

Review of the Chesapeake Bay Blue Crab (*Callinectes sapidus*) 2005 Stock Assessment.

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Executive Summary

The most important commercial fishery within the Chesapeake Bay targets the blue crab (*Callinectes sapidus*). Commercial landings of blue crab have exceeded 100 million pounds historically (1993) with more recent average landings reaching approximately 72 million pounds. The economic value of the blue crab fishery to the Chesapeake region exceeds \$200 million annually.

This fishery has now been assessed two times; the first time was by Rugolo *et al.* (1997) while the most recent (Miller *et al.*, 2005) has only just been produced. Because of the importance of the blue crab fishery to the region the NOAA Chesapeake Bay requested a formal review of the latest assessment document and the work behind it. To that end the Centre for Independent Experts, organized out of the University of Miami, arranged for four reviewers to attend a review workshop held in Annapolis over the period 9th-11th August, 2005. The NOAA office provided a large amount of written material and data on a CD before the review meeting. The review aimed to examine the validity and appropriateness of the data used in the assessment, the model and its structure, the management decision rules (control rules) that flowed from the assessment, and also requested suggestions for further research that would benefit future assessments. The review was conducted in an open and friendly atmosphere which was maintained throughout even the most intense discussion.

The 2005 assessment was found to involve significant improvements over the previous 1997 assessment document in all areas that were reviewed. Biological properties critical to an appropriate and valid assessment include the estimates of natural mortality, growth, and recruitment. Significant changes and improvements in all three areas have been made and in many cases published. Thus, natural mortality was addressed by Hewitt & Hoenig (2005), estimates and studies on individual growth have been produced by Bunnell & Miller (in press), Miller and Smith (2003), and Ju *et al.* (2001). Reproduction and recruitment issues have been considered by Hines *et al.* (2003) as well as by the continued surveys conducted by the Virginia Institute of Marine Science (Lipcius & Stockhausen, 2002; Lipcius *et al.*, 2003). In addition to improvements stemming from biological studies the reporting of current catch has been improved with new regulations, the instigation of an observer program, and recreational surveys. These have been complemented by the standardization of the previous catch history through a detailed statistical study that attempted to account for changes in reporting methods that have occurred through time (Fogarty & Miller, 2004). The single most valuable improvement has been the maturation and development of the winter dredge survey which, because of its geographical coverage and precision will provide the critical information necessary for management into the future. The methods used are now standard with the use of depletion experiments across strata and substrates to estimate catchability and improve this survey as an estimate of absolute abundance (Volstad *et al.*, 2000; Sharov *et al.*, 2003). The stock assessment model has been extended to use a number of separate survey abundance indices as data as well as estimates of exploitation rate deriving from the winter dredge survey. This latter innovation extended to the use of the exploitation rate (fraction of available biomass taken in the fishery) in some revised control rules to aid in the management of the fishery. The management of the fishery has also been enhanced through the implementation of closed areas in Virginia aimed at securing a larger proportion of the spawning females (Lipcius *et al.* 2003).

The model was an improvement over the previous model through its use of more data but was found to be relatively unstable and it was suggested that this may stem from the still limited amounts of data available compared with the relatively large number of model parameters being estimated. It was suggested that the same model be examined but using only observation errors and not the process errors. This would lead to a more stable model and maybe to somewhat different management implications.

The control rules developed for this fishery appear well structured and well defined. Unfortunately they are not supported by a well developed set of management outcomes should the control rules be triggered. It is recommended that clear and explicit objectives be determined for this fishery (this is a job for the managers not the scientists) so that suitable and acceptable management responses can be developed to respond to situations where the stock is found to be in an undesirable state. Some way of limiting the apparently run-away effort currently being expressed is urgently required.

Recommendations

- 1) It is recommended that the possibility of a size-related difference in natural mortality be examined. At very least the sensitivity trials with the assessment model using plausible schedules of such non-constant natural mortality be continued and expanded. This could have marked effects upon the outputs from the modelling.
- 2) It is recommended that the possibility of some density dependent relationship between natural mortality and population density be explored. This seems intuitively likely if cannibalism is a major source of mortality in the younger crabs.
- 3) It is recommended that the environmental drivers behind the growth transition from undersized crabs to legal sized crabs be examined in more detail. Within year dynamics are largely ignored in the assessment but this growth would have important implications for availability through the year.
- 4) It is recommended that the possibility of density dependent changes in growth with population density be examined. Such changes would significantly alter the stock productivity.
- 5) It is recommended that the spatial information from the winter dredge survey be used in conjunction with time series of environmental conditions to examine any relationship between recruitment (as 0+ abundance) and environmental drivers such as temperature and salinity. The spatial detail in the other surveys should also be investigated as, combined, they may provide an avenue to through light on whether the environment or urban development is related in any way to trends in recruitment abundance for each sex separately.
- 6) It is strongly recommended that the winter dredge survey continued to be conducted in its present form. It will provide the necessary estimates of abundance required into the future.
- 7) It is recommended that the depletion experiments used in the winter dredge survey to estimate catchability in different strata be improved by using differential GPS and associated plotters to mark the depletion tracks. This along with standard data collection of sea conditions and gear should enable the use of Generalized Linear Modelling to improve the analysis of the experiments.

- 8) It is recommended that Generalized Linear Models be explored for use to improve the analysis of the Maryland and Virginia trawl surveys. By standardizing these indices of relative abundance, confounding factors will be removed from consideration and a cleaner signal should be presented. This may provide better indices of relative abundance for both the 0+ and 1+ cohorts.
- 9) It is recommended that a formal statistical study be conducted to characterize the relative contribution to the assessment of each of the time series of survey estimates. Of particular importance is the peak of abundance observed in the Virginia trawl survey in 1970 and 1971, which influences the apparent productivity of the complete stock.
- 10) It is recommended that a formal study be made of correlations between the different survey time series to highlight any consistencies between the surveys and any inconsistencies. Their use and value in the assessment modelling could be enhanced through knowing about their inter-relationships. In addition, the relative weights applied when fitting each time series may be able to be modified. Because of its greater accuracy and generality more weight should be given to the winter dredge survey results.
- 11) It is recommended that the commercial catch and effort data collected be standardized, if possible, between Virginia and Maryland, making it easier to share the data. A central repository of the combined data should be easily available to enhance the opportunities for assessment. Efforts should be made to obtain more accurate information concerning the peeler fishery.
- 12) It is recommended that a review of regulations across the two States be undertaken with an aim of increasing commonality between the two States, which in turn may improve the ability to collect consistent data.
- 13) It is recommended that experiments and observations be designed to investigate the potential mortality arising from discarding undersized crabs from commercial pots.
- 14) It is recommended that experiments and observations be designed to investigate the potential mortality arising through the agency of ghost fishing by self baiting lost crab pots. If this is found to be significant then options for ameliorating the problem should be developed.
- 15) It is recommended that a study be made of the incidental mortality induced by the different fishing methods used for blue crabs. Once a reliable estimate of the amount of effort by gear type is available this will provide another estimate of fishery related mortality.
- 16) It is recommended that recreational fishing continue to be monitored and the use of licenses be encouraged.
- 17) It is recommended that the various sources of catch information be combined to produce one master time series. The combination should be conducted with care and attention to biases and distortions.
- 18) It is recommended that the assessment model be simplified by excluding the use of process errors, which will significantly reduce the number of estimable parameters and should stabilize the model and permit the inclusion of the exploitation fraction in the objective function used to fit the model.

- 19) The model documentation in the assessment document should be expanded to include the details of all equations along with a comparison/justification of the errors structures used demonstrating the advantages or otherwise of including process errors in the modelling.
- 20) It is recommended that clear and explicit objectives be determined for this fishery (this is a job for the managers not the scientists) so that suitable and acceptable management responses can be developed to respond to situations where the stock is found to be in an undesirable state.

Background

Statement and History of the Problem

In the Chesapeake Bay the most important commercial fishery targets the blue crab (*Callinectes sapidus*). Commercial landings of blue crab have exceeded 100 million pounds historically (1993) with more recent average landings reaching approximately 72 million pounds. The economic value 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 (Rugolo *et al.*, 1997; and the document under review, Miller *et al.*, 2005) and the NOAA Chesapeake Bay Office (NCBO) has produced annual 'Advisory Reports' for blue crab to assist resource managers in the decision making process.

The 2005 assessment here under review was initiated in October 2003. The review was requested by the Habitat Conservation Office because of the political nature of any decision regarding fisheries in Chesapeake Bay, especially the blue crab fishery. The Center for Independent Experts (CIE) organized by the University of Miami was

therefore asked to conduct a review for the NOAA Chesapeake Bay Office's Blue Crab Stock Assessment.

Review Activities

The review workshop was conducted at the Radisson Hotel in Annapolis, Maryland over the three days: Tuesday 9th August to Thursday 11th August 2005. Derek Orner of the NOAA Chesapeake Bay Office provided a hard copy of the 1997 and 2005 assessments plus a CD containing an electronic copy of the 2005 assessment plus a multitude of associated documents and data files, including the model and its code.

Those present for one or both of the two days of presentations were:

The review panel, made up of Malcolm Haddon from the University of Tasmania, Paul Medley, a private fisheries consultant, Nick Caputi from Western Australia Fisheries, and Mike Bell, now a private fisheries consultant. Useful and clear presentations relating to the data and new assessment were made by Dr Thomas Miller, of the Chesapeake Biological Laboratory, with additional discussion and contributions from Lynn Fegley and Glenn Davis of the Maryland Fisheries Administration.

The review process consisted of an introductory day consisting of a presentation of the completed 2005 assessment, with general questions. This was followed by a more intense day involving continuous questions and answers concerning details of the assessment document and related work conducted as four sessions during the day with short breaks in the morning, at lunch-time, and in the afternoon. The final day was devoted to the review panel discussing the review, the presentations, and documents. While there were no further presentations there were some additional, relatively informal discussions with Derek Orner of the NOAA. The timetable of presentations and discussions was:

Tuesday 9th August 2005

Welcome and Introductions	Derek Orner
Presentation of 2005 blue crab assessment	Thomas Miller

Wednesday 10th August 2005

Terms of Reference Review and Discussion	Thomas Miller Lynne Fegley Glenn Davis
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Detailed discussion of:

Assess and quantify the life history and vital rates of blue crab in Chesapeake Bay

Fishery-Independent Surveys

Patterns in Catch and Effort by sector and region

The Assessment Model for the Chesapeake Bay Blue crab fisheries.

Evaluation of the control rules for the Chesapeake Bay blue crab fishery.

Thursday 11th August 2005

Review panel to discuss assessment and methodologies and initiate development of individual review documents.

The format of the review explicitly followed the terms of reference and followed four main themes, with particular emphasis being placed on the three separate aspects of the data used in the assessments:

- 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.

All reviewers considered all aspects of the review but it was agreed that especial emphasis might be expected in the particular areas of expertise for each of the four reviewers. The issues and details involved with the Chesapeake Bay blue crab assessment meant that meeting the scientists involved in the research that contributed to the assessment was of great value in understanding the content and implications of the assessment. A simple review of only documentary material relating to the assessment would have been insufficient to provide a sufficient grasp of the issues and their present status.

The review process was conducted in an open and friendly atmosphere with great interest and enthusiasm being expressed by the assessment team in Maryland. The Chesapeake Bay blue crab assessment is a multi-faceted and difficult problem and great progress has been made since the first assessment in 1997 (Rugolo *et al.*, 1997). In line with the tradition of excellent work conducted in Chesapeake Bay, the enthusiasm and openness to critical discussion does both the current stock assessment team (Miller *et al.*, 2005) and their respective organizations credit.

I would like to thank all the contributors and others at the review meetings for their efforts and friendly openness during this review. The provision of documentary materials was also very thorough and appreciated.

DISCLAIMER

The information in this review has been provided by way of review only. The author makes no representation, express or implied, as to the accuracy of the information and accepts no liability whatsoever for either its use or any reliance placed on it.

Summary of Findings

Structure of Document

This review will be structured to parallel, approximately, the details of the terms of reference for the review. Thus, there will be a discussion of each of the data sources (the population and biological properties of blue crabs in Chesapeake Bay, the time series of fishery independent survey data, and the different fishery dependent data with respect to catch and effort by sector and region. This will be followed by a detailed discussion concerning the structure and appropriateness of the assessment model. Then the control rules that stem from the assessment process. And finally, there is also a discussion concerning recommendations for future research and how data collections might be improved.

Terms of Reference

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.

A discussion was had involving all details of major relevance to the stock assessment modelling. These included:

- the stock structure of blue crabs within Chesapeake Bay and beyond,
- the revision of the natural mortality estimates,
- the description of blue crab growth,
- the movement and reproductive migrations of the crabs,
- the life cycle and behaviour of blue crabs.

That the Chesapeake Bay population of blue crabs can be treated as a predominantly independent stock was supported by the available genetic evidence, the evidence concerning larval dispersal, and by the known movement patterns of adults being restricted to within the Bay and tributaries.

The importance of the revised estimate of natural mortality to the latest assessment is reflected in the time devoted to this issue both in the stock assessment document (Miller *et al.* 2005) and during the review. The array of methodologies applied to this problem included the use of mark-recapture experiments, the use of lipofuscin, observations on captive animals in experimental ponds, and various approximations based on other life history characteristics such as life span, growth rates, and age at maturity (Hewitt & Hoenig, 2005). The weight of evidence pointed to a marked increase over the assumed mortality rate used in the 1997 assessment and this has had an equally marked effect on the assessment. The decision to bracket the values used in the assessment between 0.6, 0.9, and 1.2 was a sensible compromise considering the uncertainty and differences exhibited between the array of different estimates. The arguments put forward against the natural mortality being a relatively small number (*e.g.* 0.375 as in 1997) were convincing, especially as the low estimate used in 1997 was based at least in part on limited and suspect tagging data.

The assumption of a natural mortality rate of 0.9 implies that about 60% of each age-class dies naturally each year. This assumption is implemented in the model as a

constant rate across all size classes; a common assumption in most stock assessment models. An obvious area for future research would be in size-related natural mortality rates. Intuitively, it seems likely that smaller crabs suffer greater natural mortality than larger crabs. It is known that cannibalism is a greater threat to small crabs than to larger ones. This would be reason enough to explore size-related mortality possibilities, even if only theoretically by exploring the implications of plausible scenarios in the assessment model. Preliminary trials of such sensitivity tests indicate the assessment is extremely sensitive to such influences. This in itself may suggest alternative approaches to the stock assessment modelling. At present the total mortality appears to be so high that very few older crabs survive in significant numbers so these sensitivity analyses may not lead to great insights. It would also be extremely valuable to know whether there is any density dependent release from cannibalism (a major source of natural mortality) when stocks are relatively low. Such a density dependence on natural mortality would provide a compensatory increase in productivity when stocks were low which would mean the stocks were more robust to exploitation than without such a response.

Overall there have been significant advances in the treatment and estimation of natural mortality since 1997.

A major contributor to a stock's productivity is the growth of animals already recruited. The description of growth in the latest assessment is far more comprehensive than that used in the 1997 assessment. Not only were alternative approaches to describing growth investigated (using approximations that assumed continuous growth as well as explicitly modelling the moulting process; Bunnell & Miller, *in press*) but a review of a multitude of different growth studies was undertaken. This latter was relatively uncritical but was used primarily to define the possible range of values of growth for the younger age classes 0+, 1+ and 2+. Overall, the description of growth used in the current modelling indicated slightly lower productivity for the Chesapeake stock than in the 1997 assessment, which would be precautionary. The growth of males and females do not appear to differ significantly up to an age of about 20 months, and with total mortality now being so high, assuming that growth was the same for males and females is reasonable.

There remain questions in relation to growth, especially with respect to the transition of animals from under-sized to legally sized animals and the within season timing of such moulting events. In addition, as with the natural mortality, it would be worth knowing whether there were any density dependent changes to growth rates. Such changes would significantly alter the stock productivity and it is this that gives this research direction such significance. Given more detail on the seasonality of growth and any density dependency would open up opportunities for constructing a within-year model of the stock dynamics. Given the high rate of total mortality, adding more temporal detail to the model appears to be a strategy that may be worth further investigation.

Once again, there have been significant improvements in the estimation and utilization of growth descriptions in the latest assessment.

The other major source of productivity for the stock relates to the recruitment dynamics. The knowledge of the life cycle is thorough and detailed. Knowledge of the movement dynamics of the crabs through the year should aid in the monitoring of the supply of recruits. There is a possibility that the survey for larval forms in Virginia on the spawning grounds may yield a useful index of potential recruitment. The planktonic surveys that give estimates of zoea abundance are relatively noisy and, so far, no

relation between zoea abundance and 0+ abundance has been found. It seems likely that the estimates of 0+ abundance from the winter dredge surveys will be a more reliable indicator of recruitment and future yield than the continued study of crab larvae.

It is also possible that the knowledge of the movement patterns could be used to improve the interpretation of the various fishery independent surveys. However, the sheer scale of the Winter Dredge Survey (WDS) means that information on movement is likely to come from the survey rather than knowledge of movement informing that particular survey.

Patterns in Fishery-Independent Surveys.

Without the fishery independent surveys the assessment of blue crabs could only be relatively weak. There are four time series of data to use, descriptions included in the modelling included:

- The Virginia Institute of Marine Sciences (VIMS) trawl survey (1968 – 2003) restricted to Virginian waters but useful in covering the main spawning grounds.
- The Maryland trawl survey (1977 – 2003; missing 1988) restricted to the Bay edges in Maryland waters.
- The Calvert Cliffs pot or trap survey (1968 – 2003), restricted to one set of narrows in the main channel in Maryland waters.
- The Winter Dredge Survey (WDS) (1989-2003), 1500 stations spread through the entire Chesapeake Bay.

The WDS is especially impressive through its sheer scale (about 1,500 stations throughout the Chesapeake Bay), which provides it with very great statistical power to discriminate stock sizes between years. In addition, numerous depletion experiments are conducted in different parts of the Bay each year in order to estimate the relative catchability of the different gears and vessels involved in the surveys. Despite these latter efforts it is still surprising that this survey can be used as an absolute estimate of abundance for the 0+ and 1+ age classes. However, the fact that there is a very strong regression between the survey estimates and the subsequent catch improves the confidence with which the results of this survey can be held. Beyond the clear value in providing an abundance estimate upon which to base the assessment, this survey has the potential to provide useful insights into the stock recruitment dynamics, depletion rates of the 0+ animals (which obviously become 1+ in the subsequent year), plus an early warning of spatially depletion of particular areas within the Bay. While the WDS must be expensive to run it is recommended that it continue as it provides the best quality and most spatially extensive data set for the assessment of the Chesapeake Bay blue crab stocks available.

Some discussion was spent on trying to suggest ways of improving the catchability experiments. This included the suggestion of using video observations to see if it were possible to independently estimate the number of animals in the path of the dredge. It seems likely that video observations would only be possible in a few places in the Bay as underwater visibility is usually poor. In addition, the use of differential GPS and GPS plotters should be used instead of Dann buoys to mark the ends of the dredge runs that are to be depleted. This, in combination with standardized data forms, plus recording details of depth fished, sea-state, and rope-length to the dredge would permit the use of a Generalized Linear Modelling framework to standardize the analysis and provide catchability estimates less affected by spurious factors. If the catchability experiments

can be improved the confidence in the survey abundance estimates would be improved. The uses to which the data from this survey is put to will be further discussed when the assessment model is considered.

The Maryland Trawl Survey has varied its spatial coverage from year to year (with the timing of the survey within years also varying occasionally). Again it would be possible to conduct a Generalized Linear Modelling exercise to produce an annual index of relative abundance rather than continue to use the ad-hoc averaging across the various rivers and bays surveyed each month. This may improve the analysis produced and would certainly make it more defensible.

The VIMS survey uses a standard bottom trawl survey and has the longest time series. The spatial scope has expanded, as it started with the main rivers on the western shore and is now much enlarged. Gear changes also occurred through time, and include the addition of a tickler chain in the 1970s, but most of the changes to gear occurred prior to 1968. The gear changes were not made without exploring how the changes affected fishing performance and corrections have been made to the time series of data as a result of these explorations. In particular, all the pre-1968 changes to gear led to the recommendation to exclude all data from pre-1968 from the assessment. To make the data adjustments the VIMS staff conducted paired tows to make the comparisons, but a full GLM analysis was not used and this could have improved the corrections.

The effectiveness of the VIMS survey for estimating crab abundance has been questioned because it was not designed purely to study crabs. Indeed, the estimated abundance of 0+ is invariably less than that for 1+ crabs, indicating a difference of either availability or catchability. Nevertheless, the estimates for the 1+ crabs can probably be used validly. There is, therefore, still some work required on how best to develop a better indices of relative abundance for both the 0+ and 1+ crabs.

The final fishery independent survey has been conducted at the Calvert Cliffs using pots to follow the relative abundance of crabs through time. This survey began in response to building a power station that expelled warmed water into the Bay. This survey has a long time series but is extremely restricted geographically, however, there appears to be some relationship between the trends seen in the Calvert Cliff crab pots and the Maryland trawl survey so there may be valuable information in the data with respect to early trends in crab abundance.

The trawls used in the Virginia and Maryland trawl surveys differ, and both obviously differ from the pots used in the Calvert Cliffs and the dredges used in the Winter Dredge Survey, so it is fair to ask whether their results are comparable (Fig. 1). When the different time series are compared there are clear consistencies as well as clear inconsistencies. Some of the features observed in the time series are especially influential in the stock assessment modelling. For example, much of the apparent ability of the stock to recover from depletion derives from the spike in the abundance index found in the Virginia trawl survey in 1970 and 1971. Because of the issues of comparability and variation between surveys, a formal exploration of the extent of noise and or bias, and the overall reliability of the different surveys should be produced. At very least a more complete set of sensitivity analyses should be conducted to determine the relative contribution of the different data sets. For example, when the Virginia trawl survey results are excluded from the assessment it was reported that there is a large effect because of the influence of the early years. It might be worth exploring what would happen if one were to remove the spike in apparent abundance derived from the

Virginia trawl survey in the early 1970s, as a sensitivity analysis it would be a reasonable idea to include the VATS but exclude the earlier years

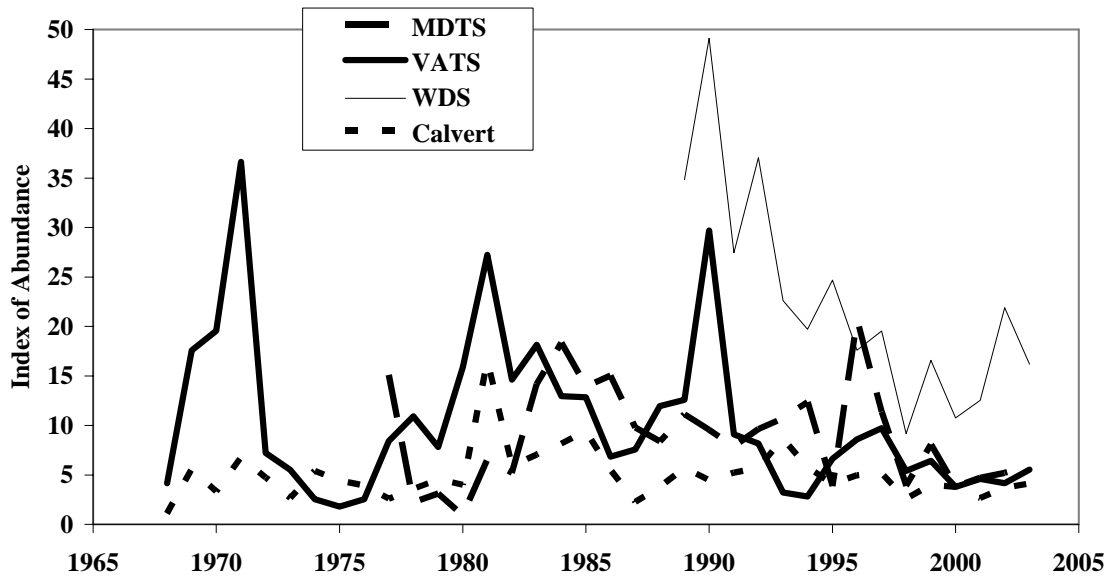


Figure 1. A visual comparison of the four time series of abundance indices for blue crabs in Chesapeake Bay. Some consistency is visible but also some inconsistency. The large spike of productivity indicated by the Virginia trawl survey around 1970 is very influential in the modelling.

Further analysis of the coherence between surveys is required. It is the case that each survey places different emphasis on different aspects the same thing. For example, the Virginia trawl survey measures more females than the Maryland trawl survey simply because of timing of the surveys combined with the spatial distribution and migration patterns of the two sexes. So are they measuring the same thing? Does each survey provide a different perception of the stock that would include implicitly the spatial details of the stock? The GIS analysis of the WDS suggests a spatial structure to abundance that should not be ignored (Jensen & Miller, *In Press*; Jensen *et al.* (a) *In Press*; Jensen *et al.* (b) *In Press*). But perhaps the annual time step addresses this in a valid fashion. Certainly if a seasonally explicit stock assessment model is ever developed then spatial details for the different surveys could be used separately.

It is recommended that the WDS is given more weight in the assessment modelling because of its extensive coverage and precision. However, in all comparisons there needs to have at least some overlap between the time series being compared. For example the WDS exhibits a strong decline over the last 10 years and this is reflected in the other series (although to a lesser extent).

Currently the different time series are being treated as if they were effectively independent. It would be worth formally exploring relationships and correlations between the different series. Because of the different quality of the surveys it is suggested that the WDS be kept separate from the remaining surveys. Some formal statistical method should be used to combine the three remaining time series (perhaps a straight-forward generalized linear model or perhaps some multi-variate ordination method).

One possible way of weighting the different survey time series would be to examine the relationships between the various surveys and subsequent yields (possibly of particular age classes. For example, there is a demonstrated strong relationship between the WDS and subsequent yield. It would be interesting to determine whether, for example, the Virginia trawl survey is related to the subsequent yield of female crabs.

Finally, in addition to the fishery independent survey time series there are also numerous time-series of sea-water temperature. These may have value for the exploration of possible relationships between relative recruitment levels each year and environment variation. This could be examined through a consideration of both the larval survey and the estimates of 0+ crabs especially from the WDS.

Patterns in Catch and Effort by Sector and Region.

There are now regulations requiring more accurate details concerning catch and effort, at least in the commercial fishers. There have been detailed efforts (Fogarty & Miller, 2004) made to understand the implications of changes to regulations and the results are an improvement over the previous situation. Despite the new regulations it is known that there is a degree of under-reporting of catch, especially in the peeler fishery (in which any mortality during the shedding process tends to get omitted). There is a myth/tradition that peeler crabs are far less effectively reported than the hard crab catchers. How true this myth is in practice should be determined.

While it could be extremely useful to obtain accurate catch rate and effort data it is essential to have accurate estimates of the total extractions from the fishery. The continued lack of accurate catch and effort information from both the commercial and recreational fishers makes management of total effort full of uncertainty.

The problem of obtaining accurate catch and effort statistics are exacerbated by the different spatial distributions of the male and female crabs leading to different degrees of fishing intensity on the two sexes. Catches of hard crab are now reported by sex except in the peeler fishery (which is likely to be biased to wards females). Overall, the selectivity by sex was reported as being approximately 50:40:10 for female:male:peeler. It would appear that more work is required to obtain better information from the peeler fisher (for both total landing and the sex ratio of the catch).

In 2002 there were reported to be 6170 licensed crabbers. Unfortunately, about 13% of these provided no catch records, while about 47% explicitly reported zero catches. Out of the total, about 17% reported less than less than 20 bushels in the year while about 24% reported more than 20 bushels. There remains an issue of measurement units where bushels are often converted first to pounds and then to numbers. The potential for making errors appears to be relatively high so it would be useful to determine whether the estimates of catch are invariably biased low (as would appear to be likely).

Currently there are estimated to be between 1,400 and 1,500 active fishers in Maryland with similar numbers in Virginia. In May 1999 a cap was put of the entry of new licenses but new entries may simply be using up latent effort (making inactive licenses active). It is unfortunate that the regulations in the fishery differ between Maryland and Virginia; this must make obtaining comparable data from the fishery difficult. For example, in Maryland ovigerous crabs (so-called 'sponge' crabs) may not be landed while in Virginia the regulation forbids only dark sponges (which would be close to spawning). Another example is that escape gaps (cull rings) are required in Maryland (though they need not be open!) whereas they are not required in Virginia. A review of

regulations with an aim of increasing commonality between the two States may improve the ability to collect consistent data.

Apparently there is now a new problem of some fishers using excess numbers of pots by attaching multiple pots to single buoys. This source of extra effort, as well as being illegal, would be very hard to detect with current data collection methods.

An observer program, started in 2002, is used to verify catch rates and could be used to corroborate total catches. In fact, this program indicates that reported catch rates are very close to the actual catch rates. The observers have been able to demonstrate some regional differences in error rates for catch rates (some of the more isolated island fishers exhibit a large bias downwards in their records). The catching characteristics of peeler pots and hard crab pots have been found to be very different.

Catch has also been reported from dealers since 2002. For hard crabs reported landings recorded by dealers were very close (within about 10%) to reported catches from fishers. However, there are known biases, for example there is a direct basket trade (direct sales from boats to consumer). In addition, females are often processed for meat but the males (a preferred product) are somewhat under-reported because of the direct sales.

Estimating the total catch is important so that the dynamics of the stock can be more precisely modelled and described. Errors and bias in the estimates of total catch could constitute a serious under-estimate of total extractions so the impact of the fishery on the stock may also be under-estimated. Related to under-estimated total catches are other forms of mortality associated with the fishery. Discarding of undersized crabs is common and whether gear associated mortality of the under-sized crabs is significant is unknown. This would be worth exploring. Another potential source of unaccounted for mortality could be a result of ghost fishing by lost crab pots. Apparently there are significant numbers of pots lost each year. If lost pots are self baiting (e.g. fish entering the pot and then dying) then this could constitute another significant source of unaccounted mortality. It is strongly recommended that the extent of ghost fishing be assessed with regard to the potential losses and how, if they are significant, they may be ameliorated.

A potentially controversial issue related to unaccounted mortality relates to the wide array of different fishing methods used to catch crabs. If some fishing methods are harder on the crabs than other methods then it would be sensible for an examination of the potential relative impact of those different gears in terms of unaccounted mortality. Such a study may be valuable in estimating the total impact of the different gears used once accurate estimates of effort by gear become available.

There have been recreational surveys but it is not known if there is a relationship between stock size and recreational take (in other words, does recreational take increase with stock size in line with commercial catches?). A second survey is being undertaken and this may provide some enlightenment with regard to this process. While there is a recreational license it is not compulsory. The people who buy the license tend to be really serious with their fishing. Thus, while the bulk of the effort comes from the mass of the public, the bulk of the catch comes from those with licences. The recreational surveys should be applauded but something should be done to improve the capture of recreational data on a regular basis.

The important thing is to be confident in the coherence of the different time series of catch estimates being developed. This coherency should be considered explicitly. The

difference between the improved catch estimates and the traditional catch estimates should be explored to determine how far normal catch estimates might be from that reported.

The most worrying aspect of the catch and effort data is the impression that effort has expanded recently to unprecedented levels. If this really is the case, methods obviously need to be developed to reduce effort to more manageable levels.

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 model used to assess the Chesapeake Bay blue crab is a modified version of the Collie & Sissenwine (1983) model. This is a simple model structure using a pre-recruit and fully-recruited staging, which was originally developed to be used with fisheries for which survey information is available. The model has been modified to include the array of different fishery independent abundance indices derived from the various surveys conducted in the Bay. The Model has been implemented in AD-Model Builder (Fournier, 2000) and the application code and data files were provided for the review. The implementation uses data relating to catches from 1968 to 2003, using an annual time step. It uses the fishery independent estimates of exploitation rate (μ) from the WDS from 1990 to 2003. In addition, it uses data from both the Maryland and Virginia trawl surveys (but does not appear to use the data from the Calvert Cliffs). This is a reasonable use of available data and attempts to include as much of the broad-scale data as possible.

In all there are 206 data points. The reason the number of data points is important is that there are 76 different parameters being fitted in the full model. This is not a particularly high density of data points for the number of parameters being estimated (about 2.71 data points per parameter). The parameters are the initial population size at the start of the modelled period, three parameters relating to the ratio of measurement to process errors, 37 estimates of the abundance of 0+ animals and 35 estimates of a component of the process error in each year; a total of 76 parameters.

The model is implemented using both measurement or observation errors and process errors. The interpretation of the meaning of the process errors is complex but perhaps the best interpretation is that they attempt to capture the variation in natural mortality that occurs from year to year.

It turns out that the model as it stands is not particularly stable. It seems best to run the model using only the adult crabs (1+) in the estimates of exploitation rate (μ) and without including the comparison of predicted versus observed exploitation rates in the likelihood function being used to fit the model to the available data. If both adult (1+) and 0+ crabs are used in the calculation of the exploitation rate then the model generates negative exploitation rate estimates (not a reasonable outcome). On the other hand, when only the adults are used there are instances of exploitation rates being predicted at levels greater than 1.0 (another impossibility – meaning more than 100% of the available biomass was taken in the fishery). This latter phenomenon seems to imply that the definition of fully recruited crabs is not correct (meaning that some 0+ crabs may be as available to the fishery as some 1+ crabs). This sensitivity to which abundance estimates are used needs to be investigated especially as the 0+ crabs are a major part of the signal in the WDS.

While it is not in the terms of reference for this assessment to suggest an alternative assessment, it would be valid to point out that some models inherent in the current model could be profitably explored further. The inclusion of process errors in the model adds 35 parameters that require estimation and these appear to de-stabilize the model. In addition, only using observation errors has the advantage that it is possible and stable to include the observed versus predicted exploitation rates in the model fitting. Other studies have found that with simple models it is often best to only use observation errors (Walters & Ludwig, 1981). Including process errors has the advantage of comparability with earlier models but before including such errors and their associated parameters their use should be fully justified. The documentation of the model needs to be updated to include the full details of the model (the implications of simulating fishing in the middle of the year should, for example be included in the model equations). Within the documentation a detailed justification and need to include the process errors should be included. Such a justification should include a comparison of the model fits with and without process error. This would provide a far more defensible position and ensure that the balance between useable data and numbers of parameters being fitted is optimized.

The contributions of the various surveys used in the assessment are weighted by the respective variance of the observation errors within each time series, which is appropriate for this model structure. However, it would be useful to know whether this weighting affected the balance between the observation and process errors in the model.

The Collie & Sissenwine model requires estimates of juveniles and adults but does not appear to pay account to the different selectivity of the survey gear for the 0+ and 1+ crabs. This may be a mis-perception however, as the survey estimates may have been made with this in mind.

Having said all that, the 2005 assessment implements and uses many advances over the 1997 assessment. The 1997 assessment did not use lagged recruitment appropriately, and there has been a re-definition of age-structure size distributions. The implementation of the exploitation rates and the suggestion of using them as a fishery performance measure is a significant improvement over the earlier assessment.

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

There is a legislative requirement to have in place a set of limit reference points and target reference points against which the fishery may be assessed. The definition implied in Figure 1 of the 2005 assessment document appears robust. Because the exploitation estimates are derived from the WDS, and this is the most reliable and accurate survey, having the greatest geographical generality, then the control rules are probably as good as they can be at the present time. While the limit and target reference points have been defined the management actions that might follow if the fishery enters an undesirable state remain unclear. The management levers that can be used to reduce effort appear to be limited to altering the open season (as in Maryland) and through the agency of closed areas (as in Virginia). The effectiveness of the closures in Virginia (Lipcius *et al.*, 2003) has been demonstrated but their effectiveness and that of seasonal closures are confounded with rapid abundance changes.

Unfortunately, there appears to be insufficient information on effort and the distribution of effort to improve the management levers of develop new ones. This is a job for the fishery managers not the scientists. The objectives towards which the fishery is to be

managed needs to be made clear before suitable means of managing the fishery can be suggested.

In short, the legislative requirements to have limit and target reference points in place has been met but the complementary levers may not be in place. The definition of overfished still appears to be based upon the minimum unstandardized abundance observed in 1968. This data point is quite strongly influenced by the first year of the Calvert Cliffs dataset and the generality of this limit is therefore questionable. What is required is a definition of minimum spawning biomass below which a rebuilding strategy is instigated. The Magnuson-Stephenson Act requires such a recovery plan is such a minimum is defined.

On the other hand, the Chesapeake Bay blue crab fishery may be so variable and unpredictable in the long term that some form of management structure may be possible if based upon recruitment processes. The WDS provides a good estimate of 0+ animals. This has been shown to provide an excellent estimate of the eventual yield possible from the fishery in that same year. Rather than some management regime based upon fisheries theory appropriate to a relatively long lived species it may be more appropriate to examine alternatives that relate more appropriately to short lived, highly variable species. Perhaps a minimum biomass required to generate the harvest could be produced using the strong relationship found between 0+ and subsequent yield. Once again this emphasizes the value and importance of the winter dredge survey.

Overall, the scientific basis of the control rule for the Chesapeake Bay blue crab fishery is well founded. The switch to using the estimated exploitation rate is a great improvement. However, it must be emphasized that no matter how good the control rules, if there are no management actions that can influence (manage) effort or catch should the controls rules indicate the stock is in an undesirable state, then, while the letter of the law may have been met, the intent has been missed. This fishery is in urgent need of some clear and explicit objectives towards which it can be managed.

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

See Executive Summary

Conclusions

The 2005 assessment constitutes a major advance over the 1997 assessment. There is an impressive array of research projects focussed on blue crab and Chesapeake Bay that have directly contributed to the new assessment.

Work has been successfully pursued that has improved the adequacy and the appropriateness of the data used in the assessment. That includes details of the biological properties of the blue crabs (natural mortality, growth, and recruitment), as well as the time series of population estimates from the various surveys and the time series of catches that have been amended to account for altered methods of data recording through time.

The assessment model used for the Chesapeake Bay blue crab population is appropriate for a species for which there exists good quality fishery independent survey data of population sizes through time (which matches the blue crab). The modifications to the original Collie and Sissenwine model help match the model to conditions and data available in Chesapeake Bay. They constitute an improvement over the original model.

The documentation of the model could be improved slightly and there should be a justification of the use of process errors in addition to observations errors or the removal of the process errors.

The control rules developed using the exploitation rate or fraction are a real improvement over the earlier control rules based on fishing mortality (which were more indirect). The new control rules are not matches by workable management levers that can be activated should the control rules inform us that the stock is in an undesirable condition. Decisions need to be made (not by the scientists) about how and towards what aims this fishery is to be managed. Some way of limiting the apparently run-away effort currently being expressed is urgently required.

Finally, 20 recommendations are suggested that would include a range of useful directions in which to move future research. The idiosyncrasies of the fishery will help determine which are the most urgent in themselves.

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Appendix 1: STATEMENT OF WORK

Consulting Agreement between the University of Miami and Dr. Malcolm Haddon

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

It is estimated that the Chair's duties will occupy a total of 17 days - several days prior to the Review Panel meeting for document review; 3 days at the review meeting in Annapolis; several days following the meeting to ensure that the final documents are completed; and several days following the meeting to review the individual panelist's Review Reports and produce the Summary Report. This report shall be a summary of the individual Panelist Review Reports, accurately and fairly representing all viewpoints. There shall be no attempt by the Chair to develop a consensus report.

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: act as chairperson, where duties include control of the meeting, coordination of presentations, control of document flow, and facilitation of discussion.
- (3) After the meeting: provide a Summary Report, which summarizes the findings of the individual panelist's Review Reports (to be provided to the chair no later than August 25, 2005). The Summary Report shall be organized like the Review Reports, with an executive summary, a review of activities and a summary of findings and recommendations that collectively emerged from the meeting. 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. The Chair shall not attempt to reach or describe consensus on the assessment, but shall fairly summarize the individual Review Reports and draw attention to the collective conclusions and recommendations.

The milestones and schedule for the Chair are summarized in the table below. The Chair shall begin the summarization using the draft individual Review Reports provided by the Panelists on August 25, 2005. When these individual panelist reports are finalized, following the CIE internal review and approval by the NMFS Contracting Officer's Technical Representative (COTR), the CIE

shall provide copies of the final versions to the Chair on September 12, 2005 for completion of the Summary Report. No later than September 20, 2005, the Chair shall submit the Summary Report¹ to the CIE. This shall be addressed to the “University of Miami Independent System for Peer review,” and sent to Dr. David Sampson, via e-mail to david.sampson@oregonstate.edu, and to Manoj Shivlani, via e-mail to mshivlani@rsmas.miami.edu. The CIE shall provide the final Summary Report to the NMFS COTR for final approval on September 27, 2005.

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:

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ANNEX 1: Contents of Chair Summary Report

1. The summary report shall summarize the findings of the individual panelist's Review Reports. The Chair shall not attempt to reach or describe consensus on an assessment, but shall fairly summarize the individual Review Reports and draw attention to the collective conclusions and recommendations.
2. The summary report shall be prefaced with an executive summary of findings and/or recommendations.
3. The main body of the report shall consist of a review of activities and, for each assessment reviewed, a summary of findings and recommendations that collectively emerged from the meeting.