for document review; the review meeting; and a few days following the meeting to prepare a Review Report). The Panelist Review Reports will be provided to the Review Panel Chair, who will produce the Summary Report based on the individual Review Reports.

Roles and responsibilities:

(1) Prior to the meeting: review the Chesapeake Bay blue crab assessment report and other relevant documentation in support of this review.

(2) During the meeting: participate, as a peer, in panel discussions on assessment validity, results, recommendations, and conclusions especially with respect to the adequacy of the assessment in serving as a basis for providing scientific advice to management.

(3) After the meeting: prepare individual Review Reports, each of which provides an executive summary, a review of activities and a summary of findings and

recommendations, all in the context of responsiveness to the terms of reference. Advice on additional questions that are directly related to the assessment and are raised during the meeting should be included in the report text. See Annex 1 for further details on report contents and milestone table below for details on schedule. No later than August 25, 2005, these reports shall be submitted to the CIE for review[1] and to the Chair for summarization. The CIE reports shall be addressed to "University of Miami Independent System for Peer Review," and sent to Dr. David Sampson, via e-mail to David.Sampson@oregonstate.edu and to Mr. Manoj Shivlani via e-mail to mshivlani@rsmas.miami.edu.

Milestones or Report Delivery Dates

The following table provides the milestones and delivery dates for conducting the panel review of the Chesapeake Bay blue crab stock assessment.

Milestone	**Date**
Panel review meeting in Annapolis, MD	August 9-11, 2005
Individual panelists provide their draft reports to CIE for review and to Chair for initiating development of the Summary Report	August 25, 2005
CIE provides reviewed individual panelist reports to NMFS COTR for approval	September 1, 2005
COTR notifies CIE of approval of individual panelist reports	September 8, 2005
CIE provides final individual panelist reports to COTR (with signed cover letter) and to Chair to complete Summary Report	September 13, 2005
Chair provides CIE with draft Summary Report for review	September 20, 2005
CIE provides reviewed Summary Report to COTR for approval	September 27, 2005
COTR notifies CIE of approval of Summary Report	September 30, 2005
CIE provides final Summary Report with signed cover letter to COTR	October 5, 2005
COTR provides final Summary Report to NEFSC contact	October 7, 2005

No consensus opinion among the CIE reviewers is sought, and all reports will be the product of the individual CIE reviewer or chairperson.

NOAA Contact person:
Derek Orner, NOAA Chesapeake Bay Office, 410 Severn Avenue, Annapolis, MD 21403; Derek.orner@noaa.gov

[1] All reports will undergo an internal CIE review before they are considered final.

ANNEX 1: Contents of Panelist Report

1. The report shall be prefaced with an executive summary of findings and/or recommendations.

2. The main body of the report shall consist of a background, description of review activities, summary of findings, conclusions/recommendations, and references.

3. The report shall also include as separate appendices the bibliography of all materials provided during the review meeting and any papers cited in the Panelist's Report, along with a copy of the statement of work.