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Proceedings of the Pacific Regional Peer Review on the Update to estimation methods for Geoduck (*Panopea generosa*) stock index

March 15-16, 2017
Nanaimo, British Columbia

Chairperson: Julia Bradshaw
Editors: Sylvia Humble, Julia Bradshaw and Dominique Bureau

Fisheries and Oceans Canada
Science Branch
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

October 2021

Foreword

The purpose of these Proceedings is to document the activities and key discussions of the meeting. The Proceedings may include research recommendations, uncertainties, and the rationale for decisions made during the meeting. Proceedings may also document when data, analyses or interpretations were reviewed and rejected on scientific grounds, including the reason(s) for rejection. As such, interpretations and opinions presented in this report individually may be factually incorrect or misleading, but are included to record as faithfully as possible what was considered at the meeting. No statements are to be taken as reflecting the conclusions of the meeting unless they are clearly identified as such. Moreover, further review may result in a change of conclusions where additional information was identified as relevant to the topics being considered, but not available in the timeframe of the meeting. In the rare case when there are formal dissenting views, these are also archived as Annexes to the Proceedings.

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SUMMARY

The BC Geoduck fishery is managed at the sub-bed spatial scale. The limit reference point (LRP) is defined as current biomass being equal to 40% of estimated unfished exploitable biomass (Zhang and Hand 2007). The stock index, defined as the ratio of current biomass (B_c) to estimated unfished exploitable biomass (B') on a bed, is calculated for each bed. Beds with a stock index below 0.4 are closed to fishing. If surplus production is occurring, the current method of estimating unfished exploitable biomass in the Geoduck stock assessment framework (Bureau et al. 2012) is likely to be biased and lead to biased estimates of stock index and consequently lead to all harvested Geoduck beds reaching the LRP erroneously. This may be an artefact of the method currently used to estimate unfished exploitable biomass and not be reflective of true stock status. Fisheries and Oceans Canada Fisheries and Aquaculture Management Branch has requested that Science Branch provide a review of the method currently used to estimate Geoduck unfished exploitable biomass and provide alternative Geoduck unfished exploitable biomass estimation methods.

The specific objectives of this review, as outlined in the terms of reference are to:

1. Provide a review of the method currently used to estimate Geoduck unfished exploitable biomass, for surveyed and un-surveyed Geoduck beds.
2. Describe alternative methods for estimating Geoduck unfished exploitable biomass for both surveyed and un-surveyed Geoduck beds, including evaluation of the relative advantages and disadvantages of each method.
3. Provide methods for calculating Geoduck stock index on a by-Geoduck-sub-bed basis. Describe the advantages and disadvantages associated with this approach.
4. Identify and discuss uncertainties and knowledge gaps in the available data and proposed estimation methods.

These proceedings summarize the relevant discussions and key conclusions that resulted from a Fisheries and Oceans Canada (DFO), Canadian Science Advisory Secretariat (CSAS) Regional Peer Review meeting held on March 15-16, 2017 at the Pacific Biological Station in Nanaimo, BC. A working paper describing and evaluating alternative methods to estimate unfished exploitable biomass intended to address the concerns with biased stock indices was presented.

Participation included Fisheries and Oceans Canada Science and Fisheries and Aquatic Management Sectors staff, the commercial fishing sector and the Washington Department of Fish and Wildlife.

The conclusions and advice resulting from this review will be provided in the form of a Science Advisory Report (SAR) providing advice to improve the current methods of estimating unfished exploitable biomass.

The Science Advisory Report and supporting Research Document will be made publicly available on the Canadian Science Advisory Secretariat website.

INTRODUCTION

A Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat (CSAS) Regional Peer Review (RPR) meeting was held on March 15-16, 2017 at the Pacific Biological Station in Nanaimo to review alternative methods to estimate unfished exploitable biomass used in stock index estimations for Geoduck management in BC.

These proceedings report on the main points developed during the presentations, review and discussions as part of the evaluation of the revised operating model. The regional peer review process is open to all participants who have appropriate technical expertise, experience and interest in the topic to engage in a robust peer review of the data inputs and model performance. The Terms of Reference (TOR) for the science review (Appendix A) were developed in response to a request for scientific information and advice from DFO Fisheries Management. In total, 23 participants with relevant expertise within DFO Science, Fisheries Management and the commercial fishing sector participated in the RPR in person (Appendix B).

The meeting chair, Julia Bradshaw, welcomed participants, reviewed the role of CSAS in the provision of peer-reviewed advice, and gave a general overview of the CSAS process. The co-chairs discussed the role of participants, the purpose of the various CSAS publications (Science Advisory Report, Proceedings and Research Document), the definition of consensus used by CSAS and the process for achieving consensus. The chair noted that the purpose of the meeting was a review of the science only and then reviewed the Terms of Reference for the meeting, highlighting the objectives to be achieved. The chair confirmed that copies of the Terms of Reference, working paper, and a meeting agenda were distributed to participants prior to the meeting. The Agenda (Appendix C) for the 2-day meeting was approved. Sylvia Humble was identified as the rapporteur for the meeting and Janet Lochead to keep track of the agreed upon revisions to the working paper.

All participants in the room were reminded that they had equal standing and were invited to participate fully in the discussion and to contribute their knowledge to the review process, with the goal of delivering scientifically defensible conclusions and advice. All participants, with the exception of Robert Sizemore, attended the meeting in person.

The following working paper (WP) was prepared and made available to meeting participants prior to the meeting (see summary in Appendix D):

Update to Estimation Methods for Geoduck (*Panopea generosa*) Stock Index by Dominique Bureau (CSAS Research Document 2017-070)

Participants were informed that Robert Sizemore (Washington Department of Fish and Wildlife) and Rowan Haigh (DFO Science) were asked in advance to provide written reviews of the working paper (Appendix E) to inform, but not limit, discussion by participants attending the meeting. Participants were provided with copies of the written reviews prior to the meeting. Robert Sizemore was unable to attend the meeting in person or by webinar and a Power Point presentation of his review was provided by the meeting chair. Rowan Haigh presented his review in a Power Point presentation in person at the meeting.

The conclusions and advice resulting from this review will be provided in the form of a Science Advisory Report (SAR) to Fisheries Management to inform the Geoduck fishery management planning (DFO 2017). The SAR and supporting research document will be made publicly available on the Canadian Science Advisory Secretariat (CSAS) website.

PRESENTATION OF WORKING PAPER

Working Paper: Update to Estimation Methods for Geoduck (*Panopea generosa*) Stock Index

Rapporteur: Sylvia Humble

Presenter: Dominique Bureau

The author began his presentation providing background into the Geoduck fishery management and stock assessment history in BC. The current methods used for Geoduck stock assessment assume that Geoduck populations were at equilibrium before the start of the commercial fishery. The ratio of current Geoduck biomass (B_c) on a bed to unfished exploitable Geoduck biomass (B') determines the stock index and is estimated for each Geoduck bed. Beds where the stock index falls below 0.4 are closed to commercial fishing. Biomass is estimated from density estimates derived from fishery-independent dive surveys, mean weights which are estimated from logbook data and bed area which is estimated from harvest locations, substrate mapping surveys and dive surveys. True unfished biomass estimates are not available for most Geoduck beds because harvest had begun before the first survey for most beds. Unfished exploitable biomass has been back-calculated by adding total historical landings to current biomass on a bed under the assumption that recruitment and natural mortality are in balance or, in other words, that there is no surplus production.

SIMULATIONS OF D' ESTIMATES USING CURRENT METHODS

When mean weight and area of a bed are assumed constant, estimates of B' are related to estimates of unfished exploitable density (D'). Simulations of D' were used to demonstrate the effects of varying surplus production rates on stock index outputs. Simulations used a constant harvest rate of 2% per year, a known initial density, a survey frequency of 10 years and assumed that density estimates are known exactly. Under conditions of no surplus production, as currently assumed, the stock index is an accurate representation of the current stock status on a bed. However, if surplus production is occurring, the estimated unfished exploitable biomass becomes inflated and the stock index is therefore underestimated which could lead to premature closures of the fishery. On the other hand, net mortality would result in a decrease in estimated unfished exploitable biomass and an unrealistically high stock index, potentially keeping a bed open when it should be closed. If the assumption of no surplus production is not met, the current methods for estimating unfished exploitable biomass are not accurate resulting in biased stock indices.

SURPLUS PRODUCTION

The assumption that mortality and recruitment are in balance implicitly assumes that no recovery from fishing activities is expected, contrary to many population growth and fishery models (i.e. logistic, Beverton-Holt, Ricker, etc.). Survey density and landings data from beds (n = 221) that have been surveyed more than once were reviewed to determine if there is evidence for surplus production. Average survey density was greater for the second survey for all regions, except for the Central Coast, suggesting that surplus production is occurring. Comparing survey density over time, from beds that were surveyed three times (n = 17), showed no evidence of varying surplus production rates over time. Given that the assumption of no surplus production is likely not valid, alternative methods of estimating virgin biomass are recommended.

ALTERNATIVE METHODS

Several alternative methods of estimating B', for both surveyed and unsurveyed beds, were suggested in the working paper. All methods of estimating unfished exploitable biomass assume that landings data is complete and accurate. However, landings data may be inaccurate in the early years of the fishery because of issues with under-reporting (during the 1970's and 1980's) and poor geo-spatial referencing of harvest events prior to 2000, which will likely affect some of the beds.

For surveyed beds, Option 1 anchors the unfished exploitable biomass estimate to the first survey, which shortens the period for which no surplus production is assumed. Options 2a – 2d use estimates of surplus production that are either: fixed by region, estimated for each bed from survey data, an estimated regional rate based on survey data or estimated from an age-frequency distribution. Option 3 assumes that the surplus production is equal to the landings before the first survey (i.e. that unfished exploitable biomass is equal to the biomass at the first survey). Option 4 is a hybrid method, based on available data, where surplus production is estimated but not permitted to exceed the landings before the first survey. This method places a limit on surplus production to ensure that unfished exploitable biomass does not fall below the biomass estimated from the first survey.

The author evaluated each of these options using survey data from beds that were surveyed either prior to first harvest or within the first year or two of harvest (i.e. an "early" biomass estimate for the bed is known) and that were surveyed more than once. In this way, estimated unfished exploitable biomass values using each of the alternative methods can be compared to biomass estimated from the early survey. The selection criteria used to evaluate options included whether the assumptions used by each method were likely valid, whether they maximize the use of available data, the level of precaution built into the methods and how broadly applicable various methods are. For surveyed beds, Option 1 tended to overestimate unfished exploitable biomass, Option 2 tended to underestimate unfished exploitable biomass and although Option 4 was generally a close approximation of the early biomass estimates, its implementation is complicated by its hybrid nature. Option 3 was the most accurate and precise option when evaluating the unfished exploitable biomass calculations and met most of the other evaluation criteria as described above.

The two options presented for unsurveyed beds were to maintain the status quo (i.e., $B' = B_c +$ cumulative landings) or to use regional estimates of unfished exploitable density to estimate unfished exploitable biomass. Approximately 12% of harvest is from unsurveyed beds, thus, changes to unfished exploitable biomass estimation methods for unsurveyed beds are unlikely to have as large an impact as for surveyed beds. Considering the uncertainty in biomass estimates for unsurveyed beds, the author recommended using Option 1 and maintaining the current estimation methods for unfished exploitable biomass.

The author further recommends calculating the stock index at the spatial scale of sub-beds to improve the accuracy and better use the landings data, which has been recorded at the sub-bed level since 2006. Otherwise, resolution in landings data is lost as the landings for the whole bed are divided among sub-beds proportionally to their area, instead of using the actual amount of harvest that has occurred on each sub-bed.

UNCERTAINTIES

Uncertainties around the input parameters used to estimate unfished exploitable biomass lead to uncertainties in unfished biomass estimates. For example, the landings data are only accurate after 1988, Geoduck recruitment is variable in time and space and there is a potential bias towards selecting commercially important beds or beds believed to be productive for re-surveying so that re-surveyed beds are not a random sample and may not be representative of all beds, including un-surveyed beds or beds surveyed only once.

PRESENTATION OF WRITTEN REVIEWS

REVIEW BY ROBERT SIZEMORE

- The reviewer was unable to attend the meeting and therefore, the Chair delivered his review in a PowerPoint presentation. The reviewer began his written review (Appendix E) providing general comments on the paper, noting the enormity of the task, along with several questions and suggestions that were addressed by the author following the presentation and summarized below.
- He thought that the author prepared an exhaustive review of the literature and given the fine resolution of the Geoduck fishery, the proposed changes to the B' calculations would be an adequate improvement. The author acknowledged the similarities and differences in Geoduck fishery management between the United States and Canada and welcomed the opportunity to compare and contrast fisheries.
- Recent observations of co-habiting species, such as the apparent increases in sea cucumber abundance that may face similar pressures as Geoduck, should be added to or expanded upon in the uncertainties section.
- Ideas for future work were suggested such as establishing index sites with known B' and harvested to 40% of B' that would be monitored long-term to determine recovery rates, similar to long-term monitoring sites in Washington State.
- The reviewer noted that siphon show factors affect Geoduck density estimates in Washington State and a discussion should be added to the paper. A reference to this discussion as it appears in Bureau et al. (2012) will be added to the working paper.
- The term recruitment should be defined clearly and used consistently in the paper.
- The reviewer suggested adding an index of quality that ranks the beds according to the accuracy and uncertainty of the data, to the B' data.

REVIEW BY ROWAN HAIGH

- Rowan Haigh presented his review with a PowerPoint presentation. The reviewer congratulated the author and acknowledged his accomplishment in this paper given the large breadth of work involved in Geoduck fishery and data management.
- The alternative options improve the current methods because they stabilize B' by relying on biomass estimates from the first survey. The current method uses the most recent survey and adds increasingly longer time series of landings as removals, which compounds the errors in the assumptions.
- The reviewer noted that "true" B_0 is not the appropriate terminology. A survey only offers an estimate of the population size with inherent sampling and process errors. We cannot be certain that any snapshot of biomass, whether it was before harvest occurred or otherwise is the true B_0.
- Landings are not necessarily the only removals from the population.
- B' could be estimated using a population model such as a surplus production model, performed in a Bayesian framework with thoughtful bounds on the estimated parameters, producing a reasonable probability distribution of B' values. Alternatively, a delay-difference model could be used if the trend in mean weight data exist or data-limited methods, such as Management Strategy Evaluation, could be explored in the future. Everyone agreed that

these suggestions were beyond the scope of the current paper, but would be good candidates for future exploration of this work.

- The notation used to describe equations in the document should be made clearer and a table of variables included in the text. In addition, "estimate of B_0" with a distinguishing variable (i.e. B') should be used to distinguish the estimates calculated in the working paper from the theoretical equilibrium value. This has been adopted in the working paper.
- Use of coefficient of variation (CV) was suggested to describe the uncertainty in densities estimates, in addition to the standard error (SE).
- The reviewer suggests adding a small summary table of the proposed alternative methods.
- The reviewer also provided several editorial comments that were acknowledged by the author.

GENERAL DISCUSSION

UNFISHED EXPLOITABLE BIOMASS ESTIMATION METHODS FOR SURVEYED BEDS

- Concerns were raised about the accuracy of landings data during the early years of the Geoduck fishery. Landings were considerably higher between 1976 and 1990 while Geoduck recruitment was low during the same time period. A period of high landings combined with low recruitment may invalidate the assumption that surplus production is equal to landings before the first survey (assumption under option 3 for surveyed beds), which may result in biased B'. There was a concern amongst participants that there is no consideration for the number of years since first harvest or the magnitude of landings. Following 1989 and into the 1990s, recruitment rates were rising and harvest rates were decreased. A cutoff point was suggested, after which the assumption of surplus production being equal to landings could be assumed to be reasonable. The author agreed and a new option was introduced (on the second day of the meeting) and accepted by the group (Option 3B – Unfished exploitable biomass = biomass from first survey + landings before 1989). This may be especially true for some beds in the South Coast, which may have been heavily harvested in the early days on the fishery before quotas and surveys were introduced. There was some disagreement over whether the timeframe of the low to high recruitment periods should be shifted to account for the time lag between settlement and recruitment to the fishery. Regardless of surplus production dynamics, the high landings in the early history of the fishery support a change to the methodology.
- A downside of adding the landings before 1989 is that the same problem as the other methods incorporating landings data persists, i.e., pre-1989 landings data are uncertain due to poor geo-referencing and under-reporting of landings before 1989. A certain level of uncertainty therefore exists in the early fishery landings data.
- There is a high degree of uncertainty in the surplus production estimates. Participants expressed concern that the uncertainty in density estimates is too high for it to be used to compare between subsequent surveys. There is not enough data or knowledge about the dynamics of surplus production to permit its use in estimating unfished exploitable biomass. There is some evidence in Zhang and Hand, 2007 that there is high spatial and temporal variability in surplus production, which would complicate the application of regional or average surplus production rates across all beds (Options 2 and 4).

- Participants agreed that a consistent approach was important, rather than using different estimation methods on different beds. Given the goals of the paper to eliminate the bias that was inherent in the current methods of estimating B', Option 3 was originally suggested as the best option. Option 3 relies on fewer assumptions that the other options. Consensus was to adopt Option 3B after it was presented.
- The term virgin biomass required clarification. Virgin biomass is a theoretical concept describing an unfished equilibrium biomass. It was suggested to replace the use of the expression "virgin biomass (B_0)" in the paper and to instead use the terminology "unfished exploitable biomass (B')".

UNFISHED EXPLOITABLE BIOMASS ESTIMATION METHODS FOR UNSURVEYED BEDS

- Participants agreed that extrapolating B' to un-surveyed beds using estimates of unfished exploitable density from nearby surveyed beds would be preferable to the current method.
- Only 9-10% of landings come from unsurveyed beds, which account for 26% of bed area. The uncertainty in biomass estimates associated with unsurveyed beds is therefore unlikely to have a large impact on the fishery.
- An alternative approach was suggested where Bayesian methods would be used to provide advice to Fishery Managers in the form of the probability that the stock index for a bed is above or below 0.4. This approach was outside the scope of the current paper and was tabled as a suggestion for future work.
- Participants all agreed that Option 2 is the preferred method to estimate B' for unsurveyed beds.

SPATIAL SCALE AT WHICH TO ESTIMATE THE STOCK INDEX

- Quotas are currently determined for each sub-bed, but harvest is not necessarily distributed among sub-beds proportionally to their area (within a bed).
- Calculating the stock index by sub-bed, rather than at the bed level will make better use of available landings data and eliminate the assumption that harvest between sub-beds is proportional to their area.
- There is consensus to calculate stock index at the sub-bed level to make better use of the available data and provide more accurate stock indices.

INCORPORATING PROBABILISTIC METHODS

- DFO's Sustainable Fisheries Framework calls for uncertainties to be incorporated into the advice given to managers. Although uncertainties are currently taken into account when determining harvest rates (Zhang and Hand, 2007) and the range of current biomass estimates for a bed, utilizing probabilistic methods (i.e. Bayesian delay-difference models) rather than the current deterministic calculations could allow for provision of science advice in the form of probability of the biomass on a bed to be above or below the Limit Reference Point (LRP).
- It was recognized and accepted by the group that the deterministic methods used in this paper and historically for Geoduck stock assessments and stock index estimations are appropriate and realistic given the number of beds and sub-beds that are managed and the goals of the fishery, but more robust stock assessment methods could be developed in

future. Further uses of modeling Geoduck stocks could also extend to an evaluation of impacts from sea otter predation pressures.

UPDATING OF B' ESTIMATES

- Participants discussed whether or not it was necessary or valid to update unfished biomass each year as new surveys are conducted. As new areas are surveyed, more bed-specific data can be used. Participants agree that B' should be re-estimated after bed area estimates are updated.
- Concerns were raised around Geoduck mean weight estimates and whether they change, or have changed, over time. If Geoduck mean weights have changed over time then current mean weight estimates may not be reflective of unfished mean weights. The author clarified that in the current methods, mean Geoduck weight is a running average across all years from 1997 to current and not merely the mean from the most recent fishing season. It may make more sense to use historical mean weights, but this needs to be analyzed in greater detail.
- Trends in mean Geoduck weight over time should be analyzed in future work. However, this was beyond the scope of the current paper. It was suggested that the mean weight estimates from the first survey could be used in the estimate for unfished exploitable biomass. It was suggested that a comparison of alternative methods of incorporating mean weight in biomass calculations be carried out. A second participant suggested that the product of mean weight and density may not vary over time depending on Geoduck growth dynamics and should also be assessed.

SURPLUS PRODUCTION

- Several participants expressed concern that the uncertainty in density estimates makes it unrealistic to compare between the densities over time. There is insufficient knowledge about the dynamics of Geoduck production to allow a definitive answer to whether or not surplus production is occurring, however, participants agreed that given the weight of evidence of theoretical considerations, conclusions from other studies and surveys in BC and Washington state as well as the assessment in the current working paper, that the assumption of no surplus production is not valid. Accurately quantifying the surplus production in a given area is likely not possible at this time.
- There was a discussion of where we are within the historical periods or regimes of productivity. Zhang and Hand (2007) show that the early fishery period was characterized by a period of lower productivity. Productivity in Geoduck has been correlated with environmental conditions (i.e. warmer conditions tend to promote productivity).
- Participants disagreed over whether or not the time scale under discussion of recruitment to the fishery should be shifted by 6 years to allow for settlement and recruitment to the fishery or not if we are discussing all exploitable biomass.

SEA OTTERS

- Although the effects of Sea Otters on Geoduck populations were considered outside of the scope of the current paper, there was some discussion of the impact of Sea Otter predation on commercially important harvest areas. Sea Otter predation of Geoduck is a significant concern to the Geoduck harvest industry in particular areas. Participants agreed that this should be flagged as a knowledge gap for future research.

- It was suggested that sea otter harvest pressure could be incorporated into a model to determine potential impacts.
- Suggested research questions could be alternative reference points that don't depend on B' (i.e. sustainable mortality rate), appropriate harvest rates given the exploitation rate of a new sea otter "fleet" in particular areas.

CONCLUSIONS

- Participants agreed that the paper addressed the bias in the current methods for unfished exploitable biomass estimation and the working paper was accepted.
- For each Geoduck sub-bed, virgin biomass (B_0) is now defined as the theoretical long-term equilibrium exploitable biomass in the absence of fishing. Because B_0 cannot be estimated using the current methods when harvest has occurred before the first survey, estimated unfished exploitable biomass (*B*') will be used as a proxy for B_0.
- Simulations showed that the current model produces biased estimates of *B*' and stock index if the assumption of "no surplus production" in the existing model is not met.
- Based on available data, literature review and fisheries stock assessment and population growth theory, the assumption of "no surplus production" in the current model is unlikely to be met, i.e., surplus production is likely occurring on BC Geoduck beds.
- The current method of estimating B' is therefore likely biased and an alternate B' estimation method is needed.
- For surveyed Geoduck beds, "Option 3B – Unfished biomass equals biomass from first survey plus landings before 1989" was recommended for estimating unfished biomass (*B'*).
- For un-surveyed Geoduck beds, "Option 2 – Use regional estimates of unfished density to estimate unfished biomass (*B'*)" was recommended.
- It is recommended that unfished biomass (*B*') be re-estimated when estimates of Geoduck current biomass are updated, so that the most up to date data inputs (bed area, mean Geoduck weight and density) are used.
- Methods were presented for estimating stock index on a by-Geoduck-sub-bed spatial scale, for surveyed and un-surveyed Geoduck beds. These methods take advantage of increased spatial accuracy of landings data that has been available since 2006. It was recommended to calculate stock index on a by-sub-bed spatial scale, instead of by-bed.
- It was recommended to explore the use of probabilistic methods rather than the current deterministic methods, to determine the probability that the stock index is above 0.4 for each bed.
- Because of the influence of Geoduck mean weight on the estimation of *B*', further analysis of Geoduck mean weight data and how mean weight is estimated for use in *B*' estimation was recommended.
- Further research is recommended in anticipation of future modifications to the Geoduck stock assessment framework that may be necessary due to expansion in the range of Sea Otters on the BC coast.

ACKNOWLEDGEMENTS

Rowan Haigh (DFO, British Columbia) and Robert Sizemore (WSDFG, Washington State) provided thorough written reviews of the working paper. Their effort in providing feedback to the author and peer review committee is greatly appreciated. The chair thanks Sylvia Humble for her diligent rapporteuring during the meeting and Janet Lochead for keeping track of the requested changes to the paper.

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Zhang, Z and Hand, C, 2007. Determination of Geoduck harvest rates using age-structured projection modeling. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/064: 49 p.

APPENDIX A: TERMS OF REFERENCE

UPDATE TO ESTIMATION METHODS FOR GEODUCK (*PANOPEA GENEROSA*) STOCK INDEX

Regional Peer Review Process – Pacific Region

March 15-16 2017 Nanaimo, British Columbia

Chairperson: Julia Bradshaw

Context

In the British Columbia Geoduck fishery, the Limit Reference Point (LRP) has been set at 40% of estimated virgin biomass (Zhang and Hand 2007) and has been applied on a by-geoduck-bed basis. The stock index, defined as the ratio of current biomass to virgin biomass on a bed, is calculated for each bed and compared to the LRP (Bureau et al. 2012). Virgin biomass must be estimated to calculate the stock index for each Geoduck bed. Few Geoduck beds have been surveyed before being harvested and therefore, virgin biomass has been back-calculated as the sum of estimated current biomass on a bed and removals from the bed, with the assumption that recruitment and natural mortality are equal (Bureau et al. 2012).

The current method of estimating virgin biomass in the Geoduck stock assessment framework (Bureau et al. 2012) is likely to lead to all harvested Geoduck beds reaching the LRP. That is, if surplus production occurs between surveys, the current methodology results in a continual increase in estimated virgin biomass, which in turn decreases the stock index. There is concern that the increase in estimated virgin biomass (for surveyed beds) is an artefact of the method currently used to estimate virgin biomass and may not be reflective of true stock status. This could lead to premature closure of some Geoduck beds and translate into loss of fishing opportunity for the industry. Additionally, stock dynamics are unknown on un-surveyed beds which may also lead to their premature closure.

The Geoduck stock index has historically been calculated at the finest spatial scale possible based on available data, i.e., at the by-bed spatial scale. Since 2006, the Geoduck fishery has been managed at the by-sub-bed spatial scale, thereby increasing the spatial accuracy of landings data. Increased spatial accuracy of harvest data may provide improved accuracy in the stock index calculations.

DFO Fisheries and Aquaculture Management Branch has requested that Science Branch provide a review of the method currently used to estimate Geoduck virgin biomass and provide alternative Geoduck virgin biomass estimation methods.

This paper is not meant to review, or provide alternatives to, the LRP currently used in the Geoduck fishery. The goal of the paper is to provide alternative methods to estimate virgin biomass and stock index only. The paper will thus provide updates to portions of the current Geoduck assessment framework (Bureau et al. 2012) and is not meant to be a completely new assessment framework. Further, the paper is not meant to provide Geoduck harvest strategies in areas occupied by Sea Otters as this issue has more general implications across species at the regional level.

This assessment, and the advice arising from this Canadian Science Advisory Secretariat (CSAS) Regional Peer Review (RPR), will be used to inform the management of the British Columbia Geoduck fishery. More specifically, advice will be used to update Geoduck virgin biomass and stock index estimation methods and to update some sections of the previous Geoduck fishery assessment framework (Bureau et al. 2012).

Objectives

The following working paper will be reviewed and provide the basis for discussion and advice on the specific objectives outlined below.

Bureau, D. Update to Estimation Methods for Geoduck (Panopea generosa) stock index. CSAP Working Paper 2015-INV-03

The specific objectives of this review are to:

1. Provide a review of the method currently used to estimate Geoduck virgin biomass, for surveyed and un-surveyed Geoduck beds.
2. Describe alternative methods for estimating Geoduck virgin biomass for both surveyed and un-surveyed Geoduck beds, including evaluation of the relative advantages and disadvantages of each method.
3. Provide methods for calculating Geoduck stock index on a by-Geoduck-sub-bed basis. Describe the advantages and disadvantages associated with this approach.
4. . Identify and discuss uncertainties and knowledge gaps in the available data and proposed estimation methods.

Expected Publications

- Science Advisory Report
- Proceedings
- Research Document

Participation

- Fisheries and Oceans Canada (DFO) (Ecosystems and Oceans Science, and Ecosystems and Fisheries Management sectors)
- Industry (fishing industry: Underwater Harvesters Association)

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APPENDIX B: MEETING PARTICIPANTS

Last Name	First Name	Affiliation
Atkins	Mike	Underwater Harvesters Association
Bradshaw	Julia	DFO Science
Bureau	Dominique	DFO Science
Christensen	Lisa	DFO Science
Curtis	Dan	DFO Science
Davis	Brooke	DFO Science
Dovey	Grant	Underwater Harvesters Association
Edwards	Andrew	DFO Science
Forrest	Robyn	DFO Science
Haigh	Rowan	DFO Science
Hajas	Wayne	DFO Science
Hay	Greg	Underwater Harvesters Association
Humble	Sylvia	Fisheries Management, Resource Management
Lochead	Janet	DFO Science
MacDougall	Lesley	DFO Science
Mortimor	James	DFO Science
Ridings	Pauline	Fisheries Management, Resource Management
Rogers	Juanita	Fisheries Management, Resource Management
Sizemore	Robert	Washington Department of Fish and Wildlife
Wylie	Erin	Fisheries Management, Resource Management
Yamanaka	Lynne	DFO Science
Zhang	Zane	DFO Science

APPENDIX C: AGENDA

Canadian Science Advisory Secretariat
Centre for Science Advice Pacific

Regional Peer Review Meeting (RPR)

Update to Estimation Methods for Geoduck (*Panopea generosa*) Stock Index

March 15-16, 2017
Nanaimo, British Columbia
Chair: Julia Bradshaw

DAY 1 – Wednesday March 15, 2017

Time	Subject	Presenter
0900	Introductions Review Agenda & Housekeeping CSAS Overview and Procedures	Chair
0915	Review Terms of Reference	Chair
0930	Presentation of Working Paper	Dominique Bureau
1030	***Break***	
1050	Overview Written Reviews	Chair + Reviewers & Dominique Bureau
12:00	***Lunch Break***	
1300	Identification of Key Issues for Group Discussion	RPR Participants
1330	Discussion & Resolution of Technical Issues	RPR Participants
1445	***Break***	
1500	Discussion & Resolution of Technical Issues	RPR Participants
1615	Check in on progress and confirmation of topics for discussion on Day 2	RPR Participants
1630	Adjourn for the Day	

DAY 2 – Thursday March 16, 2017

Time	Subject	Presenter
0900	Introductions Review Agenda & Housekeeping Review Status of Day 1	Chair
0915	Discussion & Resolution of Technical Issues (Continued from Day 1)	RPR Participants
1030	***Break***	
1045	Discussion and Resolution of Working Paper Conclusions	
1130	Develop Consensus on Paper Acceptability & Agreed-upon Revisions	RPR Participants
1200	***Lunch Break***	
1300	*Science Advisory Report (SAR)* Develop consensus on the following for inclusion: • Sources of Uncertainty • Results & Conclusions • Additional advice to Management (as warranted)	RPR Participants
1430	***Break***	
1445	*Science Advisory Report (SAR)* (Continued)	RPR Participants
1600	Next Steps – Chair to review • SAR review/approval process and timelines • Research Document & Proceedings timelines • Other follow-up or commitments (*as necessary)*	Chair
1615	Other Business arising from the review	Chair & Participants
1630	***Adjourn meeting***	

APPENDIX D: WORKING PAPER ABSTRACT

The stock index in the British Columbia (BC) Geoduck fishery is estimated on a by-Geoduck-bed basis and is defined as the ratio of current biomass (Bc) to unfished exploitable biomass (B'). The limit reference point (LRP) for the BC Geoduck fishery was defined as current biomass being equal to 40% of B'. When biomass is estimated for a bed, the stock index is also estimated and beds for which the stock index is below 0.4 are closed to fishing. To date, B' has been back-calculated as the sum of current biomass and fishery landings on the bed. This method assumes no surplus production on a bed after fishing begins.

The methods currently used to estimate B' on surveyed and un-surveyed beds were reviewed. Simulations were performed to illustrate how surplus production affects estimates of B' and stock index over time using the current method. If surplus production occurs, the method currently used to estimate B' produces biased estimates of B' and stock index. Density dive survey data, for beds surveyed more than once, showed that surplus production may be taking place on harvested Geoduck beds in BC and that therefore the assumption of no surplus production is likely not met.

Alternative options of estimating B' on surveyed and un-surveyed Geoduck beds were proposed and evaluated. Data requirements, assumptions, applicability, advantages and disadvantages of each proposed option were reviewed. The performance of each option for surveyed beds was evaluated for beds where early estimates of B' were available. Estimating B' as biomass from the first survey plus the landings before 1989 was recommended because it has few assumptions, the assumptions are believed to be reasonable, it is applicable to all surveyed beds and is simple to implement.

Few alternative B' estimation options were available for un-surveyed beds because less data is available for those beds. For un-surveyed beds, the recommendation was to use estimates of unfished exploitable density from surveyed beds to extrapolate unfished exploitable biomass on un-surveyed beds.

Methods for estimating the stock index at the by-sub-bed spatial scale were presented along with advantages and disadvantages of this approach. An evaluation of the possible impact of changing the spatial scale at which the stock index is calculated was presented. A recommendation was made to implement calculation of stock index at the by-sub-bed spatial scale.

APPENDIX E: WORKING PAPER REVIEWS

ROWAN HAIGH, FISHERIES AND OCEANS CANADA

Prelude

The issue at hand is how to improve the assessment of Geoduck populations in hundreds of beds along the BC coast. Currently, a stock index that is essentially depletion (B_t/B_0) is used and the limit reference point is identified as $0.4B_0$. The problem is that B_0 is derived using a very simple calculation that sums the estimated current biomass and the estimated total historic landings, ignoring population growth dynamics. The author identifies that the current method of calculating B_0 and stock status is biased when surplus production occurs (and that this bias can be compounded over time) and then shows that surplus production does occur at re-surveyed sites. A number of options for improvement are proposed.

Virgin Biomass

The differences among proposed options to calculate B_0 are subtle but rely on simplifying assumptions that essentially amount to creative book-keeping. There's nothing wrong with this approach given (i) the scale of the problem and (ii) an important flaw in the current method (recognized by the author): excluding surplus production (i.e., assuming recruitment = natural mortality) leads to a biased estimate of B_0, and consequently, a biased stock index (B_t/B_0).

The first alternative method (option 1) simply shortens the period over which surplus production (SP) is ignored by using the first survey rather than the latest. In subsequent methods (options 2a-d), SP is estimated in a variety of ways, but all rely on ad hoc approaches – fixed from the literature, calculated between surveys, calculated from age data – to estimate SP before the first survey. Option 3 simply assumes that SP equals landings before the first survey, which cancels out the latter and leaves B_0 equal to the first survey biomass. Option 4 adopts the method (from options 1-3) based on the data available from each bed.

Whichever options are adopted, the main factor that will stabilise B_0 is the focus on using the biomass estimate from the first survey. Using biomass estimates from the latest surveys and summing increasingly longer time series of landings simply compounds the errors from the assumptions made and destabilises B_0. Given this observation, it may not matter a great deal if surplus production is incorporated or not.

Regarding the assumptions made in the paper, I have a few concerns. The first is the statement that the "true" value of B_0 is known for some beds simply because they were surveyed before any harvest took place. To begin with, a survey only offers a population estimate that contains sampling error (design and coverage) and process error (inability to detect small individuals or invisibility to survey divers at the time of survey). Even if a survey could accurately detect every individual, how can we be certain that this represents the true B_0? At the time of the first survey, maybe the population is at a low point due to poor growth (low-productivity regimes), high predation, disease, habitat destruction, etc. The authors acknowledge that bed areas change from time to time.

The second assumption is that landings reflect the true removals from the population. Again, landings are not necessarily known with 100% accuracy (as the author states) and removals can be due to the same things mentioned above (disease, predation, habitat destruction, etc.).

Ideally, B_0 should be estimated using a population model such as a surplus production model (1), where next year biomass = this year biomass + surplus production - catch. Granted, these models make many assumptions and can lead to unbounded estimates of B_0; however, if performed in a Bayesian framework (e.g., BSP of McAllister 2014) with thoughtful bounds on the estimated parameters (usually *r* and *K*, especially given the physical size limits of each bed), the estimate of B_0 could be described by a reasonable probability distribution. Additionally, decision tables offer a manager some guidance on how likely a catch policy (TAC) will cause the population to cross a reference point (e.g., $0.4B_0$). I would have expected to see this as a proposed alternative method, even if the time series data are meagre.

$$B_{t+1} = B_t + rB_t\left(1 - {B_t}/{K}\right) - F_t B_t \quad (1)$$

where, B_t = biomass at time (year) t,

F_t = instantaneous fishing mortality at time (year) t,

r = intrinsic rate of growth, and

K = carrying capacity or virgin biomass B_0.

Within the model system, abundance indices (CPUE and/or survey indices) are assumed to be directly proportional to stock biomass:

$$I_{jt} = q_j B_t \quad (2)$$

where, q_j = constant of proportionality (est. parameter) for the abundance index j, and

I_{jt} = the observed abundance index j in year t.

Perhaps many/most of these beds do not have adequate survey time series; however, all are presumably harvested on a regular basis and should support some form of CPUE series. Another possibility is to apply one BSP to each region, using available bed survey indices and one regional CPUE series. This would offer regional estimates of B_0 that might consume less management time, i.e., managing five stocks instead of 221 (or 2,859!). Effort allocation within region would likely need addressing (e.g., implementing annual catch caps, say 0.1 $D_b A_b W_b$) to avoid excess harvesting on specific beds.

The methods ultimately adopted by the custodians of Geoduck populations depends on the management objectives. If the goal is to manage each bed (fine spatial scale), then ad hoc rules presented in this document offer a reasonable shortcut. If the goal is to manage stocks sustainably, then some form of population model should be explored using stocks that comprise groups of beds that make sense on a bioregional scale or represent genetic coherence. Alternatively, there is the option to explore data-limited methods like DLMtool, which may only offer sustainable management actions without ever knowing B_0; however, time needs to be invested if exploring DLM options.

Mathematical Notation

The author might consider that the mathematical notation in this document is cumbersome and distracting. Parameters should be represented by single letters and defined in a table that describes the indices and variables. Biologists tend to use acronyms like SP for surplus production, but in mathematical notation this means *S* times *P*. Other distracting occurrences like SI_{SubBed} could be more concisely represented by I_{b_d}, where I = stock index, b = bed, and d = subbed within bed, for example. The time element can be represented as a single variable t, where t spans years and the current year is 2016. This means that t_0 would differ for all beds. Regardless, I only point this out to alert the author to a more precise method of communication. At the very least, the author should define the variables in a table before they appear in the equations. This notation summary helps the author think about his variables, and provides the reader a place to look up variables that are discussed later.

Density Uncertainty

In the density section, the reporting of uncertainty using standard errors (SE, Table 7) seems a bit misleading as SE automatically becomes lower as the the number of beds in a region R increases. I'd much rather see the coefficient of variation (CV = standard deviation/ mean = σ_R/μ_R) as a measure of uncertainty in addition to SE.

In the same table (7A), evidence is given that Geoduck densities increased between the first and last surveys. As a rough check using the the means and standard errors between the first and last surveys in a t-test (3), two-sided, alpha=0.05, none of the regions appeared to show significant differences. I'm not a statistician, but the author might wish to double-check that the observed differences were significant given the data.

$$t = \frac{\bar{x}_2 - \bar{x}_1}{\sqrt{V_2/n_2 + V_1/n_1}} = \frac{\bar{x}_2 - \bar{x}_1}{\sqrt{SE_2^2 + SE_1^2}} \text{ WHERE } V = SD^2 = SE^2 n \quad (3)$$

Clarify the Alternative Options

In Section 5.2, it would have been nice to see a small summary table outlining the various model options proposed for estimating B_0 before the details were presented. This would have helped clarify the details later in the text. An example in-text table for surveyed beds might look like the following (presuming that variables are defined earlier in the text, as suggested above). The author offers more detail in Table 11, which is good, but Table 11 should be mentioned earlier (in Section 5.2) and renumbered if necessary.

Option	Description	Surplus Production	Equation for B_0
1	First survey (B + prior L)	None	$B_{s1} + L_{bs1}$
2A	Opt 1 - prior SP	Fixed	$B_{s1} + L_{bs1} - 0.01(Y_{s1}\text{-}Y_{s1})AW$
2B	Opt 1 - prior SP	Survey rate	$B_{s1} + L_{bs1} - SPR_j(Y_{s1}\text{-}Y_{s1})$
2C	Opt 1 - prior SP	Regional density	$B_{s1} + L_{bs1} - SPD_R(Y_{s1}\text{-}Y_{s1})AW$
2D	Opt 1 - prior SP	Recruitment from ages	$B_{s1} + L_{bs1} - [(1\text{-}p_r)D_{s1}\text{-}D_{h1}]$*
3	Biomass from 1st survey	Implied	$B_{s1} = D_{s1}AW$
4	Hybrid	Variable	$B_{s1} + L_{bs1}$ - min(rNY_1, L_{bs1})

* probably incorrect but author should clarify for completeness

Additional Comments and Edits

- Avoid the term "true estimate of B_0" and simply use "estimate of B_0". The estimate may be biased or non-biased; however, B_0 is a theoretical equilibrium value that is unlikely to be represented by a single survey on a non-harvested population at a specific point in time. An estimate of B_0 is perhaps better designated $\hat{B}_0$.
- If B_0 is not estimated by traditional models, perhaps call it something else like *B′* (prime). This would be especially relevant to Option 3 where the proposal is to set B_0 to the biomass from the first survey. It's obviously not B_0 but it is the first *B* observed.
- Tables 12A and 12B offer estimates of B_0 by bed stratified by regional area (and by default, number of years between surveys). Evaluation of the ratio of estimated B_0 to "true" B_0 is done using an overall mean, which assumes that the samples come from the same

statistical population, but when a stratified mean is used (grouping samples by identifiable statistical populations), results differ. Assuming my quick calculations are correct, option 1 has the lowest CV and option 4A's ratio is closest to 1 while being less than 1.

Option	$\bar{x}$	σ	CV
1	1.0266	0.9059	0.8824
2A	0.9467	0.8874	0.9373
2C	0.7040	1.0653	1.5133
3	0.8903	0.8235	0.9250
4A	0.9649	0.8740	0.9058
4B	0.9389	0.8681	0.9246

- Ensure that units of measurement are identified in all tables and figures. For example, what is the unit of measurement for density in Table 1? I assume it's Geoducks/m^2, or more generally bivalves/m^2, but the reader shouldn't have to assume.
- The word "data" is plural (singular = datum).
- Parameters, variables, indices represented by letters (not numbers) should be italicised throughout the document (e.g., B_c vs. B_0). Do not italicise acronyms (e.g., LRP).
- If variables are represented by single letters throughout the document, equations don't really need the "multiplied by" sign. For example, AW instead A×W. However, if you retain variable names like "SPR", you will need them for clarity.
- The paper states that trends in mean weight of Geoducks have not been investigated (beyond the scope of the paper); however, if these data exist, there is an opportunity to use a delay-difference model to estimate B_0.
- Predation (e.g., sea otters) could be incorporated as another source of removals. In fisheries model terms, it might be represented as a fleet with its own catchability quotient.

Summary

The author has performed a lot of work and proposed sensible alternatives for managing thousands of Geoduck beds. If this is what management wants, then the methods have to be quick to implement. These quick methods use a proxy for B_0, and all the alternatives proposed by the author essentially anchor this value to the first survey (when available). There are model-based alternatives, not presented in the paper, for managing coherent regions that estimate B_0 in its truest sense (long-term, equilibrium, unfished biomass). Model-based methods should offer sustainable-catch management on larger-scale populations.

References

McAllister, M.K. 2014. A generalized Bayesian surplus production stock assessment software (BSP2). Collect. Vol. Sci. Pap. ICCAT, 70(4): 1725-1757.

The Five Questions

1. Is the purpose of the working paper clearly stated?

Yes

2. Are the data and methods adequate to support the conclusions?

Yes

3. Are the data and methods explained in sufficient detail to properly evaluate the conclusions?

Yes, but clarification may be useful in places.

4. If the document presents advice to decision-makers, are the recommendations provided in a useable form, and does the advice reflect the uncertainty in the data, analysis or process?

Yes, but recommendations need discussion with RPR.

5. Can you suggest additional areas of research that are needed to improve our assessment abilities?

Yes. Use surplus production model to estimate B_0. Explore estimation of B_0 in logical groups of beds (e.g., bioregional, genetic) to facilitate more efficient management. See review.

ROBERT SIZEMORE, WASHINGTON DEPT. OF FISH AND WILDLIFE

The author should be congratulated for presenting a thorough review of geoduck estimation methods and analyses of the strengths and weaknesses of each approach. It is no small matter to attempt estimates of benthic bivalve densities that have high variability of siphon show over various temporal and geographic scales and under a variety of survey and harvest histories. It is very encouraging that on-the-ground surveys are being done on most geoduck beds in British Columbia (BC) and that density indices are available at a bed or sub-bed level. There are many similarities between the BC and Washington approach to managing commercial geoduck fisheries and this is an excellent opportunity to compare and contrast our respective fisheries to improve management in both regions.

The management guidelines for commercial geoduck harvest in BC are well documented and readily available on-line. Even so, there may be some aspects of management that could possibly be open to interpretation. I suggest that author should consider a brief background section describing basic management principles in BC to give the reader a broader context for the review and analysis of geoduck stock estimation methods. It is my impression that harvest rates in BC are calculated for 3 large geographic regions (North Coast, West Coast and Inside waters) and the harvest rate selected is multiplied by <u>current</u> biomass estimates to calculate regional TACs. Then harvest occurs on one of 3 sub-regions within each large geographic region on a 3-year rotation. In addition to the regional TACs, there is a benchmark Limit Reference Point (LRP) of 40% of estimated virgin biomass set for each bed. The precautionary TACs (ranging from 1.2 to 1.8% of current biomass), fishery independent surveys of biomass, and bed-by-bed LRPs is a reasonable approach given the uncertainties of recruitment, natural mortality, and catch accounting. The focus of this manuscript is to examine existing methods to estimate virgin biomass (B_0) and current biomass (B_c) and how surplus production simulations affect these estimates and ultimately affect the LRP estimates. In Washington we use surveyed B_0 as a starting point for geoduck beds, since all beds are required to have surveys prior to harvest. We also do not have a bed-by-bed limit reference point, but use a F_{40} strategy as part of the age-based equilibrium yield model to calculate a 2.7% exploitation rate.

For surveyed beds, I agree with the author that under most circumstances the best estimate of B_0 is the first survey estimate (aka Option 3). It appears that in many cases a back-calculation of B_0 using current surveys and landings is not possible due to geo-referencing limitations of historic landings and also the reliability of landings information is difficult to verify. However, I suspect that the precision of density estimates of first surveys vary greatly from bed-to-bed. One may want to consider this by ranking of beds based on the precision of first surveys and then evaluate the best method to calculate B_0 based on a comparison of precision between the first survey and subsequent surveys on a bed. For situations where the landings are geo-referenced and thought to be accurate, and where more recent surveys have high precision, may result in a more accurate estimate of B_0 than use of a low precision first survey. This would be a modified approach to Option 3 using survey estimate and quality of landings data criteria to make decisions about improving the estimate of B_0. In the manuscript the author should consider including a case study of one bed and the effects of various options and results.

I also agree that Option 3 has advantages over other methods by not relying on estimates of surplus production. Surplus production is highly variable within beds over time, is not constant and is not predictive of future production. Like BC, we apply a geoduck harvest rate to current biomass estimates. One effect of this is an increase in geoduck TAC when the population is growing and a decrease in TAC when the population is declining. This method links exploitation to population dynamics and indirectly takes empirical surplus production or decreased production into account, which in turn may compensate for less precautionary estimates of B_0 relative to LRP.

If I understand this correctly, “unsurveyed beds” have at least one current density estimate. If this is correct, then the author should consider using a different description such as “beds with one survey”. For beds with one survey, Option 1 using current survey estimates of biomass and harvests to calculate B_0 may be the best approach. One survey will provide variance of the biomass estimate and if this is combined with accurate landings (which have no variance) then the precision of the B_0 estimate is known. In addition, our experience in Washington is that geoduck densities may change over small geographic scales. Applying mean regional density to beds with one survey (Option 2) has an inherent risk of over- or under-estimating densities on beds with no other information taken into account to determine true densities. The precision of the bed estimate will not be known when using Option 2. The recommendation to prioritize beds with one survey geoduck beds for future surveying will introduce greater certainty into fishery management.

The scope of uncertainties within a fishery management framework is well described. However, there may be other uncertainties outside of the scope of normal fishery parameters that the author may want to include in Section 7 (Uncertainties) or in Section 10 (Future Concerns). In Washington we have made observations of an apparent increase in juvenile sea cucumbers. Several working hypotheses include enhanced recruitment due to changing oceanic conditions or reduced predation due to sea star wasting disease, or both. If these forces are affecting sea cucumber productivity, then the same factors may enhance geoduck production. Rising sea surface temperature and decreasing pH may become a concern for geoduck populations in the future.

Additional considerations:

- Relevant time scales could be brought into the manuscript sooner, so the reader can evaluate the possibility of production over time. Production is often defined in terms of survey events without the benefit of time scale. What is the mean number of years between surveys or between harvests and surveys?
- The author uses the term “recruitment” frequently in the manuscript without distinguishing between larval settlement and recruitment into the fishery. This is somewhat confusing in Section 5.2.1 when recruitment is characterized as being reduced in geoducks younger than 5 years. In fact these geoducks have recruited, but are not fully selected into the fishery.
- In Washington we continue to observe signs of illegal harvest and a long-term decline in rates of recovery on geoduck beds that have been harvested. We have made stock assessment a high priority to enhance real time feedback on the status of exploited stocks. Adjusting geoduck counts with a siphon show factor is an important variable in our geoduck density estimates. In addition to current stock estimates, we have selected geoduck beds to monitor long term recovery of geoduck density compared to pre-fishing estimates. I am not

sure if this would work under the BC harvest strategy, but perhaps beds with true B_0 estimates and harvested to a LRP level (40%) could be assessed frequently to determine natural recovery rates. A discussion about how siphon show factors affect density estimates in BC would be useful.

- We have established geoduck index stations in Washington to monitor the combined effects of recruitment and natural mortality. This has provided fishery independent information about geoduck populations and has been used to compare natural fluctuations in geoduck abundance with areas that have been illegally harvested. Are index stations used in BC geoduck fishery management?
- The rationale for the review of geoduck estimation methods is not well described. There seems to be some motivation for using a less conservative approach in geoduck fishery management. Is this review a request from UHA and how will the recommendation support sustainable fishery practices?

APPENDIX F: WORKING PAPER REVISIONS

Revisions to paper –Update to estimation methods for Geoduck (*Panopea generosa*) stock index – Recorded by Janet Lochead

- Revisions made to the paper were done using Track Changes so that you can see what changes were made. Below I've tried to indicate where in the document I have made the requested changes so you can find them easier and tick them off.
- Made variable names in the text in italics (accepted the format changes to make more readable).
- At the meeting there was back and forth regarding using mathematical notation in the equations or not. I ended up switching to mathematical notation, i.e., each variable referred to by a single letter (e.g. I for stock index instead of SI). This allowed me to simplify the look of some of the equations (i.e., get rid of "x" signs and also get rid of some brackets in a number of places. I accepted those changes already.
- Add more background to intro on BC fishery management (Robert S.). Done
- Clarify what is meant by "true" estimates of B_0. (Section 5.5.1 & Table 12) Replaced "True B_0" with "early B'" through section 5.6.
- Acknowledge that B_0 is an estimate/proxy/surrogate and call it B prime. Done. Added paragraph to intro to differentiate between B0 and B' and define B'. I replaced instances of "virgin biomass" with "unfished exploitable biomass" (where necessary) to be consistent with new B' definition and wording in the SAR. I replaced B0 with B' where appropriate to be consistent with SAR. I accepted all those changes to make the document more readable.
- Clarify that B_0 and B prime are for the exploitable population, not total population. Done in Introduction third paragraph.
- Expand section 10 to include other ecosystem considerations that may affect Geoduck population dynamics. Done.
- Speak more to frequency of harvest between surveys. Consider adding the number of years the beds were harvested between surveys. Added to 4.1.
- Added stats to sections 4.1 and 4.2 and adjusted wording around "increased", "greater", etc accordingly.
- Clarify what you mean by recruitment, i.e. larval settlement versus recruitment to the fishery clarified in a number of places.
- Wording around "precautionary" when describing rationale for changing methods.
    - Highlight removal of bias in current methods? Added wording around bias, sometimes biased estimates are also more precautionary (lead to earlier closure).
- Delete tables 1-6 (redundant). Andy Edwards asked to keep when I suggested deleting. Kept them, made all fields 3 decimals as requested by Wayne. Clarified captions as requested by Wayne and Andy.
- Refer to how siphon show factors affect density estimates in paper and refer to 2008 assessment framework Already in the paper, Section 7.6.
- Clarify in the paper the reason for updating B_0 on an annual basis (as new data is available, less extrapolation, more accurate if you are using real data and not inferred, that B_0 won't

change for most beds) Added a few sentences to clarify, second to last paragraph of discussion.

- Add a table of variables. Added as Appendix 1. Need to decide on order: 1- as they appear in text (that's the way it's sorted now) or 2- alphabetical.
- Add a summary table outlining the various model options proposed for estimating B_0 before details are presented. Beginning of Section 5. Done.
- Add units of measurement in all tables and figures (eg. unit for density in Table 1). Tables 1 – 6 are relative densities and therefore dimensionless. Added a sentence to captions to clarify. Other tables had units already.
- Add comment in Section 5.3 for option 3. Put these in Section for Option 3B as justification as to why 3B is preferred.
  - If the difference between first harvest and first survey is large (landings were huge in 80's when fishery started), the B_0 could be underestimated. It's not the difference between first harvest and first survey so much as whether or now a bed was heavily harvested in the 1980's.
  - The longer the assumption that SP = landings is to hold, the less likely it is to be true (esp. with really high landings).
  - Consider visually presenting # of years or # of harvest years between first harvest and first survey AND/OR include a median in Table 10. Table 10 shows data for UN-surveyed beds, therefore cannot show data between first harvest and first survey, since there is no survey for these beds.
- Change wording in table 13 from "more accurate" to consistent. Done (under Advantages for Option 2).
- Change unsurveyed recommendation in paper to option 2. Done.
- Surplus production (SP) rates, Table 8 pair-wise comparisons, the relevance of $p = 0.53$: tighten up wording around "increased"/"decreased"/"different" and your ability to detect a difference (Wayne H. comment). Include a more fulsome description of the statistics added to test for differences in SP rate and uncertainty around density estimates. Some suggestions are to say that SP could be occurring, or that we can't say that it isn't occurring, or that we have no evidence to support the assumption that there is no SP. The statistical test here was not to determine whether or not there was surplus production (i.e. not testing for SP>0). The statistical test was to determine if the two estimates of surplus production rates (1st and 2nd survey intervals) were different.
- Add to Uncertainty Section that these methods don't carry uncertainty through the process. Consider outlining how you could carry uncertainty through in Future Work Section. Added section 7.7 within the Uncertainties section. All dealt with there, there is no "Future Work" section in the Res Doc.
- Remove reference to sea otters on page 9 and 10. Done, also deleted Table 9 as it is no longer called upon. Table 9 only referred to in now-deleted text. Re-numbered following tables (and references to them in text) and accepted those changes.
- Add how you identified non-otter impacted areas. Added in Section 2.2.
- Rename option 3 to 3A Done and add Option 3B Done.
- Add that re-surveyed beds may not be representative of all beds Added in Section 7.6.

- Added Figure 4 (Fishery history) as part of justifications for Option 3B.