Oyster (*C. virginica*) Demographic Model
Final Peer Review Report and Lead Agency Response

Report Content and Charge:
This report describes the peer review process and presents the lead agencies response to the peer review. Also included are the names of the peer reviewers and their organizational affiliations and a compilation of all the peer review comments on the Oyster Demographic Model (ODM), and the principal investigators responses to the peer review.

The ODM was developed as a supporting document for the Programmatic Environmental Impact Statement (EIS) for Evaluating Oyster Restoration Alternatives for the Chesapeake Bay, Including the Use of Native and Non-Native Oysters. The process followed for this peer review is consistent with the peer review plan that was developed by the Lead Agencies for the EIS project. This peer review plan was specifically designed in order to comply with the December 16, 2005 Office of Management and Budget's Peer Review Guidelines and was accepted by the US Army Corps of Engineers for this purpose.

The peer review plan designated that the Independent Oyster Advisory Panel (OAP) as the principal review group for the peer review of the demographic model. In addition, the OAP was tasked with the review of the sufficiency of the EIS. The OAP's charge includes the following additional tasks:

1) Review the adequacy of data and assessments used to identify the ecological, economic, and cultural risks and benefits, and associated uncertainties for each EIS alternative;
2) Provide advice on the degree of risk that would be involved for each EIS alternative if a decision were made in 2005 based on the available data and assessments; and
3) Recommend additional research, and associated timeline, that could be obtained to reduce the level of risk and uncertainty.

Study Objective:
The objective of the oyster demographic model was to predict population growth of *C. ariakensis* and *C. virginica*, both spatially and temporally, within Chesapeake Bay, for each of the oyster restoration alternatives being evaluated in this EIS.

The Lead Agencies Review and Response Process:
The OAP met four times in 2005 and 2007 with the principal investigators and provided review on sections of the demographic report, as it was prepared. The report entitled "A Demographic Model of Oyster Populations in the Chesapeake Bay to Evaluate Proposed Oyster-Restoration Alternatives" was provided by the Lead Agencies to the OAP on June 6, 2007 for review. The OAP produced a peer review document for submittal to the Principal Investigators for the ODM. The peer review report was finalized by consensus during the July 12, 2007 meeting of the OAP members. In addition to the general input provided during the drafting of the final peer review report, comments to the ODM were submitted by Dr. Michael Roman, Dr. Maurice Heral and Dr. Roger Mann and Dr. Eric Powell and are presented in the peer review comments. OAP members, Dr. Jim Anderson and Dr. Mark Berrigan, did not comment on the OAP peer review report because their areas of expertise do not include population dynamics of fish stocks. OAP

members were also involved in reviewing the research findings that provided model input data. The Scientific Advisory Committee for the EIS (SAC) and the Atlantic States Marine Fisheries Commission, Interstate Shellfish Transport Committee (ASMFC, ISTC) were also provided opportunities to review and comment on the development of the demographic model and to review and comment on the demographic modeling results.

The final OAP peer review report was provided to the principal investigators for the ODM study on October 1, 2007. The principal investigators revised the demographic model report in response to OAP comments. The revised ODM report and documentation summarizing the manner in which the major OAP comments were resolved in this report were submitted to the Lead Agencies on October 5, 2007. The response document submitted by the principal investigators included a list of specific issues that were extracted from the OAP report summary and review comments of individual OAP members and an explanation of how and why each were either addressed, or not addressed in the revised ODM report.

The Lead Agencies for the EIS reviewed the OAP peer review report and the response to the peer review and requested that the principal investigators for the ODM and Environmental Risk Assessment (ERA) propose an approach for utilizing the demographic modeling results with consideration to the peer review comments. The proposed approach, which was delivered to the Lead Agencies on October 31, 2007, identifies how the OAP comments to the demographic model may impact the ERA development and proposes a method for evaluating *C. virginica* based on the demographic model and an approach for evaluating *C. ariakensis* given the lack of quantitative modeling. On behalf of the OAP, Dr. Brian Rothschild (chair) submitted a final summary statement in response to the ERA/EIS proposed approach on November 13, 2007.

Although the OAP expressed concern with the high degree of uncertainty in the modeling results that were produced by the ODM, the final recommendation by the OAP indicated that the model could be used to guide management decisions regarding the implementation of the EIS alternatives. Finally, the proposed approach for the use of the ODM output data for the development of the ERA and the EIS was accepted by the OAP as reasonable with some qualifications concerning growth estimates and how qualitative approaches should be applied. The Lead Agencies are satisfied that the key concerns raised by the OAP have been addressed.

The remainder of this report presents the OAP consensus review comments, the ODM Modeling Team Response to the OAP Report, the proposed approach for utilizing the demographic modeling results with consideration to the peer review comments, and the peer reviewer's final comments on the proposed approach.

Deposition of Peer Review:

Dr. Brian Rothschild, Director
School for Marine Science and Technology
University of Massachusetts - Dartmouth

Dr. Eric Powell, Director
Haskin Shellfish Research Laboratory
Rutgers University

Dr. Jim Anderson
University of Rhode Island
Department of Environmental and Natural Resource Economics

Dr. Mark Berrigan, Chief
Bureau of Aquaculture Development
Division of Aquaculture
Florida Dept. of Agriculture and Consumer Services

Dr. Maurice Heral
Director of Scientific Research
IFREMER
French Research Institute for Exploitation of the Sea

Dr. Roger Mann
Department of Fisheries Science
Virginia Institute of Marine Science, College of William & Mary

Dr. Mike Roman, Director
Horn Point Laboratory
University of Maryland Center for Environmental Science

Oyster Advisory Panel Consensus Review Comments (October 1, 2007)

The Independent Oyster Advisory Panel (OAP) envisions the ODM as providing advice on the proposed action and alternatives 1, 2, 3 and 7 [see below] that can be used to support the EIS. In this effort, the OAP expected that sufficient documentation on the model would be provided to enable the Panel to judge the quality and reproducibility of model scenarios. *Review comments concerning these specific actions are italicized.*

The proposed action "…is to establish a naturalized, reproducing, and self-sustaining population of *C. ariakensis*…while continuing to restore *C. virginica*…"

Alternative 1. Involves no action **-** maintain current level of effort to restore *C. virginica*.

This is the proposed action absent introduction of C. ariakensis. It does not seem that this will be acceptable to stakeholders.

Alternative 2. Expanding *C. virginica* restoration techniques.

*This alternative includes an increased scale of habitat rehabilitation and hatchery production, and potential use of disease-resistant strains of C. virginica. In order to model this alternative, a set of assumptions needs to be adopted with regard to the successfulness, so what would new techniques (see appendix 2) consist of and how successful will they be? It is not clear that the remedies proposed in Alternative 2 are efficient (i.e. "*assessment*" is an activity, not an action plan with focused results in mind) of the restoration techniques. Existing techniques have not had well defined goals, and seem to have not been successful based upon poorly guided evaluations. Utilizing the findings of the EIS, new strategies with clearly defined goals should be developed (i.e. use of more scientific criteria for identifying sanctuary areas, use different physical structure of oyster reef construction, expand off-bottom propagation). Developing these new strategies should include an evaluation of the goals of ecological restoration and the goals of economic restoration in the context of determination of the extent to which they are mutually exclusive.*

Alternative 3. Temporary harvest moratorium.

By itself, this action assumes that if there was no fishing, the oyster stock would rebuild. However, the oyster stock is not limited by a reasonable amount of fishing—it is limited by the extent of habitat, the reduced quality of existing habitat, and the continuing disease pressure of Dermo and MSX. Based upon model results, it does not appear that this alternative will result in a measurable bay-wide oyster population increase. Model results on a finer spatial scale may assist in assessing whether or not the implementation of this alternative in certain areas (i.e. river systems) would have a measurable impact on a regional scale.

Alternatives 4 and 5. These involve aquaculture and differ in the species utilized.

The ODM is not being used to evaluate alternative 4 and 5. The biological and socio-economic factors currently limiting aquaculture operations in Maryland and Virginia should be included in the pre-draft EIS to facilitate the Panel's review of these alternatives.

In 2003, the National Research Council report concluded that large-scale triploid aquaculture of C. ariakensis would result in a de facto introduction of a reproducing population. In the Panel's deliberations, it was noted that this risk has been reduced since the report was published. The pre-draft EIS should also include an assessment of the risk in having a reproducing wild population of C. ariakensis develop from a large-scale triploid aquaculture program.

Alternative 6. Introduce and propagate alternative oyster species (other than *C. ariakensis*) or an alternative strain of *C. ariakensis*.

The ODM is not being used to evaluate this alternative.

Alternative 7. Establish *C. ariakensis* and discontinue restoration of *C. virginica.*

This is the proposed action absent continued restoration of C. virginica. It does not seem that this will be acceptable to the stakeholders of Maryland and Virginia, including the oystermen. In order for the Panel to assess whether or not the introduction of C. ariakensis will contribute the ecological benefits associated with an oyster reef, information on the reef-building characteristics of C. ariakensis should be included in the pre-draft EIS.

Alternative 8. Combinations of alternatives.

The ODM is not currently being used to evaluate this alternative, however, it could be used when a combination alternative is defined.

The extent to which model output enables managers to choose among the modeled alternatives depends on two things: 1) the quality of the data used in the model, and 2) the assumptions and logical structure of the model. An important question relates to the model results. If some results are not distinguishable from other results, is this due to the data or the model, or from the fact that if one had a perfect set of data and a perfect model, the results would still be indistinguishable?

Everyone recognizes that a model such as the ODM model involves many assumptions. However, the decision maker that uses the model results needs to thoroughly understand the modeling assumptions. These assumptions should be clearly spelled out, as well as any imputed conclusions or results. The approach should not be more complex than the data or understanding allows.

Before moving directly into the ODM, it seems worthwhile to revisit the issues that were intended to be addressed by the modeling effort. It is important that these issues are clear, so that any overlap among the proposed action and the alternatives is delineated.

The proposed action is to establish a self-sustaining population of *C. ariakensis* in Chesapeake Bay while "using best available restoration strategies and stock assessment techniques [concerning *C. virginica*]".

The proposed action is in two parts: establishing *C. ariakensis* and rebuilding *C. virginica*. If *C. virginica* could be rebuilt, would establishment of *C. ariakensis* be necessary? Based upon experiments with triploids, it appears that *C. ariakensis* can exist in Chesapeake Bay, at least in localized areas, but it is not clear that reproductive success is possible. What would the restoration strategies be, and how would they be implemented? To what extent would the contemplated restoration strategies be more of the same? Restoration needs to include major and extensive habitat reconstitution and focus on the necessity of habitat reconstitution to enable *C. virginica* to thrive as well as to support possible introduction of *C. ariakensis*.

In reviewing the sense of these alternatives, it is clear that they center on a material increase in oyster abundance in Chesapeake Bay. Further, it is clear, at least in the Maryland portion of the Bay that some oyster bars are good performers while other oyster bars are not. It appears that some oyster bars produce a lot of spat while other oyster bars are more productive with regard to small and market oysters. It does not appear that salinity always determines the quality of an oyster bar. This is also evident in Virginia where there is regularly a two order magnitude variation in mean oyster densities in the James River in locations that are only hundreds of meters apart.

What this means is that any restoration strategy will be driven by capitalizing on the most productive bars, not the average bar. The average bar has neither good recruitment nor abundance of small and market oysters. The smaller scales and metapopulation dynamics probably dominate the population biology of these animals insuring that approaches using broad means (such as used here with salinity zones) will be unable to identify important cause and effect features.

Our analysis further reflects that the goal of a successful oyster population in Chesapeake Bay ultimately depends on habitat. It is our understanding that the intensive mega-program on habitat reconstruction has not been implemented. These should begin on a **proof-of-concept** level. Work should continue on all species of oysters and not be limited to *C. ariakensis*. Intense ranching of oysters should be implemented in carefully selected areas as part of the proof-of-concept. What we need now is a demonstrably feasible program, with clearly defined goals, time frames, deliverables and economic evaluation, not hand-wringing on alternatives.

WHAT DOES THE Oyster Demographic Model TELL US?

The results of the ODM are subsumed under Figures 9-23 in the ODM document. In this section, we make observations on the conclusions and implied conclusions of the model. First we make some general observations; then we discuss the validity of the model.

General Comments: There are general features of the Figures that need to be kept in mind as they are reviewed.

- Sustainable age structure – Sustainable age structure examines the numbers of spat, small, and market oysters. Qualitatively speaking, there should be enough spat to replace the small and market oysters. Because of the scale, it is difficult to determine whether there is a balanced age structure. How could a low recruitment in Maryland sustain a large population of markets with a 40% exploitation rate (see Figure 10)? Why would the number of spat in Virginia equal the number of markets and smalls in Virginia? These discrepancies imply errors in spat assessment as well as small and market size oysters. To highlight this point—at least for Maryland data—let's assume that spat are un-fished. Let's further assume that small oysters are un-fished. Both the Cokely and Rothschild data suggest that small oysters are a single age class. We should be able to calculate the replacement magnitude of the spat population. This depends on the mortality rate, and we can see that a mortality rate of 0.5, for example, would require 1500 spat to produce 100 small oysters. It generally appears in the document that there is an equal number of spat and small oysters.

- <u>Magnitude of variability</u> – The size of the vertical lines might be thought of as analogous to 90% confidence intervals. There is substantial overlap among the many scenarios. Extensive overlap suggests that one scenario cannot be distinguished from another. This needs to be discussed in the document in detail, pointing out which scenarios are thought to be different and which scenarios are thought to be the same.

- <u>Asymmetry</u> – The error bars are not only not symmetrical. They are generally positively skewed, so catastrophes are impossible for any of the scenarios.

- It is important to put into perspective the harvest rates used in the model. The exact formulation is not given. However, if we assume that the harvest rate is equal to the conventional exploitation rate, F/(F+M), then we can understand the total mortality and fishing mortality rate. If we examine recent years (see Volstad et al., Figure 5), we might guess that natural mortality is about 0.5. So if the harvest rate is 40%, we would expect F=.3, roughly. This means that oysters on average are exposed to a total mortality rate of about 0.8.

- <u>Model Validity</u> – From a decision-making and policy point of view, it is important to consider the validity of the model. There are at least three components of model validity: 1) is the modeling effort focused on the right question(s); 2) does the model fit the data; and 3) are the input and procedures consonant with standard procedures, do they pass the test of common sense, and what are the confidence intervals of the model output?

    1) *Is the modeling effort focused on the right question(s)?* **-** The modeling effort, even if it were perfect, addresses conditions associated with the average oyster on the average oyster bar in Chesapeake Bay. There is tremendous variability in oyster demographics, which seem to be oyster-bar specific and not necessarily related to salinity (although salinity is important, on average). Some of the ambiguities regarding the effects of salinity on oysters could be alleviated by mining the literature or conducted better experiments on the effects of salinity on oyster growth (see Oyster Recovery Partnership review currently being conducted by MD Sea Grant).

       Why wouldn't the feasibility of the restoration effort as implied by the ODM focus on only the best oyster bars? The growth trajectories would be greater and a more optimistic picture would be obtained relative to the target (cf. Figures 21 and 22). In fact, the sensitivity analyses (which really should be interpreted only in the context of the over-all assessment of the ODM), if taken literally, imply significant increases could be obtained by modifying parameters such as growth. But the same results could be achieved if the analysis was restricted to only high-growth or lower mortality oyster bars. Future research and monitoring programs should focus on obtaining data to improve the growth rate estimates used in this model.

2) *Does the model fit the data?* **-** The report states that the ODM, "…was judged to be adequate if it reproduced trends in abundance, and absolute estimates did not differ by a large amount (i.e. an order of magnitude)".

   In other words, one hundred oysters is equivalent to one thousand oysters, or one hundred thousand oysters is equivalent to one million oysters.

   We feel that an adequate resolution of an ODM should be a factor of 2 or 4, rather than 10, to be useful to decision makers.

   Conclusion: It is not clear whether the model fits the data.

3) *Are the input and procedures consonant with standard procedures, and do they pass the test of common sense?* **-** Alternative 1—both States combined under Alternative 1 (no action) the ODM shows a decline in recruitment for all four fishing intensity scenarios. In other words, as a base case, the trends in recruitment are independent of the intensity of fishing. The fishing rate goes from F=.2 to F=.15 and F=.8 to F=2.0. This is a tremendous range.

   Similarly the abundance of market oysters did not appear to vary with fishing intensity. In other words, fishing intensity, even very high fishing intensity, had no effect on the oyster population as modeled by this ODM. There is some evidence that if harvest mortality were reduced/eliminated some selection occurs for disease resistance – and hence a lower potential natural mortality. **The Panel finds it difficult to accept that fishing intensity has no effect on the oyster population estimates, and would like a more detailed explanation before accepting this model result.**

   Alternative 1 (states are separated in Figure 8)—These Figures suggest that the oyster population in Virginia is several times greater than that of Maryland. How can the oyster population grow in Maryland if recruitment is constant over a ten-year period? Why are the error bars so much greater in Virginia than in Maryland? These are portrayed to be the result of 40% harvest rate. What would happen at the 20% harvest rate?

   The starting population is based upon observed 2004 fall survey data in MD and VA. In Figure 10 it appears that there are 10 times more spat in Virginia than in Maryland; there are 10 times more small oysters in Virginia than in Maryland; and there are twice as many market oysters than in Maryland. Is this simply an artifact of the demographics in the 2004 oyster population?

Specific Issues:

- Introduction – The Introduction sets the stage for the report. It emphasizes the importance of the flow field. It points out that the flow field is important because 1) the eastern oyster and the Suminoe oyster *may* have different vertical swimming behavior; 2) high salinity increases susceptibility to disease; 3) freshets can have a negative effect on oyster populations; and 4) the flow field distributes oyster eggs and oyster larvae until they settle.

  The Introduction appears to justify the fluid dynamic model. The justification results from assertions on the dynamics of the oyster that may not be warranted. The different vertical behaviors are cited as "**may**". While disease susceptibility and other life history variables are related to disease, it is not generally true that low salinity or high salinity is necessarily good or bad as evidenced by the Maryland fall survey. Finally, we are not sure that the fluid-dynamic model resolves the small-scale eddies in the vicinity of oyster reefs.

  While we have no particular criticism of the fluid dynamic model, the ODM report does not explain how the variability in the fluid dynamic model impacts the results. It is obvious that the fluid dynamic model generates noise in the demographic model, and it is not clear whether the noise is correctly modeled?

  The study would have been much more informative if it was presented without the fluid dynamic model because, as stated above, the model seems to simply generate noise.

- Data Sources and Parameter Estimates:

  1) *Starting Population (Note: This section describes the Maryland survey and Maryland data.)* – The users of the report need to know that the Maryland survey is highly variable because the length of the dredge tows is not standardized. Furthermore, as shown by Chai (Chai, et al 1992), the dredge survey underestimates oyster density by a factor of 20. Comparisons need to be made between observations in the Chai report and the 10% efficiency used to expand the Maryland population. Furthermore, the statistical interaction suggests that across-age group comparisons are tenuous, even though these differences may not be large.

     There is considerable asymmetry in the data base in that comparable data sets from Virginia are not available; and as a consequence, one wonders how representative the results are if Virginia data are not included.

     In particular, it appears that James River data is used to extrapolate to the entire Virginia portion of the Bay. Do all oysters in Virginia grow more slowly than Maryland oysters? Is the enhanced recruitment in more saline waters in Maryland replicated in Virginia? How does the model account for the observed higher recruitment in Virginia?

2) *Available Habitat* – It is not realistic to reduce Maryland's oyster bar habitat equally across all regions. Sedimentation rate may be much different in the upper tributaries compared to the lower tributaries. In addition, the lower part of the tributaries may experience a complete loss of habitat in deeper depths due to anoxic conditions

   This is a crucial section because the extent of habitat, the quality of the habitat, and the capability to modify the habitat are absolutely critical to any increases in oyster population. The habitat is also absolutely crucial to the demography of the oyster.

   This section is not adequately discussed. There are no charts of the distribution of habitat.

3) *Environmental Conditions* – It is not clear in the report if the model is running with real observed data on what period of time, or if it is working with scenarios of dry or wet summers. In the latter case, it is not clear how the probabilities have been calculated.

4) *Fluid Dynamic Setting* – It is not clear from the report whether the hydrodynamic model contributes signal or noise. If it is noise, then how important is the noise? If it is signal, then what is the signal? The sensitivity to the fluid dynamics model appears to be negligible (Table 4). But surely the variability generated by the fluid dynamics model complicates the comparisons among alternatives. If this is true, as it seems to be, then the report under estimates the value of the most critical alternatives. The report, for example, does not give the exposure time of eggs and larvae to different environmental conditions.

- Recruitment – The approach used is not orthodox. The orthodox approach is to plot recruitment numbers against spawning stock.

  Given the range of assumptions and the variability associated with fecundity, wouldn't it make sense to compute the spawning stock biomass and spat separately for both states based on MD and VA survey estimates corrected for efficiency? Plot spat against female biomass and then fit a model to it. When one is dealing with order of magnitude differences, it does not seem that the Kennedy correction is worthwhile.

  A main point is that stock and recruitment relationships are not usually a straight line and the actual data reflect that the 3:1 ratio is rarely met.

- Growth – It is not clear how the James River growth data translate to all of Virginia waters—How good is the length-weight relationship (Eq. 10)?

Conclusions

The ODM model and models like it are easy to criticize. The problem lies in the fact that the intended comprehensive modeling efforts are often, by their very nature, based on data sets that have been collected for purposes unrelated to quantitative analysis or modeling (e.g. the Maryland fall survey upon which many of the conclusions are based or Virginia estimates of biomass). In the ODM, relatively small and restricted data collection programs are used to make inferences to larger regions or temporal settings (e.g. making inferences on Virginia waters using data collected in Maryland or using James River growth estimates to infer oyster growth for all Virginia waters). And, finally, in some instances, comprehensive data sets data simply do not exist (e.g. abundance estimates in Virginia waters). The validity of these extrapolations is not certain.

Studies providing data used to estimate input parameters for the demographic models can contain many assumptions so that they result in conclusions that are not definitive. These studies are ambiguous or equivocal (e.g. oyster growth; natural mortality; and the biology of *C. ariakensis*) and reduces confidence in the comprehensive model. In other words, the developer of the comprehensive model is afforded many choices and guesses. To focus on this issue, consider that the so-called confidence intervals in these studies depend on the choices made by the model builder and may have little to do with the real world.

Cumulative uncertainty in the model is high. The recruitment pattern of *Crassostrea virginica* has not been well described. Differences between *Crassostrea virginica* and *Crassostrea ariakensis* are mainly in their reproduction, growth rate, disease resistance and salinity tolerance. As the recruitment is not well predicted, the Demographic Model will be a poor tool to predict the consequences of an importation of *C. ariakensis* and to analyse the competition between the two species of oysters. Furthermore, as the reproductive pattern of *C. ariakensis* is not included in the model, it is not possible to evaluate the risk to become an invasive species.

It is for these reasons that any study intended for high-stakes decision-making needs to explore the effects of the assumptions and less-than-perfect data on the modeled outcomes. The present model is too complicated for the available data and concepts. Beyond the assumptions and less-than-perfect data sets, the model introduces its own complexities that make the interpretation even more difficult. To name a few, there are the representations of growth, stock and recruitment, and the impact of the hydrodynamic model.

It is fair to say that the explorations are cursory. Components of the ODM are neither adequately explained nor transparent. At the end of the day, is the report too pessimistic or optimistic about restoration efforts? It is hard to say.

Does this mean that the report needs to be redone? It is our belief that pushing on with this approach will refine the degree of uncertainty, not reduce it. It is difficult to imagine that useful information on *C. ariakensis* will devolve from a model that cannot be validated within “an order of magnitude” for the intensively studied *C. virginica*.

We believe that the model can serve as a guide for making management decisions about the response of the native oyster population under the range of management alternatives under evaluation in the EIS. However, it is important to note that the modeling exercise has highlighted our limited ability, even inability, to distinguish between these options. We must seek other approaches to their evaluation, but this will require significant improvements to MD and VA's data collection programs.

What is the next step? The EIS needs to move forward, but a branch in the decision process needs to be articulated. Despite our concerns regarding the particular modeling approach, it seems fairly obvious that a restoration effort would have a "substantial" (can we get to 1920-70 level?) benefit on the oyster population in some areas of the Chesapeake Bay. It also seems reasonable that the benefits of the restoration effort would be proportional to the investment. In other words, from the point of view of risk assessment, it appears that the task is done. Even without the model there is intuitive agreement that restoration—at least as far as *C. virginica* is concerned—can be more successful is some areas of the Chesapeake Bay if strategically implemented.

The real risk, or perhaps more correctly, real uncertainty, relates to what is meant by restoration. The activity of restoration can be perfunctory or real. Real restoration is going to require rebuilding oyster reefs. As assistance to the design of restoration efforts, paper studies (we believe some of these studies have already been conducted) should assemble the following information:

- Building oyster reefs in optimal locations using shell, or alternative materials (i.e. slag, concrete). (Use alternate materials to rebuild structure of reef.)
- Evaluate the sanctuary program; what are the results? Did it work or did it not? What are the reasons?
- Evaluate growing oysters off the bottom to definitively determine whether bottom contact slows nutrition and increases susceptibility to disease.
- Determine the properties of a good reef and a bad reef independent of salinity.

As far as the introduction of non-native oysters is concerned, it does not appear that there is a scientific answer to introduction or non-introduction. Chesapeake Bay, and particularly its benthic habitat, has been modified to an extensive degree. While there are some risks associated with the introduction of the non-native oyster, it needs to be recognized that worldwide a significant component of oyster production results from non–native oysters. Simplistic scenarios involve the non-native oyster not succeeding and then the effects would be minimal. On the other hand, the non-native oyster might be very successful and the results would be achieved. It is problematic whether the native and non-native oyster will compete with one another. It is further problematic whether competition between two species can be evaluated absent inserting the non–native oyster in the real environment.

In any event, the reefs need to be rebuilt, and it is only a matter of time before introductions—accidental or otherwise—occurs. This leads us to believe that controlled triploid introductions should continue while working extensively to rebuild the native population.

Most importantly, oyster restoration can only succeed with a coherent well-managed program. A Program Plan needs to be developed. The Plan should carefully analyze what is known, and particularly is not known, about oysters in Chesapeake Bay. It should determine the need-to-know issues separating those issues from simply interesting research. It should specify how to begin immediately with the restoration effort. It should specify detailed inputs and outputs, costs and results. The Chesapeake Bay Oyster Development Program will be large and successful, owing to its adoption of "putting a man on the moon" philosophy. The management of the program could be bi-state, but greatest success and efficiency would seem to result from the creation of a single management authority.

Appendix I - Additional Reviewer Comments:

The draft report of the July 12 Oyster Advisory Panel (OAP) oyster demographic model peer review was prepared by Dr. Brian Rothschild (OAP chairman) and sent to all OAP members for review. Comments from OAP members who attended the July 12 review - Dr. Michael Roman, Dr. Maurice Heral and Dr. Roger Mann - that were specific to topics discussed at the meeting were incorporated into the draft report. More generalized review comments from these OAP members as well as comments that go beyond the charge of the Oyster Advisory Panel are included in this Appendix.

Three OAP members - Dr. Eric Powell, Dr. Mark Berrigan and Dr. James Anderson – did not attend the meeting. Dr. Berrigan and Dr. Anderson did not comment on the draft because their areas of expertise do not include population dynamics of fish stocks. Dr. Powell's comments are provided below.

Dr. Eric Powell

In general, I agree with the draft report and with the comments attached from other committee members. In addition to those, I list the following concerns.

- The ODM report does not deal explicitly with shell budgets. Much of what we know now on this issue has come to light subsequent to the beginning of the EIS process and so it is understandable that this issue is not adequately raised. However, it now should be and this should be clearly indicated as a deficiency in the information necessary to develop a restoration plan for Chesapeake Bay. We now know that the taphonomic loss rates for oyster shell are relatively rapid. As a consequence, as abundance declines, and the number of shells added to a bed declines, the loss rates will exceed the addition rates and the bed will begin to degrade. For Delaware Bay, we can now calculate the shell budget for each of the major beds (see 2007 SAW report). The numbers show significant and continuing net loss of shell at abundances permitted by Dermo disease. Overall, Delaware Bay is losing about 1,000,000 bushels of shell a year, perhaps a little less.

  No restoration program in Chesapeake Bay can be successful without a shell budget that provides an estimate of the current status of the beds. If shell is being lost, the number one requirement is to stabilize the present footprint by adding shell. Restoration cannot proceed if deterioration is not first prevented. Stabilizing the present bed footprint needs to be done before any new beds are created or any other restoration process moves forward.

Given an estimate of the amount of shell that would need to be added to the present bed footprint, we then need to ask the question: is that much shell or alternative substrate available? And, how much will it cost to complete that addition rate yearly forever!? Then, we should ask the question: are there any approaches by which that yearly addition rate requirement can be ameliorated by the natural production of shell on the bed?

This leads to comments 2 and 3 that follow.

- Simulations of the influence of fishing on shell budgets show that fishing always results in a loss of shell. At the very least, the shell removed by the fishery should be replaced so that the fishery is shell neutral. This can be done with a shell tax on a bushel harvested, as is done in Delaware Bay. Otherwise, the bed's need for shell puts a constraint on fishing because animals need to die naturally to provide shell to the bed. Estimates of the impact of fishing cannot be fully evaluated except within the context of the shell budget.

- We need to know the taphonomic rate for ariakensis shell. Because these shells tend to be thinner, it is likely that they degrade faster. However, we know that very similar shells degrade at very different rates. Rangia degrades rapidly, Mulinia very slowly. Lucina atlantica degrades rapidly at petroleum seeps, whereas the other Lucina at petroleum seeps is nearly inert. C. virginica shells degrade relatively rapidly, but the taphonomic rate half life is at least as long or longer than the generation time of the animal producing the shell (before disease). That means that the animal, through normal population dynamics processes, can replace lost shell if abundance is maintained. If the ariakensis loss rate is more rapid, then this animal cannot produce reef at a rate adequate for long-term restoration purposes. The use of ariakensis to restore natural oyster reef cannot be evaluated without knowing the shell degradation rate relative to the expected generation time. Maintaining the oyster bed is the single greatest cost in restoration and the single task that can never cease. If ariakensis cannot materially reduce the cost or time commitment, then there is no reason to introduce the animal for restoration purposes.

- The insensitivity to fishing in the model is a cause for concern. In Delaware Bay, we know that fishing mortality rates exceeding 0.2 have routinely led to population declines. This is based on good quantitative data over a 54-year time series. Therefore, I am very suspicious of any model that does not show that oyster population dynamics is sensitive to fishing rates. Note that the rise in mortality rate with MSX/Dermo disease is from a background rate of about 10% per year, likely the historical mortality rate for C. virginica, to a population average of about 20% (higher downbay, lower upbay). That increase is enough to materially reduce total abundance, as we all have observed. This suggests that an increase in Z of about 2-3 cannot be sustained by the population as a whole without a demonstrable decline in abundance. There is no reason why death by fishing should differ from death by natural causes in this calculation. Either the animal is sensitive to shifts in mortality or it is not.

- Alternative 3, p.3 is an all or nothing alternative. The alternative should include regulated fishing (a TAL) that will permit the population to achieve a positive surplus production during the year. That way, the population will always tend to grow, even without restoration. We calculate (project) surplus production for each major oyster bed and use those projections to fix a TAL for Delaware Bay. I cannot see how any restoration program in Maryland/Virginia can succeed without a similar calculation to identify an allowable F.

- The comment about fishing intensity and model sensitivity needs to be highlighted. We know that a doubling of natural mortality by disease causes significant drops in abundance. That experiment has occurred naturally many times. To think that fishing mortalities of the range tested would not have commensurate effects is incomprehensible. The conclusion must be that the model is misspecified in some way with regards to fishing and that these simulation results should be discounted in further use of the report.

Comment [JFJ1]: This seems off the record, should it be deleted?

- A quantitative oyster population survey in Chesapeake Bay is strongly recommended. In no way can restoration proceed without a modern survey program that produces quantitative results.

Dr. Mike Roman

- Fertilization – An additional adjustment will be made for fertilization interference between Suminoe and Eastern oysters – I do not think investigators have shown this

- Natural mortality **-** Although one may assume that Asian oyster natural mortality due to Dermo and MSX would be less than the native oyster – higher predation mortality due to a thinner shell should be recognized.

Dr. Maurice Héral

- Recruitment **-** The assumption that a stock recruitment relationship occurred is not well established for the oysters in the literature. Of course, to have reproduction, you need to have some breeding population, but you can have tremendous amount of spat with a small population of reproducers and in the opposite even if you have a large amount of reproducers it is not at all a guaranty for a good spatfall. Recruitment in the case of shellfish, is function of an environmental window including hydrodynamic factors such as retention area, dispersion function of currents and wind effects, including abiotic factors such as salinity, temperature, oxygen depletion and biological factors as quantity and quality of planktonic food, larvae diseases.

  The larval transport model was used to distribute larvae within a given geographic area based on the distribution of the spawning stock and the effects of flow. It would be informative to include a salinity dependent larval mortality rate and compare the number of observed spat with the output of the stock recruitment relationship. It would also be informative to compare output for salinity dependent mortality runs with the output of the larval hydrodynamic model as currently configured.

- Fecundity**,** oysters are not spawning eggs but gametes, which could be fecundated in the water column, giving eggs (larvae). The way to calculate the spawning biomass with the fecundity is a bit too complicated and induced large incertitude. Furthermore, in oysters it has been demonstrated in hatcheries that largest oyster or older one does not present the higher survival rates of larvae.

- Growth - No comment, except that it is done for shells without integration of temperature, recent DEB models are predicting growth rate of the flesh, of the shell and of reproductive effort.

Dr. Roger Mann

- EIS Goal Statement - The Goal Statement of the EIS includes reference to returning the oyster population of the bay to a level that would support ecological and economic services commensurate with those provided in the period 1920-1970. I submit that this is a confusing statement for several reasons. It homogenizes the bay as a unit or limited series of subunits. The bay is a complex series of environments so the homogenization approach will fail to produce useful simulations in most all instances. Some parts of the bay may be suitable for some restoration goals, other parts for other, very different goals. We should consider this mosaic of real estate for location specific activity. This is not obvious in the approach of the demographic model, and not evident in the output.

  There was, at the time of developing this goal statement, a lack of consideration for the fact that the dual goal(s) of ecological and economic services may not be attainable. I suggest they are mutually exclusive. The longer we consider this suggestion the more rational it appears. There is not enough surplus production to support a fishery if the intent is to make a self-sustaining population (see below). I fail to understand how the model seems so insensitive to fishery effort if the lack of surplus production is appreciated.

  Restoration needs to be defined in the context of EIS goals. I submit there are two optional, but mutually exclusive restoration goals. Each of these must have a clear definition, and any "restoration plan" to achieve those goals must have timeframes, deliverables, cost estimates as both upfront and continuing amounts, and evaluation plans.

- Ecological restoration is the provision of ecological services by a **self-sustaining population** within a defined footprint. Ecological services comprise benthic-pelagic coupling and the physical provision of complex, three-dimensional habitat structure. The attributes of oysters to improve "water quality" through filtration are subsumed within benthic-pelagic coupling. Ecological restoration includes increase in habitat complexity and resultant enhanced species richness. Oysters have pelagic larvae with the capability of lateral dispersal. Thus apparently isolated populations, extant as reefs or the contiguous footprints of former reefs separated by regions devoid of either live oysters or characterized by sedimentary habitat unsuitable for oysters, can be connected as subunits of a larger population (metapopulation). It is tempting but erroneous to consider all oysters in the Chesapeake Bay as a single metapopulation with open recruitment from a limitless or undefined spatial region. Thus the metapopulation comprises exporting source populations and importing sink populations, differentially distributed from year to year imposing complex structural requirements for stability even in the short term. Metapopulations are severely spatially limited at this time by the end products of past harvest practices and the current disease pressure on unselected stocks.

A prerequisite for ecological restoration is that the end product MUST be SELF SUSTAINING. The restored population MUST exhibit recruitment in excess of mortality to insure a vibrant population, and MUST exhibit shell production to insure accretion of habitat. Without these attributes a population is not self-sustaining and will not provide **continuing** ecological services – it will degrade and go locally extinct without continual addition of substrate and/or broodstock – and that is not allowed. Without these self-sustaining attributes any investment in alternate substrates is completely foolhardy. With these attributes the addition of alternate substrate is arguably unnecessary except, in rare cases, as a nucleus to restart a formerly present population. Substrate addition alone will do nothing for a population that has the inability to proffer a positive accretion budget over time.

- <u>Fishery restoration</u> is the provision of a sustainable economic resource. **It does not require ecological restoration** although it may contribute to it. It is possible to sustain an economic resource at less than maximum sustainable yield through careful management based on an understanding of recruitment and mortality rates **-** this is routinely accomplished with finfish during rebuilding plans. Both recruitment and mortality rates are difficult to estimate in oysters, and rarely examined with adequacy in extant exploited populations. Fishery restoration can be supported in its entirety by direct stock enhancement procedures such as hatchery seed production and deployment. Such exploited stocks are ephemeral and may not by themselves supply desirable long-term ecological services because, by definition, they are destroyed at harvest. The more effective the harvest, the more complete the destruction. There are disease related reasons why complete harvest may be desired under some management scenarios and as this extreme is reached the dual option of exploitation and ecological restoration obviously becomes untenable. THE YARDSTICK FOR SUCCESSFUL FISHERY RESTORATION IS THAT FOR EACH DOLLAR INVESTED MORE THAN ONE DOLLAR IS RETURNED. THIS HAS LITTLE, IF ANYTHING, TO DO WITH ECOLOGICAL SERVICES.

These are clearly different restoration definitions and goals. Do not confuse them. It is not clear to me what end point the model was pursuing (or was directed to pursue) so we cannot evaluate its utility in either case. How do they fit in the continuing debate?

<u>C. Virginica Ecological Restoration</u> – It is naïve to believe we can affect an ecological restoration bay wide. In regions where disease pressure is high the mortality rate of oysters is such that they will not form long lived, self-sustaining populations, even with the addition of substrate to rebuild habitat. Oysters do not recruit every year, so year classes will be missing, and eventually the ability to generate habitat will fail. Local extinction will result. In SELECTED AND WELL TARGETED LOCATIONS the possibility arises that local circulation will retain larvae to locally enhance recruitment. If

these occur in salinity regimes where disease impacts are lessened the options to maintain populations with multiple year classes remains. This is why the James River population persists without any "restoration" activity. As with real estate only three things matter – location, location and location. We have only one such ongoing attempt to simulate such a situation by very large scale restoration on the scale of Brian's suggested proof of concept – in the Great Wicomico River in VA. In order to drive the Great Wicomico system massive habitat rebuilding was required with broodstock addition to force increased recruitment assuming a broodstock-recruit relationship (in fact the genetics data so far do not support the contention that the observed increase in recruitment originates from this additional broodstock so the interpretation of the proffered broodstock-recruit relationship is open at this time). This approach has limited application in the bay. It has location prerequisites. Where it can be pursued it should be investigated, not with single reef construction but with whole river basin habitat restoration. This will be very expensive and the time frame for response may be many years. It is not to be undertaken lightly. It is foolish to try this approach where it is already compromised by salinity, disease and recruitment limitations.

C. virginica economic restoration – is about setting a dollar target and working towards it with investment – assumed to be continual although not always constant – in terms of habitat (shell) and/or broodstock and/or spat on shell as a short term response to low natural recruitment. The end point is harvest. Dollars produced must exceed dollars invested. This is very simple. Implementation can be a simple opening and closure of a resource on a time schedule, or, as we propose for the Rappahannock River in Virginia, a rotational harvest. Other options are limited only by imagination. The geographic limitations for this are probably far less than that for ecological restoration, but there are still places where the disease pressure make this untenable at the outset. So there is former oyster bottom in the bay that we cannot reclaim with the native species unless that species suddenly has very marked improvement in its disease resistance – and this is very unlikely.

C. virginica aquaculture – is up and running. It is going to expand as hard clam culture did. The issues here are a regulatory environment to foster it and suitable guidelines to develop best management practices to moderate environmental impacts (consider analogy of Canadian mussel culture in Nova Scotia). This should be a bay wide opportunity. MD is way behind VA here, but they will catch up when the MD watermen see how much money the VA former watermen are making in this business.

C. ariakensis ecological restoration – The demographic model cannot be used to evaluate a ***C. ariakensis*** ecological restoration for the reasons that Brian articulated during the review session. We can use a simpler approach noting increased growth rate, disease resistance and filtration capabilities of this species in comparison to the native species. This may generate support for a diploid introduction. There is a large amount of information being generated on this species; however, IF THE NON NATIVE FAILS THE LITMUS TEST OF BEING ABLE TO GENERATE SUFFICIENT SHELL TO ACCRETE HABITAT THEN IT FAILS THE PREREQUISITE FOR ECOLGICAL RESTORATION. This is a calculation we should attempt. If we cannot make this positive then all else does not matter. As a footnote there is little interest in the option in Virginia at this time – the industry has looked at this species and decided its real value is in aquaculture (see below).

C. ariakensis economic restoration – The same questions apply as for the native species, BUT the disease resistance and growth parameters are different. So we can work this out on a money produced versus money invested balance, and consider using some that of unusable (by the native species) formerly productive bottom. This is not about ecology, on the other hand if we try growing the non-native in higher salinities there is no guarantee that predation pressure will not be increased – so they survive the diseases only to get eaten and we still lose money.

C. ariakensis for aquaculture – This is THE emerging option and a very attractive proposition for triploid *C. ariakensis* as a 9-month crop. 3n technology is continually progressing, as is experience with off bottom culture. 9-months produces a crop of desired size and limits all the reproductive concerns. I think the attendant technical challenges of effectively eliminating reversion to 2n are surmountable and will allow economic diversity within the culture industry. Again, the yardstick here is money. The ecological impacts and/or benefits are as for the native species (see above) and require development of best management guidelines and supportive regulatory infrastructure. This is feasible.

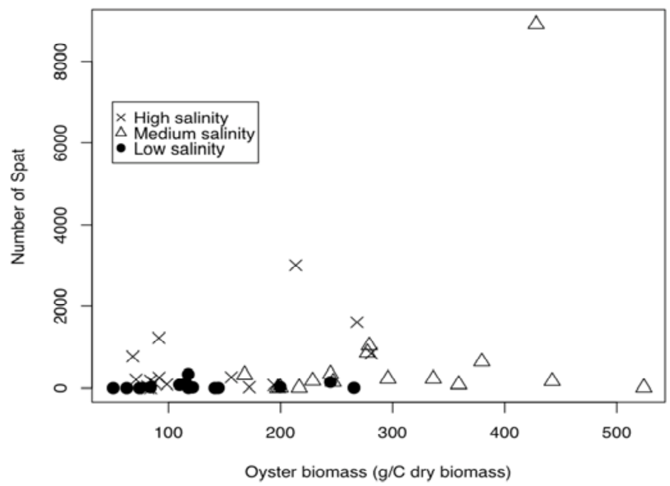
Oyster Demographic Modeling Team Response to the OAP Report (October 5, 2007)

The report, *A Demographic Model of Oyster Populations in the Chesapeake Bay to Evaluate Proposed Oyster-Restoration Alternatives*, has been revised (dated 5 October 2007) in response to comments provided to the Oyster Demographic Modeling Team (Team) by the Oyster Advisory Panel (OAP) (final report dated October 1, 2007). This document provides a summary of the major OAP review comments and the manner in which those comments were addressed. Not all comments in the OAP report are addressed here, since many did not apply to the model itself, but were related to other elements of the EIS process and oyster restoration efforts.

The initial portion of the OAP report states that the alternatives being addressed in the EIS may not be adequate or appropriate. Several other portions of the report address management approaches and other general topics. These observations do not relate to the demographic model and, thus, are outside the purview of the Modeling Team. The EIS Management Team and Project Delivery Team (PDT) are the appropriate entities for responding to these comments.

The portion of the OAP review applicable specifically to the demographic model identified a number of limitations or weaknesses of the model, including its use of restricted input data sets, constraints precluding appropriate validation, and the large magnitude of uncertainty in model outputs, each of which is addressed further below. Although many of the specific comments related to these issues are now addressed through better explanation of model constructs and interactions, the Team is in general agreement with the OAP on most issues. In most cases, the modeling team was aware of these limitations during model development. However, the team believes the demographic model represents the only feasible tool for making relative comparisons among EIS alternatives for restoration of Eastern oysters given the complexity of oyster life history and population dynamics within Chesapeake Bay. The model simulates population changes that result from differential recruitment, growth, survival, harvest, and habitat improvements, with effects integrated over nearly 8,500 bars distributed throughout different salinity zones in the Bay. These calculations cannot realistically be made using simplified methods because oyster population vital rates interact in complex ways, which can only be captured in an integrated model. The comparison of EIS alternatives necessarily requires the use of some type of model, whether it is narrative, semi-quantitative, or quantitative. No matter how an assessment is conducted, it will necessarily require the use of the existing limited data, be un-validated, and exhibit great uncertainty in results. We have revised the text to describe more clearly the sources and magnitude of uncertainty encompassed in the model.

A key issue raised in the OAP review was the adequacy of the recruitment submodel within the demographic model. One reviewer (Héral; p. 15) stated that the existence of a stock-recruitment relationship is not well established in the literature. If no stock-recruitment relationship exists in the Chesapeake Bay, then recruitment cannot be estimated in the model. This is because no reliable estimates of absolute abundance are available for the Bay, as the reviewers point out. Therefore, no realistic estimates of true spat production are known from which to select random recruitment events. Conversely, the data reported in the model documentation indicate that a stock-recruitment relationship does exist (Figure 5 in the model documentation report) but is punctuated by episodic large spat sets. The OAP report suggests that a simpler approach to estimating recruitment would be to model the relationship between oyster biomass and number of spat recruited. This cannot be done directly, because oysters are not weighed in Maryland. Biomass may be estimated from shell height, as we have done in the model. There are three major differences between this approach and the one now included in the demographic model: (1) the model now accounts for the fact that larger oysters tend to be more fecund than smaller oysters; (2) the model accounts for sex ratio changes as oysters grow; and (3) data from a subset of bars where length is measured were expanded to leverage a larger data set where length was measured to the level of small or market size classes. Although these additions do make the recruitment model more complicated, they almost certainly improve its precision. We do not include additional variance in the model for adjustments 1 and 2, and they correct for well-documented relationships. Adjustment 3 may add some additional uncertainty to the model, but is important because it allows for the inclusion of a much larger data set with potentially different size structures on bars. We explored the procedure suggested by OAP using the subset of Maryland bars where oyster height was recorded, as depicted below. The resulting pattern was similar to the relation between standardized oysters and spat now included in the model, but with fewer data points (Figure 5 in the model documentation report). This indicates that the additional adjustments did not have an overwhelming effect on the resulting submodel, and that model results would likely have been similar using either method.



We agree that stock-recruitment relationships do not normally follow a straight line (P. 10, par 2 of the OAP report), but when episodic large spat sets are included, such a model is parsimonious and fits the observed data well (Figure 5 in the model documentation report). The obvious limitations of such a model are addressed in Section 8.0, par 5, of the revised report. We also agree with the reviewer that the 3:1 ratio of spat to spawners is rarely met, but note that it is rarely met by definition; the line indicates a statistically rare event. This reviewer may have misread the documentation here. We believe the data set from the James River, the only reliable long-term estimates of absolute abundance available, confirm that the recruitment submodel is behaving reasonably. Estimates were within a factor of 2-4 of the field values, except for the first several years simulated and an unusually large spat event set in year 8.

Reviewers did not believe that the model fit the James River data well. The modeling team believes that the explanation in the first draft of the model documentation report for how the James River data were used to establish the adequacy of the model may have been misleading. Although the report indicated that there were no suitable data for use in validating a model that projected Bay-wide oyster populations, this section of the report may have mislead readers to believe that what was being presented was in fact a validation. In reality, the authors' intent in comparing output from a model developed for Bay-wide estimates to the tributary-specific data from the James River was to provide a very general check of model performance. The James River data were the only long-term comprehensive data set available for such a purpose. Recruitment and mortality rates in the model could not be parameterized specifically for the James River, because they were constructed to depict average Bay-wide values. Thus, projections were not expected to match the details of the James River perfectly. The Team erred in including a statement in the draft report indicating that model results within an "order of magnitude" of James River data would confirm that the model was acceptably valid. The intent of the check was to determine if large differences between model projection and James River data were evident (i.e., order of magnitude) at various points over the projected time period. Such difference would suggest that model parameterization was completely incompatible with a known population structure, and/or indicate an error in the model construct. In fact, most model values were within a factor of 2 to 4 of actual values, a range that the OAP review indicated would be reasonable to expect. The section has been revised to make the "reasonableness" argument more clearly, and section title has been changed to emphasize that it is not a true validation.

The OAP suspected that harvest was not specified correctly in the model because varying harvest rates had little apparent effect on results. One problem was that the model output presentation had been focused on showing trends, but did not allow for easy comparison of final results among alternatives. The report also reported predicted numbers instead of proportional changes. This may be misleading given model uncertainty, as the OAP has described. We have revised the figures to first compare all alternatives at the end of year 10, expressed as percent changes from the starting population (Figure 11 in the revised report). These results make it clear that there is an effect of harvest, and the effect increases as populations increase. We then report the trends and data for entire runs more clearly with combination table/graphs (Figures 12-15 in the revised report). Predicted numbers for the starting population are now also reported in Table 1 of the revised report to allow for easy conversion between percentage changes and numbers.

The effect of harvest is still less than might intuitively be expected for several reasons. The most important cause is that harvest does not simply simulate a large removal of a healthy population, as does an increase in natural mortality due to disease; harvest occurs as an additional removal of remaining larger oysters from a population that has already experienced relatively high natural mortality rates due to disease. Under these conditions, the year class that has just reached market size, but has not yet experienced natural mortality or harvest rates for market sized oysters, composes a large proportion of the total number of market sized oysters. A comprehensive explanation of the effects of varying harvest rate on project oyster population size is presented in Appendix F of the revised report. As noted in the text of the revised report (Section 9.0, first paragraph), we do not suggest that fishing is unimportant in controlling oyster populations in the Bay. Fishing becomes an increasingly important factor in limiting population growth as natural mortality decreases or the population size increases. This means that managing harvest will likely be necessary to achieve the restoration goal. Further, fishing may reduce the development of disease resistance through natural selection, or have other effects that are not modeled, as described in the text.

Given the large uncertainties in the model outputs for *C. virginica* EIS alternatives, the OAP suggested that modeling of potential outcomes of *C. ariakensis* alternatives not be conducted. After reviewing the OAP report, the modeling team concurs that model outcomes for *C. ariakensis* may be misleading because not all factors affecting the fate of this species in the Bay could be quantified and incorporated into the model. Instead, the modeling team believes it is appropriate to use sensitivity runs for *C. virginica* to inform speculation on possible outcomes of *C. ariakensis* alternatives, given certain assumptions. The team proposes to take that approach for all of the model parameters for which research studies have provided data (e.g., mortality rates, growth), but without attempting to predict any interactions. Phenomena not accounted for in the model (e.g., higher predation of *C. ariakensis* by blue crabs) that would either enhance or reduce potential growth of *C. ariakensis* populations could then be incorporated into a narrative discussion of the potential outcomes of the alternative. We have accordingly removed the section describing proposed parameterization for *C. ariakensis* from the revised report.

We provide two lists of specific issues that were extracted from the OAP report summary and review comments of individual OAP members. The first is a list of issues that we have addressed in the revised report and explanation of how the issue was addressed. The second is a list of issues, which could not be addressed, and an explanation of why no response was possible. The page and paragraph of the OAP report on which the issue appears precedes each of the issues.

OAP Issues Addressed in the Revised Model Documentation Report

P 2, par 4. *Model scenarios are not documented adequately* – We have added a spatial figure with bar locations and starting population densities (Figure 1). Note that Appendix E already has maps and numbers for shell and seed plantings under each alternative.

P 5, bullets 1-2. *The age structure is not sustainable* – The comment is based on the assumption that there should be more spat than small oysters, and more small oysters than market-size oysters in a stable population. We explain the apparent inconsistency in section 6.0, last paragraph. The major reason is that small and market-size oysters represent more than one year class. An average oyster remains in the small size class between 2 (mean size 70 mm) and 3 (mean size 88 mm) years in Maryland, and for about 4 years (mean size 71 mm) in Virginia. The market size class includes all remaining cohorts. We have also added the specific growth equations to Figure 6. A second partial explanation for small differences in abundances among size classes is that survey counts of spat are estimates for late fall, after most of the expected annual mortality has occurred (i.e., the juvenile bottleneck). We also note that if the model did not have a sustainable structure, populations could not remain relatively stable for ten years as they did for simulation of alternative 1.

P 6, bullet 1. *Alternatives cannot be distinguished because confidence intervals overlap* – We clarified and expanded the discussion to indicate that what are presented are probabilities in a weight-of-evidence approach, not hypothesis testing (Section 8.0, second paragraph). The wide confidence intervals reflect real-world uncertainty in individual outcomes, but do not invalidate probabilistic comparisons among the outcomes of the alternatives.

P 6, bullet 2. *Confidence intervals are asymmetric, and most are positively skewed* – We have provided a more comprehensive explanation for this result in the text (Section 6.0, first and second pars.). The positive skew generally occurs because the model includes episodic large spat sets. Confidence intervals are negatively skewed in Maryland (opposite) because wet years cause low recruitment and greater freshet mortality, but there are few large-recruitment events.

P 6, bullet 3, P 14, item 4. *The measure of harvest used is unclear* – We clarified that we use the exploitation rate (*F*; the proportion of a population at the beginning of a given time period that is caught during that time period) for winter, after annual mortality has occurred (Section 2.11), and explained how this affects estimates (Appendix F).

P 7, par 7. *How can the oyster population in Maryland grow when recruitment is constant*? – The text has been expanded to indicate that the model takes a several years to reach an equilibrium, given that the parameterization at time step one does not match the starting population used as model input (Section 8.0, par 1). Maryland is particularly problematic because abundance of spat in the starting population is fewer than the number of small or market-size oysters.

P 8, par 3. *The flow field within the estuary simply generates noise* – We have changed the word “may” in reference to the larval transport model and expanded the text. These results have been published in the peer-reviewed literature, supporting the use of the transport model output. There are clear differences in mean survival and recruitment across salinity zones, as demonstrated by the empirical data that we report (Tables 4-5; Figures 5 and 7). If we did not account for effects of salinity, this variability would be included in the model as unexplained variation or “noise”. Simulating the effects of salinity also allows managers to see how the states or different areas of the Bay are affected by different management strategies.

P 8, final 2 pars. *The starting population may be underestimated, and age groups may be captured with different efficiencies* – The uncertainty in the starting population is addressed in the report appendix where methods are presented, but we have included some discussion of the issue in the main text (Section 2.3, pars 2 and 3; Section 2.6.2, par 1; Section 7.0, par 7; Section 8.0, pars 1 and 3; Section 9.0, par 3). We now present model results as percent changes in abundance from the starting population rather than numbers to avoid misleading readers. We have also addressed this issue by depicting the effects of larger changes in the starting population as part of the sensitivity analysis (Table 5; Section 7.0, par 7).

P 9, par 1. *How does salinity affect recruitment?* – We clarified that recruitment is modeled by salinity zone (Section 2.6.2, second paragraph).

P 9, par 4. *It is unclear how weather years were used* – The description of how weather years were used (as a categorical variable with levels dry, average, or wet) has been expanded and clarified (Section 2.4.1, 1^{st} and 2^{nd} pars).

P 9, par 5. *How is the larval transport model affecting results?* – The major reason for incorporating LT model inputs into the demographic model was to account for potential differences in the transport and distribution of larvae of *C. virginica* and *C. ariakensis*. Sensitivity analyses indicated that the LT model did not have a large effect on model outcomes because small numbers of spat actually move into different basins. This has been clarified in the revised report (Section 7.0, par 5).

P 15, par 1. *Fertilization interference has not been demonstrated* – We had planned on using data from the NOAA-funded Bushek et al. study of fertilization interference. The section has been deleted because the model will not be used for evaluating *C. ariakensis* alternatives.

OAP Issues That Could Not Be Addressed in the Revised Model Documentation Report

P 4-5. *Relatively rare, unusual bars dominate the population dynamics of oysters* – Data sets with this level of detail are unavailable for most of the Bay due to the nature of the survey designs. The data used in the model most likely provide reasonable averages (i.e., some of the bars sampled are above average, and some below) and thus reasonable outcomes in terms of

Bay-wide projections. With improved survey design, this type of detail could be incorporated into the model in the future.

P 7, last paragraph *The starting populations may not be representative and believable* – We have partly addressed this issue with sensitivity analysis and discussion of model limitations, as described above. MDNR may expand on this issue in the appendix documenting population estimation.

P 9, Par 1, P 10, Par2. *Growth data from the James River are used to model growth throughout Virginia* – The Team concurs that the data are weak, but have been unable to obtain any other spatially-specific data for Virginia populations. Dr. Roger Mann indicated to the Team that growth rates generally are lower in Virginia than in Maryland, and that the James River rates are generally representative of rates throughout Virginia.

P 9, par 2. *The available habitat data may not be appropriate* – MDNR provided the habitat data, and may be able to elaborate on the justification for the data used. However, until a comprehensive Bay-wide habitat survey is conducted, no better data are available.

P 10, par 4. *The model draws extensively on restricted data sets that were not collected for the purpose of modeling* – The modeling team agrees with this characterization of the data sets, but used the best available data. This issue is partly addressed in Sections 8.0 and 9.0, as described above.

P 13-14. *The demographic model does not address shell budgets* – We agree, but modifying the model to address this would require data, which are not currently available for the Bay.

P 15, par 5. *The growth submodel does not include temperature* – Temperature is an important factor controlling growth, but there are no data with which to estimate bar-specific temperature-dependent growth in the Bay on the spatial scale included in the model. Because empirical data have been used to structure the growth submodel, ambient and variable temperatures are accounted for in the variance structure, at least in a general way.

ODM/ERA Principal Investigators Proposed Approach for Using the Oyster Demographic Model (October 31, 2007)

ERA/EIS Team Proposed Approach for Using the Oyster Demographic
Model, Taking in to Account the OAP Model Review

Introduction

At issue is the manner in which the model should be used in preparation of the ERA and the Environmental Impact Statement (EIS), taking into account its limitations identified by the OAP. Because the OAP has also been designated as a review panel for the EIS, it is essential that there be agreement between the OAP and the ERA/EIS Team on the appropriate use of the model before further development of the ERA and EIS continues. This memo presents the ERA/EIS Team's proposed approach for using the model, for consideration by the OAP.

Background on the Original Conceptual Approach to ERA and EIS Development

An ecological risk assessment of a proposal to introduce diploid *C. ariakensis* into the Bay was called for in the NRC report entitled, "Non-Native Oysters in Chesapeake Bay," published in 2004. The NRC report was prepared because such an introduction was being considered by Maryland and Virginia. The scope of the recommended ERA was later broadened when the USACE, in concert with the states, initiated preparation of an EIS that would also evaluate a range of oyster restoration alternatives that did not involve introduction of a non-native species. When the ERA/EIS process was initiated, the general view of the Team and the oyster managers contributing to the ERA/EIS effort was that there was a wealth of available data and information on the biology of the native oyster, *C. virginica*, in Chesapeake Bay, based on over 50 years of extensive study and numerous scientific publications on the species. An oyster demographic model (ODM) created using this existing information was viewed as a tool that could be used to predict the possible outcomes of various alternative restoration strategies for the native oyster. The model was also envisioned as a tool for investigating the potential outcomes of a *C. ariakensis* introduction. This would be done by revising a number of the vital parameters of the model to reflect knowledge of the biology of this species being gained in on-going, concurrent research studies.

The ODM was viewed as being an essential tool for use in both the ERA and the EIS because it represented the only feasible means of projecting the magnitude of potential oyster population changes that result from the combined and interacting effects of recruitment, growth, survival, harvest, and habitat improvements under different management scenarios. Also, a meaningful ecological risk assessment would require that consequences to oyster populations present on nearly 8,500 bars distributed throughout different salinity zones in the Bay be accounted for. Calculations of this nature cannot realistically be made using simplified methods because oyster population vital rates interact in complex ways, which can only be captured in an integrated model.

Given that the ODM would be the primary tool used to compare the outcomes of different restoration alternatives, the approach established for the ecological risk assessment was to employ a Relative Risk Model. Using such a model, potential "negative" and "positive" implications of restoration scenarios on ecological receptors in the Bay are established by considering the spatial dimensions of the restoration alternative outcomes, along with how various receptors (e.g., SAV, benthic invertebrates, fish, wildlife) may respond to changes in oyster abundance and biomass. The spatial characteristics of the outcomes of different alternatives thus represent information essential for the implementation of the Relative Risk Model. The results of the ERA are to be incorporated virtually in their entirety into the EIS and will constitute conclusions regarding the environmental consequences to ecological receptors of each of the alternatives.

ODM outputs were also viewed as being critical for non-biological elements of the EIS. For example, assessment of the potential economic benefits that might result from various alternatives requires an estimation of size of an oyster population as well as an estimated exploitation rate. Such information then feeds into an assessment of the potential social and cultural outcomes of different alternatives (e.g., how many watermen might benefit from oyster population increases under each scenario).

Major Issues Regarding the OAP Model Review and Its Impact on ERA/EIS Development

As noted in the Introduction, the OAP's review of the ODM report was documented in their October 1, 2007 report, and the Team's summary of responses to the major OAP comments was presented in their October 5, 2007 document. As of October 31, no further communications between the OAP and the Team have occurred regarding the report revisions and the manner in which OAP comments have been addressed. The Team hopes that many of the issues raised by the OAP in their review have been resolved to the OAP's satisfaction based on revised presentations of findings, the addition of new information and a number of explanations and clarifications. However, as indicated in their October 5 response document, the Team agrees with a number of the major points made by the OAP.

At issue is whether the limitations of the ODM identified by the OAP are so great, that it has no value as a tool to be used in conducting the ERA and preparing an EIS. The Team believes that some of the factors that might have lead the OAP to draw such a conclusion have been resolved in the revised report, which the Team hopes would lead to a reassessment by the OAP of the model's value as an evaluation tool. The Team does take issue with several of the OAP conclusions, albeit that the comments were made regarding the original ODM report and not after review of the revised ODM report. In the conclusions section of the OAP report (pg. 10), they state: "We believe that the model can serve as a guide for making management decisions about the response of the native oyster population under the range of management alternatives under evaluation in the EIS. However, it is important to note that the modeling exercise has highlighted our limited ability, even inability, to distinguish between these options. We must seek other approaches to their evaluation, but this will require significant improvements to MD and VA's data collection programs. " One point of contention is that while the OAP indicates the need to seek other evaluation approaches, they recognize that such approaches would require data that does not now exist (i.e., it would be dependent on Md and VA improving their data collection programs). Given the current time frame for EIS preparation, the Team is limited to conducting an evaluation of alternatives using only data that exist at the present time. The OAP does not provide guidance on alternative evaluation approaches that could be applied to the alternatives that have been established for the EIS using existing data.

The Team's second point of contention with this part of the OAP conclusions relates to statements about the usefulness of the model for distinguishing among outcomes of alternatives. The Team believes that the ODM outputs for the various *C. virginica* alternatives provide insight into what may be expected with each of the alternatives, at least from a relative perspective, and the associated probabilities of those outcomes. Of particular importance for the ERA, the model provides insight in to the spatial characteristics of population outcomes. It is important to note that the outputs of the probabilistic demographic modeling are distributions expressed as percentiles, not statistical hypothesis tests. The center line plotted in graphs depicting model outcomes over time is the median value of 1,000 model runs for each year. The box and whisker plots in the revised ODM report show the 25^{th} and 75^{th} percentiles of the model outcomes, and the 5^{th} and 95^{th} percentiles of the distributions. For traditional hypothesis testing of controlled experiments, it is conventional to reject the null hypothesis if the *p* value is greater than 0.05. That is, the effect is not accepted if it cannot be demonstrated that the results did not occur by chance alone with a probability of 1 in 20. However, confidence intervals and probability distributions contain additional information that can be used in a weight-of-evidence approach. Such estimates of effect size should always be considered when the analysis does not pertain to a formal controlled experiment. Probability distributions of this nature can overlap but still be very informative (e.g., one alternative may have a 20% probability of yielding outcomes higher that the outcomes of another alternative). Such overlap does not diminish the value of these modeling outputs for evaluating risks. Furthermore, the uncertainty reflected in model outcomes is caused by measured variation in oyster vital rates. It does exist, regardless of whether it is explicitly recognized using the model or not.

Two greater concerns regarding the usefulness of the model outputs are: 1) whether the variability incorporated into each of the model input parameters reasonably represents their true variability, and 2) whether there are additional sources of variability not incorporated into the model. Regarding the first issue, the distributions of many of the model input parameters incorporated into the model were based on existing data or information from the literature; thus, the distributions for those parameters are likely to be reasonable. However, for some inputs, such as the starting population, it is not possible to establish the validity or reliability of the estimates. In those cases, sensitivity runs have been conducted to assess the extent to which inaccurate inputs for such a parameter may affect model outcomes. Results of such sensitivity runs can inform the discussion of uncertainty in model outputs. Regarding the second concern, the Team recognizes that a number of potentially relevant factors are not incorporated into the model. One identified by an OAP member is shell budget. A recent presentation by Dr. Roger Mann to the Maryland Oyster Advisory Commission illustrated the strong relationship between growth of oyster populations and creation and maintenance of shell required for further population growth. Another example of factors not accounted for in the model is the potential for evolution of disease resistance in the native oyster, and the extent to which harvest may preclude or impede rate of disease resistance development. Dr. Mann also reported that he had revised the growth rates he had previously provided for incorporation into the model for oysters in Virginia waters and established that the correct growth rates are substantially higher[1]. Given the current EIS time line, it is not possible to modify the model to account for these or other additional factors. However, it is possible to assess the nature of the effect that such factors may have on oyster populations (in some cases, by considering the sensitivity run outputs), and address those effects in a narrative that expands upon model outcomes.

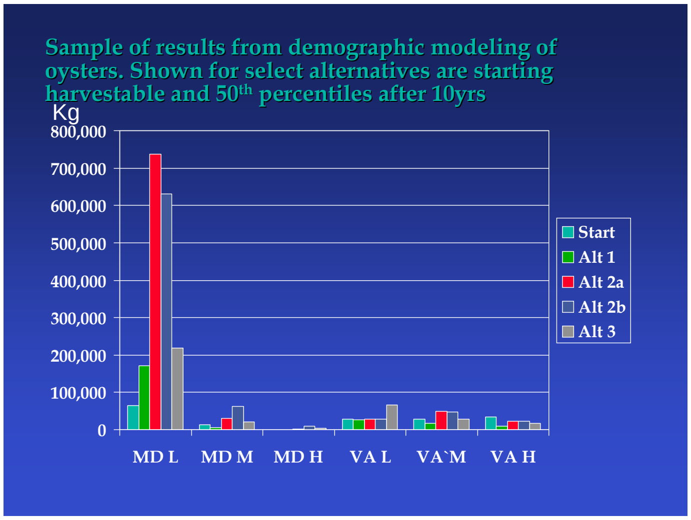
The Team is in agreement with one of the most significant conclusions of the OAP. The OAP states (pg. 10) that "…., the Demographic Model will be a poor tool to predict the consequences of an importation of *C. ariakensis…*" Much of the potential biology of *C. ariakensis* in Chesapeake Bay relating to vital parameters remains unknown, despite the extensive research that has been conducted over the past four years. Given the uncertainties in the ODM as applied to *C. virginica*, application of the model to *C. ariakensis* , would add much greater uncertainty to model outcomes, to the extent that the Team agrees that any *C. ariakensis* model outcomes would be of questionable value and potentially misleading. Thus, the Team concurs with the recommendation that model runs not be used for assessment of *C. ariakensis* alternatives.

[1] Dr. Mann has provided the new growth rate information to the Team; an initial review suggests that the new rates fall within the range of growth rates employed in the sensitivity runs of the ODM; thus, the potential affect of the increased growth rates in Virginia for ODM projections can be acknowledged and discussed in the assessment narrative.

Proposed Team Approach to Use of the ODM for ERA and EIS Development

- Evaluation of *C. virginica* alternatives – The Team concurs with the following statement from the OAP report (pg. 10): "We believe that the model can serve as a guide for making management decisions about the response of the native oyster population under the range of management alternatives under evaluation in the EIS." We propose an approach that will use the ODM outcomes to "guide" the evaluation of *C. virginica* alternatives, but recognizing the uncertainties in those outcomes. The focus in the assessment will be not on the quantitative outcome after 10 years, but on differences in the magnitude of change in oyster population over time between the alternatives, and also on the spatial characteristics of those differences.

  For the ERA, Dr. Menzie has been compiling information on the potential "negative" and "positive" implications of restoration scenarios on ecological receptors in the Bay. This compilation considers the spatial characteristics of the outcomes of the restoration alternatives along with how various receptors (e.g., oysters, SAV, benthic invertebrates, fish, wildlife) may respond to changes in oyster abundance and biomass. The results of the relative risk model are being structured around states and salinity zones. An example of an input to the analysis is provided below from the demographic modeling (L, M, H refer to low, medium and high salinity zones in MD and VA): This comparative analysis is informed by the demographic modeling because that modeling provides a feel for what could occur under each of the modeled scenarios. The modeling work also provides insight into the probability of outcomes. This type of assessment cannot be conducted using a purely qualitative approach.



  Although there are uncertainties in the demographic modeling outputs, there are also clear differences when results are organized in a fashion that managers can visualize. Results compiled in this manner are also needed to extract spatially specific results of

Carl Cerco's Chesapeake Bay water quality model that assess the consequences of changes in oyster population size on water quality and SAV.

As described earlier, the effects of a number of factors not accounted for in the model will addressed in the ERA in a narrative fashion. For example, regarding shell budget, the ODM results shown in the figure suggest that shell availability would increase in low salinity areas in Maryland under Alternative 2, while not changing substantially or decreasing in other portions of the Bay. The ERA will document all uncertainties with respect to how they affect our ability to estimate ecological risks. The "uncertainty analysis" will be presented in narrative form and will include a discussion of the implications of the uncertainty for risk estimates.

- <u>Evaluation of *C. ariakensis* alternatives</u> – Evaluation of *C. ariakensis* alternatives in the absence of quantitative model projections poses some problems. One major problem is that it could result in these alternatives being evaluating in a manner that is different from and inconsistent with the type of evaluation applied to the *C. virginica* alternatives (i.e., we would not have an "apples to apples" comparison of potential effects among alternatives). The Team has discussed this issue and proposes a "hybrid" approach to *C. ariakensis* alternatives.

For the ERA, Dr. Menzie will initiate his assessment based on findings presented in the NRC report. That report provided a set of conclusions as well as a set of questions regarding ecological risks associated with the introduction of *C. arikensis*. The research needs related to uncertainties concerning the implications of introducing this species and served as a basis for much of the *C. ariakensis* research that has been conducted for the past four years. Dr. Menzie will revisit the NRC conclusions in light of the research results to date. The research has answered many questions, had shed light on others, and leaves some open. Dr. Menzie will structure a narrative that ties directly to the NRC conclusions and that incorporates what we have learned as a result of the research and what that newly acquired information tells us about risk. He will characterize the uncertainties that remain and the implications of those uncertainties. This will be a largely qualitative discussion informed by the research, issues that remain open, and a fresh look at the NRC conclusions.

To link this *C. ariakensis* alternative assessment more closely to the assessment of the *C. virginica* alternatives, the intent is to further inform the evaluation by drawing upon sensitivity runs of the model runs for *C. virginica*. For example, the research studies confirm the high degree of disease resistance and high annual growth of *C. ariakensis* in the Bay. Sensitivity runs of the *C. virginica* model for low disease and greater growth, independently, will allow the Team to visualize the relative benefits to rate of oyster population growth of a species that has that particular characteristic. Of further value will be that the potential differences in spatial characteristics of population growth for such a species could also be established. The narrative assessment would draw on those findings to draw inferences about potential oyster population outcomes for a species with characteristics of *C. ariakensis*. Such a narrative will also address factors not accounted for in the ODM that could adversely affect population growth, such as greater susceptibility of *C. ariakensis* to predation by blue crabs. Based on such a narrative, the ERA would then consider the potential ecological implications of this hypothetical outcome for other ecological receptors as well as for the native oyster. In essence, the demographic modeling and relative risk model will provide a framework for organizing that available information and analysis and will be accompanied by a clear and thorough discussion of inherent uncertainties.

The emphasis in application of ODM results for *C. ariakensis* alternative evaluation will be on relative magnitudes of effect (e.g., high disease resistance might contribute to a factor of X greater population growth), not on specific quantitative outcomes (e.g., the oyster population in year ten will be X million oysters).

Concluding Remarks

The OAP has recognized the complexity of the issues that the Team is addressing in the ERA/EIS development process, and the Team is in agreement with the OAP on many of the major conclusions they present in their report, particularly regarding the limited adequacy of existing information on population dynamics of native oysters in Chesapeake Bay. As indicated in this document, the Team believes that the ODM is an essential tool in the ERA/EIS development process, and that it contributes insights not available through any other approach. Should the OAP disagree, it would be helpful if the OAP would recommend a specific alternative assessment approach that would be consistent with the existing ERA/EIS format and schedule.

Comments On The ERA/EIS Proposed Approach – Dr. Brian Rothschild (November 13, 2007)

A key issue in the proposed approach is the statement, *"…we remain uncertain about whether the OAP believes the models limitations are so great that it has no value for developing the ERA and preparing an EIS."*

Following on the Proposed Approach says, *"The OAP provided no guidance regarding alternative approaches that could be applied using existing data to evaluate the alternatives that have been established for the EIS."*

I wouldn't want to say, and I don't believe the OAP would have wanted to say, that the ODM model "has no value". Rather, I think the OAP report reflected that the panel read the report and cited a number of concerns and issues that challenged any certainty that might be attached to the reports conclusions. These are all detailed in the OAP report. So I would say that the Proposed Approach could take the ODM at face value with the condition that there are significant uncertainties as outlined in the OAP report.

As specified in the Proposed Approach, it seems to me that it is materially important that Roger Mann announced at the recent meeting of the Oyster Commission that there were substantial errors in the growth rates of Virginia oysters incorporated in the ODM. This determination occurred well after the OAP submitted its final report. I am sure the model is sensitive to growth rates providing yet another challenge to taking the ODM report at face value.

In terms of providing alternative approaches, I do not believe this was in the OAP's remit. However, what I would take away from the OAP report is that the ERA/EIS team might consider a more qualitative interpretation of the ODM that takes into account conventional wisdom on rebuilding oyster stocks. This is contrary to the statement in the Proposed Approach that says, "*Calculations of this nature cannot be made using simple methods because the vital rates of oyster populations interact in complex ways that can only be captured in an integrated model.*" From my perspective, an integrated model that contains complexities on the interaction of vital rates will not be of much use if in fact these interactions are not understood, which appears to be the case in oysters. I guess I personally opt for the simple methods. At least one should go through the simple methods.

The Proposed Approach cites the importance of the probabilistic outcomes of the model. This was not really discussed in any detail in the ODM report; and as a consequence, the OAP did not have much to say about it. One has to recognize that these probabilistic outputs are the result of the information and assumptions used in the model. I do not mean this in any negative way. It is just a reminder to those who have to interpret the results of the ODM.

The Proposed Approach document makes other observations that include, for example, the shell budget. Again, the OAP did not have the opportunity to review material on the shell budget.

Having said all this, the proposed approach outlined starting on page 4 for *C. virginica* does seem reasonable. Beyond the growth estimate problem, that some might take as a serious issue; there are a few other points worth considering. For example, qualitative approaches are used with probability theory all the time. One-hundred people are asked if it will rain tomorrow—30 say yes, and 70 say no. The probability of rain is assigned .3.

The approach to be used for *C. ariakensis* also seems reasonable.

Obviously, the ERA/EIS team worked hard on developing the proposed approach. I hope my observations have clarified the report of the OAP.

Literature Cited

Chai, A., M. Homer, C. Tsai, and P. Goulletquer. 1992. Evaluation of oyster sampling efficiency of patent tongs and an oyster dredge. North American Journal of Fisheries Management 12:825-832.