North Totten Inlet Mussel Culture Proposal

Response of the Independent Technical Review Committee (ITRC)
to MEC Analytical Systems, Inc.

Regarding October 2004 Literature Review:
"An Assessment of Potential Impacts of Mussel Raft Culture
to Surrounding Waters and Associated Biota of Totten Inlet"

On October 21, 2004, members of the Thurston County Independent Technical Review Committee (ITRC) received from MEC – Weston Solutions, Inc., consultant to Taylor Resources, a document entitled *An Assessment of Potential Impacts of Mussel Raft Culture to Surrounding Waters and Associated Biota of Totten Inlet*. This document was described by Bill Gardiner (MEC) as "a literature review that attempts to answer the question of nature and extent of impacts to the water column and water column resources" associated with operation of the Taylor Resources proposed mussel culture rafts in North Totten Inlet. This document incorporates the results of recent fieldwork conducted by Aquatic Environmental Sciences, the Pacific Shellfish Institute (PSI) and others within South Puget Sound (SPS) Totten Inlet. The October 2004 literature review was prepared for ITRC review, to assist Thurston County with determining whether there are any remaining significant data gaps prior to the County's use of the document to prepare the Environmental Impact Statement (EIS) for the project, and make permit decisions. In the event that the ITRC identifies data gaps, MEC proposes to develop a study plan, conduct fieldwork, and prepare (or revise) their technical report to respond to these questions.

The ITRC reviewed the October 2004 literature review in the context of: 1) the Findings and Conclusions of the Thurston County Hearing Examiner (June 1999), and 2) prior recommendations of the ITRC that identify information requirements for preparation of the EIS; in particular, the *Response of the ITRC to Thurston County and Taylor Resources regarding Letters of Comment Received in March 2002 during the Process to "Refresh" the Scope of the EIS* (August 20, 2002). These are the required guidance documents for the North Totten Inlet Mussel Culture EIS. In the context of these prior requests, the ITRC has identified data gaps and incomplete information in the October 2004 literature review, though good progress was made on documenting elements of the Affected Environment and the analysis of some affects of the mussel raft. Given the need to correct information and/or to better substantiate conclusions for the document to be used in preparing the EIS, the October 2004 literature review should have been issued as a draft, and the ITRC considers it as such. The MEC document should be finalized after addressing the requests for clarification and improvement identified by the Thurston County Independent Technical Reviewers, provided below and in three attachments.

Scope of Study, Elements Addressed

Prior to issuance of the October 2004 literature review, the MEC work product was discussed during a May 21, 2004 conference call with ITRC members, representatives of MEC, and representatives of Taylor Resources. At that time, it was anticipated that the report would update and further analyze the probable affects of the proposed mussel raft on three elements of the aquatic environment required for study in the EIS, as previously listed by the Thurston County Hearing Examiner: A) impacts to bottom-dwelling organisms (the benthic community); B) impacts to the surrounding water column; and C) impacts to the phytoplankton resource, including the affects this could have on other aquaculture and aquatic life in Totten Inlet. The October 2004 draft literature review does not address the affects of water column impacts to the benthic community, or the coupling of these two affects. This analysis is requested in the final literature review.

Critique of Methods of Analysis, Interpretation, and Reporting

1. The estimates of phytoplankton and chlorophyll removal or change in nutrient concentrations upstream and downstream of the rafts compared to background conditions (i.e., the PSI monitoring data) are not reported in the context of tidal stage or water current velocity. This is likely a most important factor controlling the extent to which phytoplankton will be removed by the mussel raft operation. Were current velocity data collected during sampling? The ITRC suggests that these data be re-evaluated with respect to current speed during sampling, if possible, and if not collected, incorporate tidal stage to approximately normalize the results for this factor. This amendment should not be difficult to prepare, but should go far to enhance the extent to which the data are useful and representative. See additional detailed comments in Attachment A.

2. Many of the analyses focus on annual averages. Seasonal averages are more important; specifically, the mid- to late summer critical period that occurs when the water column becomes vertically stratified and sensitive to nutrient perturbations. Several notes are inserted in Attachment A regarding this issue throughout the draft literature review. This is one criticism of the ECOPATH modeling approach that has caused other regions to reject it as inappropriate for shellfish and phytoplankton modeling (i.e., Chesapeake Bay). But MEC only uses the ECOPATH study data, not the actual model, so it seems that the analysis could be amended to deal with the late summer critical period. See additional detailed comments in Attachment A and below.

3. Disclaimers are made in the draft literature review that the data and analysis are for Windy Point and may not apply to the proposed project site in North Totten Inlet. More importantly, there are no data from the inner (shallow southern) inlet or Skookum Inlet. This area may often be highly stratified during summer, and has extremes of temperature and salinity not experienced further north. Within this region, it is likely that the biota are somewhat different than in the other regions of the inlet. While MEC may not be able to find suitable data or information, the document should not omit a discussion of these factors and how they may tend to balance out or not when considering the better flushing and mixing in the northern inlet.

4. Attachment A provides a number of comments regarding possible misinterpretations or lacking data for the carbon food web model. For example, adult chum salmon are included as consumers of lower food web components in the model. A local expert informs us: “ People caught-on to the fact that in-bound adult chum can be caught on sport gear in Totten Inlet proper (mid- and outer inlet) using a herring on a bobber, dead-drifted through a school (idenitified by seeing jumpers). Perhaps someone has interpreted this to mean that the fish are actively feeding. Given that the fish are 2 to 3 weeks away from spawning when they are staging in the inlet, I doubt it” (personal communication with Tim Tynan, National Oceanic and Atmospheric Administration, November 12, 2004). With regard to forage fish such as herring and sand lance, the central and northern inlet are probably very different with regard to the occurrence of these fish in summer compared to the southern end (for the reasons given above). With the exception of cutthroat trout, all other species of salmonids only have a short residency in Totten Inlet in the spring. There is no evidence of blackmouth chinook or other resident or migratory salmonids inhabiting the area for extended periods at other times. As a result of this, the affects of the mussel raft on salmonid resources described in the draft literature review may be unfairly overstated beyond a conservative degree.

5. Data should be provided for jellyfish, as their medusa form constitutes a major second trophic-level predator in this area during the summer and fall, especially during the critical period discussed above. During some summers, there is massive abundance of these organisms stretching all the way out into the main channels. From the ECOPATH SPS report (underscore added):

"One large unknown in SPS, and indeed many ecosystems, is the role of organisms such as jellyfish (jellies). To date, there is a paucity of scientific study for these organisms in the Pacific Northwest. Previous marine ecosystem modelers have had difficulty in measuring their trophic effects on other organisms because estimates of jellyfish biomasses may be wrong by an order of magnitude (Beattie, 1999; Dalsgaard et al. 1998; Arai, 1996). Knowing when jellies are abundant or not may be crucial to understanding fish production. There is growing evidence (Baird and Ulanowicz, 1989; Strickland, 1983) that jellies may represent a 'trophic shunt' diverting energy flow away from fish production. Further, estimating the contribution of jellies to the diets of organisms is problematic because they are very difficult to observe in stomach content samples."

The draft literature review does not acknowledge the prominent seasonal existence of jellyfish in Totten Inlet, and the ECOPATH modeling of SPS was unable to assign a quantitative value to them. Though data may be lacking for a major seasonal component of the food web, this component should not be ignored. MEC is asked to check with local and regional authorities on the subject to see if any data are available to include these organisms. Claudia Mills at the University of Washington, Friday Harbor Laboratory responded to Jack Rensel's request for information about abundance of jellyfish in SPS during his review of the MEC October 2004 draft literature review. She did not have any specific information for SPS, but there may be other work she has done from nearby areas, or perhaps others at Evergreen College have some knowledge on this subject. Claudia did indicate that there is evidence that parts of Central or North Puget Sound have had shorter seasonal occurrences of the medusa in recent years than in the past. If no local data are available, estimates from other SPS or Puget Sound area could be applied over a probable range of abundance as a general sensitivity analysis.

6. Conceptually, if food is not limiting to second trophic levels or above, and is only used at 10% of the available production (or standing stock), how is it that there would be ANY reduction of upper food web members such as juvenile salmonids? Just because MEC states that their model is built that way, doesn't mean it makes sense as the primary conclusion. Why is the model used as such? It is a conservative approach, but logically it seems too conservative. Rather than a single-point estimate of 10%, it would be better to re-run the assessment using a range of values for the poorly-known components (e.g., medusa) to arrive at a range of possible results (i.e., a sensitivity analysis).

7. The persistence of vertical stratification that occurs in Totten Inlet during summer and fall is misrepresented and understated by following previous unpublished opinions on the matter. It is simply not a matter of opinion; the inlet has a degree of persistent stratification that is mediated by weather conditions and other factors. In calmer, warmer summers, the inlet may become more vertically stratified. Saying that there is "little" thermal or other stratification is misleading and incorrect. Existing literature is available to quantify this matter; less meaningful generalizations should be avoided. In this same regard, the report should seek not to use short or single-year databases to describe typical conditions of the inlet. There are adequate long-term data to generate more useful plots and tables for characterizing conditions, which was already done by Dr, Brooks, although the ITRC has not as a group concurred with his interpretations of the data. See additional detailed comments in Attachment A.

8. The velocity and transport data from the proposed North Totten Inlet site is not sufficient to characterize the site, as the ITRC has previously pointed out (ITRC Response to Scoping Comments, August 20, 2002). A single mean current velocity value for the proposed site is used repeatedly in the MEC draft literature review in several important estimates of effects, so this is not a minor matter. Nor have any of the relatively easy Lagrangian motion (drogue) studies suggested by the ITRC been performed. The approach used to characterize the proposed site is fine, but the data were cobbled

together. Just as with the phytoplankton removal data, if it is not possible to characterize the mean tidal exchange during sampling, relative to the local mean or diurnal range, then the data summaries including the mean velocity are not quantitatively defensible. The same criticism applies to Lagrangian studies that could be done during a single day in late summer, specifically chosen to be "average" in exchange characteristics), but the opportunity was apparently missed in 2004.

9. Analyses in the draft literature review rely heavily on standing stock estimates of food web components. As phytoplankton, in particular, are best described by dynamic estimates of production (rates of primary productivity with Carbon-14 fixation), there should be some discussion of how the selected method does or does not approximate the dynamic methods in principal seasons.

10. If Brooks (2001) is to be cited, the ITRC suggests that every reference be substantiated, particularly with regard to physical oceanography data and summary statements. The Brooks report contains many interesting and useful observations, but some conclusions are opinion or are not substantiated. A few examples include:

    - LOTT drift card studies conclusively show that south Puget Sound is well flushed with respect to the main basin (page 49).
    - Totten Inlet is "seldom stratified." The temperature profiles clearly demonstrate persistent summer stratification, and it is widely accepted as the case; e.g., *"The persistent stratification in the region, however, argues for evaluation of a residence time based on the tidally averaged baroclinic (internal or residual) exchange flow"* Albertson et al. 2001.

    MEC is asked to rely on the original literature or real, local measurements whenever possible in this regard. Dr. Brooks may be correct about some factors (e.g., current speeds at the mouth of the inlet); however, MEC should cite the original documents as a source of information (e.g., NOAA) for the sake of acceptable scientific rigor.

Carrying Capacity

The report should identify the possible range of definitions of the term "carrying capacity" from the literature sources cited, and clarify the selected definition for this report. The definition should be restated in the conclusions and summary to put the estimates of effect into context.

Most importantly, in the Conclusions (page 70) and elsewhere, there is reference to previous predictions of carrying capacity that are, apparently, cited as key findings of this report. It is implied that the present bivalve population (wild and cultured) is only using 10% of the available phytoplankton production. If true, this IS a key finding, but if this was based on unpublished estimates, the ITRC insists that this report clearly lay out all aspects of the prior analysis, and work it into the present analysis appropriately.

Alternatively, MEC may want to drop this reference if it is not defensible, and rely on the carbon reduction estimates derived on their own. The latter is a potentially powerful argument about the scale of possible impacts.

Flushing Characteristics

The ITRC provided a Suggested Experimental Setup to Establish the Residence/Ventilation Time of Water in Totten Inlet on pages 6–7 of the Response to Scoping Comments (August 20, 2002). The Committee still considers it very important to perform these physical measurements, because these data are needed to define the near-, mid- and far-field regions, which form an essential element of the intellectual framework of the study. These fields must be defined in terms of *locally determined* physical conditions. Totten Inlet is heterogeneous enough that an *a priori* determination based on physical conditions elsewhere will not be justifiable. In particular, the mid-field region must be determined in terms of local tidal excursion (Suggested Experimental Setup element #4), and timescales of exchange between the mid- and the far-field regions must be established (Suggested Experimental Setup element #3).

The rationale for estimating the mean flushing rate of 4 to 11 days is not clear but may involve a previous, apparently arbitrary reflux estimate rate of 78%. The actual reflux rate will be much lower, assuming reflux refers to water parcels that leave the inlet for time scales of weeks. It is conservatively legitimate to model SPS as a closed system (as we did with Kiefer and Atkinson in 1991; see WDF 1991, PEIS for floating fish culture in Puget Sound), so eventually some of the same water molecules will return to the inlet, but that isn't the reflux being considered here. From Jack Rensel's review and his discussion with Mitsuhiro Kawase, the high-end (11-day) flushing rate is probably not valid. Dr. Kawase believes that flushing rate is not underestimated when using the tidal prism model, unless reflux is high (which it most likely is not due to fast transport rates in Pickering and Squaxin Passages).

The large uncertainty in the stated estimates of residence time for the inlet (4 to 11 days, or a factor of three, page 10 of the MEC October 2004 literature review) is of principle concern, because water mass residence time is comparable to timescales of key biological processes such as phytoplankton cell generation times. The remainder of the ITRC suggestions made in the August 20, 2002 document address this concern. Efforts must be made to either reduce the uncertainty or establish how the residence time depends on the time of the year and physical conditions.

Specific additional comments regarding the content of Sections 2 and 4 of the draft literature review are provided in Attachments B and C to this ITRC Response document.

Water Quality, Phytoplankton and Nutrients

Some effects of the mussel rafts, such as dissolved oxygen (DO) depression, and ammonium increase, are not treated in sufficient detail. Other effects, e.g., the effect of nutrient release on nutrient-limited phytoplankton found in the area, are not addressed.

Nutrient sensitivity of South Puget Sound and Totten Inlet is largely neglected throughout the October 2004 draft literature review. The section on nutrient conditions is much too brief, and misses key points on several accounts, especially the relative ranking of Totten Inlet compared to other SPS and Puget Sound water bodies. Use of a single year as "typical" was not justified. How was it determined to be typical? Is weather ever "normal"? (No) Some existing literature is available and cited, but not used to the extent necessary. Citing unpublished opinions is not sufficient in this matter, especially when there is published literature available. See additional specific comments provided in Attachment A.

MEC is asked to do a more thorough job of discussing the immediate effects of the raft on dissolved oxygen. The substantial depression of DO indicated in Figure 15 (page 47) of the draft literature review is not even mentioned in the text citing "the biological and physical processes affected by the presence of a mussel raft on the surrounding environment" (page 40).

Drawing a conclusion regarding DO values returned to pre-raft (north of North Boom) values down-current of the raft (south of South Boom) on the basis of only one sample point (Figure 15) is a poor spatial representation. MEC is asked to discuss both the uncertainty of any conclusion regarding the affect of the raft on DO, and the potential for DO affects to occur.

MEC is asked to discuss the extent to which increased nutrients (e.g., ammonium, urea) could stimulate the nutrient-limited phytoplankton stock in the inlet, and whether this increased production could result in localized hypoxia.

In many places in South Puget Sound, phytoplankton are nutrient-limited for much of the summer, particularly in late summer. While this is acknowledged in the draft literature review, the implications in the context of nutrient release from the raft are inadequately addressed. The document does mention that water column nutrients are different after passage through the raft (page 41), and that there would be a possible affect on phytoplankton, both species and amount (e.g., page 54). But this is not discussed, even admittedly so (page 63), in light of the nutrient limitation of South Puget Sound phytoplankton (e.g., as much as 200%, page 63). How this, in turn, could also affect DO in the inlet is also of importance (as noted above). The discussion in the context of Hood Canal (pages 67-68) is inadequate. Some calculations should be done to assess the magnitude and uncertainty of this potential impact. An improvement is needed over the statement: "*The magnitude and nature of the phytoplankton community response to the forms of nitrogen available downstream from the rafts is still unclear*" (page 68).

The draft literature review (page 68) maintains that raft mussels and biofouling will reduce nitrogen concentrations in the water column. This may be true on an annual basis, but during the critical period of late summer, it will actually have the opposite affect, as dissolved nitrogen is virtually absent from the upper water column (or cycled at such low levels that it may be undetectable). The cultured mussels will consume particulate nitrogen, incorporate some of it as tissue, but discharge some of the same nitrogen as dissolved nitrogen. While this may be a matter of scale of affect, it should be quantified and discussed. As requested in comments above, the report should give at least minimal consideration to seasonal variation.

General

Units of Measure

Units of measure should be consistent throughout the document. The scientific standard of MKS units is preferred. When a different unit is more customary (e.g., knots instead of meters per second for velocity), please provide the equivalent numerical value for the alternative unit of measure in parentheses.

For purposes of the EIS, it will be requested that English units of measure be provided in parentheses following metric units, nautical units, degrees Centigrade, etc., for ease of understanding by lay reviewers.

Glossary Required

There are numerous technical terms throughout the document that are not defined for lay reviewers. Rather than interrupt the flow of text with definitions in parentheses following each technical term, please prepare a glossary to be inserted at the front of the revised literature review (following the Table of Contents and preceding the Executive Summary). This glossary will also be used in the EIS.

Graphic Illustrations

For purposes of using these graphic illustrations in the EIS, it would be preferable (from a cost standpoint) for them to be black-and-white figures (to the extent possible, using different degrees of shading, different patterns, different line types, etc.). It is acknowledged that some modeling results depend on color presentations, such as the Alden Lab figures.

Additional clarifying information is also requested in graphic illustrations. For example:

Figure 1. Please provide a distance scale on this and any other figure that is a map or chart.

Figure 2. Please provide a legend that indicates the unit of measure for the depths indicated (i.e., fathoms?), and an explanation for the clear areas.

Figure 5. Please provide a legend for the distinction between the "salinity" indicated by two different types of lines.

Figure 10. Please define BP and DOC in a legend. Please provide an explanation for why percentages don't add up to 100%.

See additional detailed comments in Attachment A, a pdf version of the October 2004 draft literature review in which editorial notes have been entered.

All Figures:

- Cite the source of the data collected.
- Provide clearly marked axes, and increase the font size of axis titles to improve readability.
- Make sure information provided in the figure title and callouts makes the figure completely self-explanatory, free-standing from the text.
- Make sure figure and table legends are sufficiently explanatory to provide reviewers (particularly lay reviewers) with the necessary context.

Check and Confirm Citations

Example (page 27): There is a citation for Hay and Fulton 1983 that does not appear in the References section at the end of the document.

Example (page 38): There is a citation for Redmond and Newton (1998) that does not appear in the References section. Further, one of the authors (Jan Newton, an ITRC member) does not recall that there ever was a publication for this work with Scott Redman on the ECOPATH model. If there is, she would like to have a copy.

It is advised that the revised, final version of the literature review should undergo and thorough edit and careful review for details, including citations. Example: There are citations in the phytoplankton sections for WDOE 2002 and WDOE 2003a for the same document.

Context

The terms "environmental assessment" and "environmental impact statement" appear to be used interchangeably in the Executive Summary and Background section of the October 2004 literature review. An Environmental Assessment is a NEPA document (triggered by a federal nexus), and is not what will be prepared for the North Totten Inlet Mussel Culture Proposal. The Environmental Impact Statement is being prepared by Thurston County, with substantial input of technical information from Taylor Resources and their consultants. Given this context, the statement "*Thurston County has asked Taylor*

Resources to conduct an environmental assessment to determine the nature of any affects the rafts may have on the surrounding environment" could be misleading to lay reviewers.

Also, the title of the document, itself, is misleading. It is not a complete assessment of affects to associated biota; for example, benthic macrofauna are not discussed. Rather, the title should clearly indicate that the document (draft literature review) focuses on water column issues and food web affects.

The following sentence from Section 1.1 of the draft literature review misrepresents the environmental review emphasis previously stated by the Thurston County Hearing Examiner and ITRC: "*Members of Thurston County and the Independent Technical Review Committee have identified salmonids and bivalve shellfish as the key receptors for our current evaluation and thus, these species are the focus of our investigation*" (page 6). Salmonids are one group of organisms for which potential impacts will be evaluated, particularly listed species for the Endangered Species Act (ESA) evaluation that will be required as an element of the Corps permit for the project. The ITRC response to Scoping comments (August 20, 2002), Item #7 states that "Potential impacts to resident demersal and pelagic fishes should be addressed in the EIS in addition to potential impacts to Puget Sound chinook salmon." The paragraph that follows in that ITRC document reports that a fisheries biologist has been retained as a member of the EIS team (not a member of the ITRC) for this impact analysis, and will also review potential affects to other threatened and endangered species in a Biological Assessment (BA). These are expected to be secondary affects of mussel culture operation. The ITRC's focus has consistently been to request assessment of potential impacts to the critical biological components of the water column. The Hearing Examiner identified five elements for investigation and analysis, as follows: A) impacts to bottom-dwelling organisms (the benthic community); B) impacts to the surrounding water column; C) impacts to the phytoplankton resource, and the effects this could have on other aquaculture and aquatic life in Totten Inlet; D) impacts caused by escapement and propagation of mussels; and E) impacts caused by navigational lighting. Of these, it is expected that the MEC literature review will address elements A through C.

References

Tynan, Tim. National Oceanic and Atmospheric Administration. November 12, 2004. Personal communication with Jack Rensel, Thurston County Independent Technical Review Committee member, re: adult chum salmon as consumers in North Totten Inlet. Lacey, Washington.

Attachment A

Additional Specific Comments with respect to MEC October 2004 Draft Literature Review:

"An Assessment of Potential Impacts of Mussel Raft Culture to Surrounding Waters and Associated Biota of Totten Inlet"

Additional detailed comments prepared by J.E. Jack Rensel, ITRC member, on the MEC draft literature review, "*An Assessment of Potential Impacts of Mussel Raft Culture to Surrounding Waters and Associated Biota of Totten Inlet*" will be provided to MEC – Weston Solutions, Inc. in an electronic pdf file.

Attachment B

Additional Specific Comments with respect to MEC October 2004 Draft Literature Review:

Water Column Impacts – Flushing Characteristics

Additional Specific Comments provided by Mitsuhiro Kawase, University of Washington
ITRC Member
regarding Sections 2 and 4 of the MEC October 2004 Draft Literature Review

Section 2.2

- Average current speeds at the mouth of the inlet are quoted to be 90cm/s flood and 50cm/s ebb. Is this the current through, or just outside, the mouth? If the former, this would imply tidal imbalance.

Section 2.3

- "There appeared to be little stratification in the water column at Windy Point . . . " This refers to temperature stratification; salinity effects will be equally important.
- What is known about the lengthwise gradients of properties in Totten Inlet? This is important information for characterizing the inlet as an estuary (e.g., Hansen and Rattray).

Section 4.2

- Note that raft-generated turbulent mixing is likely affected by the stratification of the incoming water, which would tend to damp out turbulence generation (page 49).
- It would be useful to demarcate the extent of the mid-field on a chart. Local current data will be needed to do this (page 52).
- Table 2, minimal neap tidal current at the mouth of Totten – shouldn't this be zero? Or does this mean peak current during neap tide? (page 53)
- " . . phytoplankton populations and chlorophyll a concentrations in the wake of the raft were increased due to upwelling and advection (Figure 19)." Seems to reference an incorrect figure (Figure 19 is from Deep Water Point, not Gorges Harbour). Also, the phytoplankton response seems very fast if it is an upwelling response, which would likely be over in a few minutes. Could this be more of a response to turbulent mixing of a stratified water column, which would supply nutrients from the deep into nutrient-limited upper layer? (page 55)
- Figure 19: It is customary for such plots to have the depth as the vertical (y) axis (page 57).
- " . . . percentage reduction in phytoplankton abundance relative to the reference attributable to turbulent mixing alone . . . " But turbulent mixing cannot remove phytoplankton from the water column! It would merely redistribute it over different parts of the water column. Equation 3 needs better explanation (page 58).
- Figure 22: Unclear why Phytoplankton abundance and Chlorophyll-A have different recovery length scales, if both recoveries are due to turbulent mixing of the ambient water in the wake (page 61).
- "Slower currents . . . would presumably result in recovery over shorter distances, while faster currents would reduce removal rates." Current velocity would affect transit time of the water through the raft, so the integrated rate of removal can be affected in this way, as well. A quantitative comparison of different processes will be needed to correctly ascertain how tidal current speed influences raft impact on the water column (page 63).

Section 4.3

- "However, without more localized standing stock and current data it is difficult to predict the local extent of these reductions" (page 65). This is precisely one of the reasons why the TIRC has requested that local current measurements be taken.
- Hood Canal is hydrodynamically a very different system with very high degree of vertical stratification, slow circulation and long residence time. Comparison with Totten Inlet should be drawn carefully (page 67). Also see ITRC comments in the Water Quality, Phytoplankton and Nutrients section of this response.

Attachment C

Additional Specific Comments with respect to Questions Left Unanswered in MEC Draft Literature Review, Sections 4.2 and 4.3

Comments on
"An Assessment of Potential Impacts of Mussel Raft Culture to Surrounding Waters and Associated Biota of Totten Inlet"

Mitsuhiro Kawase, University of Washington

Questions addressed in this report pertain to potential impacts of a proposed mussel raft deployment on a fairly heterogeneous body of water for which not much data is available. This is a challenging situation, but one can make inferences about possible impacts based on sound semi-quantitative reasoning by being attuned to the characteristic time- and length scales of the processes involved. MEC's approach, in which the impact is considered over three different spatial scales based on physical processes, is a solid one and a good basis for study; at the same time, I believe there are questions for which more concrete answers are possible without expending resources on further field work or complex modeling.

Based on my own expertise I'd like to offer extended comments on a couple of sections, where I believe scaling arguments can be pushed further to address questions left unanswered and to fine-tune answers given here.

1. Modeling the near-field effect of the raft on the surrounding water column (Section 4.2)
The data on percentage change in phytoplankton density, presented in Figures 17 and 18, is very valuable. I believe it is possible to model the mixing process inside and in the wake of the raft in a way that is more flexible in that it can then be adapted to a different flow regime expected at the North Totten site.

Phytoplankton biomass concentration C_p, is affected by advection and turbulent mixing, as well as by primary production and grazing by mussels. Assume that the latter two can be characterized in terms of kinetic timescales, τ_p and τ_g respectively; then one can write down a simple advection-diffusion equation with source-sink terms:

$$\frac{\partial C_p}{\partial t} = -U\frac{\partial C_p}{\partial x} + \kappa\nabla^2 C_p + \left(\frac{1}{\tau_p} - \frac{1}{\tau_g}\right)C_p$$

Here, x is downstream distance, U is tidal current velocity and κ is the turbulent (both horizontal [primarily cross-stream] and vertical) diffusion coefficient. Based on this, one can construct a straightforward model of phytoplankton concentration change as the water sweeps past the raft, by giving an ambient value of concentration upstream of and surrounding the raft.

Even without formally solving the equation, this can serve as a basis for scaling arguments that would enable us to estimate the unknown coefficients. First, the characteristic time scale of the problem should be the time it takes for the water to sweep past the raft; with the current speed of 27cm/s and raft length of 30 meters (??) should be about 100 seconds or less than two minutes. Processes with characteristic time scales that are long compared with this (for instance, primary production τ_p) are not likely to affect the *local* distribution of C_p, and can thus be neglected. Similarly, ambient concentrations are likely to change over tidal timescales (advection of patchiness is a concern, but since the equation is linear and we are concerned about average conditions, we assume this averages out), so the time rate of change term on the left hand side of the equation may be neglected and we will be dealing with a quasi-steady state.

Given these assumptions, we can estimate the turbulent diffusivity from the length scale over which the concentration recovers to the ambient value, say L_r. In the wake of the raft the balance is between advection and diffusion, with the turbulence bringing in the ambient concentration into the wake, so turbulent fluxes are predominantly in the cross-flow direction:

$$U \frac{\partial C_p}{\partial x} \approx \kappa \left(\frac{\partial^2 C_p}{\partial y^2} + \frac{\partial^2 C_p}{\partial z^2} \right)$$

A simple scaling for the mixing coefficient can then be given in terms of cross-flow length scale L_c, which we may assume to be raft width/depth (whichever is smaller):

$$\kappa \sim \frac{U L_c^2}{L_r}$$

From values discerned from the report ($U \sim 0.27$m/s, $L_r \sim 50$m, $L_c \sim 5$m) I estimate κ to be about 0.14m^2/s. Of course, turbulence itself would decay in the wake of the raft; a more refined model in which κ becomes a function of x should be possible, if we have data or if we make further assumptions regarding turbulence behavior. We now have kinematic parameters for advection and diffusion, which can be used for a similar model for carbon / nitrogen budget with appropriate kinetics; it could also be taken to a different flow regime, such as the north Totten site, by specifying a different value of U.

Based on data we can also tune for the time constant for grazing by mussels, τ_g. If the difference between ambient concentration and concentration at the raft center is ΔC_p, and the raft center is located distance Δx from the raft edge, then the terms in the equation scale as:

$$U \frac{\partial C_p}{\partial x} \sim \frac{U \Delta C_p}{\Delta x}, \quad \kappa \nabla^2 C_p \sim \frac{\kappa \Delta C_p}{L_c^2} = \frac{U \Delta C_p}{L_r}, \quad \left(\frac{1}{\tau_p} - \frac{1}{\tau_g} \right) C_p \sim \frac{C_p}{\tau_g}$$

Of the three, the diffusion term is likely small if the raft length is short compared with the wake length L_r (however, it is likely this term will be dominant over primary production and can be significant in supplying phytoplankton to the raft interior). A scaling for τ_g would then be

$$\tau_g \sim \frac{C_p \Delta x}{U \Delta C_p}$$

Based on the parameters listed in the report, I find a τ_g of about eighty seconds (surprisingly efficient, to my non-expert mind!), which would mean loss of phytoplankton biomass to grazing by mussels totally dominates over increase in phytoplankton biomass through primary production. Again, a more refined estimate can be obtained by actually solving the equation and fitting the solution to the observed data. This model (or at least the estimated parameters) can now be used for a semi-quantitative assessment of raft effects under different flow conditions.

2. Localization of food chain impact (Section 4.3)

The trophic transfer model makes an assumption of uniform application to the entire inlet; however, it would be natural to ask if some effects may have a more localized impact around the raft. It is possible to approach this problem by considering the timescale of biomass transfer and comparing it with the distance over which biomass is likely to spread over the same timescale.

A detailed knowledge of the flow field in the inlet would be needed to specify the spreading timescale completely; however, we may argue that over the "inner" far field region surrounding the raft, tidal stirring will be the predominant effect, which may be characterized in terms of "effective horizontal diffusivity" D. Tidal currents are variable in time and not exactly repetitive, causing displacements of water parcels originating from a given area; they also contain shear and strain due to bathymetric and coastline irregularities and the nonlinear nature of the current itself, which stretch and deform water parcels. The net effect of these parameters is stirring and spreading of water parcels in a complex manner better characterized as dispersion than systematic advection. One can scale for D as mean tidal flow speed times a characteristic length scale; the latter can be channel width (Banas, et al., 2004). If we assume tidal velocity of 0.25m/s and characteristic scale (inlet width) of 500m, then $D \sim 125\text{m}^2/\text{s}$. It is likely that this is an upper bound on diffusivity, since the characteristic scale can be smaller; e.g., the width of one of the deep channels near the entrance to the inlet, about 100m.

Given D and the rate constant for trophic level transfer expressed in terms of time scale τ, we can scale for the linear dimension L of impacted area as $L \sim (D\tau)^{1/2}$. Note that L is not proportional to τ but rather to the square root of this. This scaling should be interpreted as: for example if the tidal stirring diffusivity is $100\text{m}^2/\text{s}$ and rate of consumption of detritus from the raft by scavengers is such that, say, over an hour detritus concentration is reduced by a factor of e, then detritus distribution will be limited to an area around the raft of radius roughly equal to $(100 \text{ x } 3600)^{1/2} = 600\text{m}$.

This relationship can also be inverted to give the minimum rate (maximum timescale) for localization of effects for a given basin. For Totten Inlet, assuming representative D to be $100\text{m}^2/\text{s}$ and the length of the inlet to be 15 km, we obtain a scaling for τ of 26 days; in fact, this is long compared with the estimates of residence times given in Section 2.2 (but the above scaling is somewhat sensitive to the choice of the linear dimension). It is likely that mean circulation, either in the form of exchange flow or tidal rectification, would help carry impacted water away from the raft site and reduce localization.

If the kinetic timescale is comparable to or shorter than the tidal half-period, then the impact of the raft is sure to be localized, but it will not leave the mid-field area as defined in this study. Based on the rough argument given above, I would postulate that localization of impacts are possible only for processes with rate constants giving characteristic time scales of ten days or less; in other words, all effects of nutrient perturbation on the growth of phytoplankton cells that are in the order of a day or two. Clearly there is much room for refinement of the argument above, and effects of multiple transfer through the food chain could be complex.

References

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