Developing Robust Management Approaches for Hand-Harvested Marine Invertebrates; Review of Geoduck Operating Models for Blue Matter Science Contract 2022/2023

Welcome/Introductions:

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Background:

1. Overall goal:
    a. To build a framework for making decisions to ensure FSP requirements and conservation objectives and met for management of hand-harvest marine invert fisheries

2. Timeline:
    a. We are on year 2 of this 3 year project

3. What:
    a. 4 case studies for operating models (geoduck, green urchin, sea cucumber, manila clam); today will focus on geoducks

4. Where we are now in Year 2 of the project:
    a. Refining reference (base case) Oms
    b. Developing robustness (or alternative OMs)
    c. Establishing a range of quantitative performance metrics
    d. Establishing and preliminary testing of alternative management procedures (MPs), including reference points, with management options relevant for marine invertebrates
    e. Determining additional management objectives beyond the FSPs for the four case studies

Agenda:

1. Feedback on the operating models that will be presented
2. Discuss goals for the fishery (i.e. what do you want the fishery to look like in 5 years? 10 years?)
3. Discuss metrics that you think would represent fishery success (i.e. high catches, consistent catches, biomass above a threshold, etc.)
4. Discuss any other management options that you would like to see tested in the simulation framework
5. Discuss any other issues you would like to see addressed with the simulation framework

*This is not meant to be formal but rather a conversation so that the simulation framework can best address the needs for the fishery

Tom's Presentation

Purpose of Operating Models:

1. Motivation for operating models:
    a. Usually Fisheries Management and Science gets top down directives; historically this has required expert advice from Fisheries Management and Science which is demanding and difficult to resolve.
    b. This is difficult to resolve unless you make a calculator that can produce these answers therefore not depending on intensive advice and input from Fisheries Management and Science. Operating models are becoming more accessible (can use to test fisheries managements processes first in the model) and therefore help solve this issue.

2. Functions of an operating model:
    a. We ***can't predict*** what will happen to stocks due to growth, climate change, etc.
    b. We ***can*** be certain that we have a management system if those things happen.
    c. We can't be certain what will happen but with operating models we can be certain that we have management systems if those things happen.

Data updates:

1. General
    a. We've had new data and more recent data to the model. The model has become more sophisticated to account for sampling regimes, etc.
    b. The OMs to be presented today were updated with data as recent as a few months ago
    c. Geoduck is best informed of the 4 case studies because of the range of data we have;
        i. Age-length observations
        ii. Age-composition survey data by stat area
        iii. Length-weight observations
        iv. Annual absolute biomass survey by sub-bed
        v. Annual catch data by statistical area
        vi. Fishery dependent CPUE data
    d. The operating model is based on empirical evidence from our data
    e. Survey biomass by stat-area shows that some stat areas (2, 6, 7, 4, 5, 24, 23) are substantially bigger than other areas; 80% of the biomass are from these 7 areas. The operating model currently will focus more on these 7 areas since they have the majority of the biomass.

2. Unchanged since the last meeting in February:
    a. Empirically derived somatic growth for each stat area
    b. Each simulation provides uncertainty in each operating model

3. New:
    a. Blue Science Matter has been provided with survey biomass for multiple years;
        i. The data has discontinuities in them which makes it hard for models to approximate.
        ii. Some of the survey data isn't credible (some increases don't make sense in terms of recruitment)

Biomass Data:

1. Caveats:
    a. For some older missing biomass data points the biomass was back-calculated (by Erin P.)
    b. Biomass from 2010-2015 for Stat Area 23 doesn't include closed area data (this explains the huge biomass increase in Blue Matter's biomass time series graph)
    c. Where sea otters were abundant/colonized in a bed that data was zeroed out originally implying no harvest option.
    d. The biomass time series given to Blue Matter Science currently only go back to 2010.
        i. This is because it was labor intensive to parse out issues and fill data holes in the data, so this shortened time series was given first to test whether it was useful before continuing through older data.
        ii. It was decided that the time series were not helpful given various data inconsistency issues
    e. Weight Correction factor for area 3,4,5,6,2 was used previously which would cause biomass jumps when the correction factor was taken out. *The density didn't change but the survey method changed around 2014.
    f. When considering biomass, considering beds not sub-bed status except for older data.
    g. It was suggested that the changes in biomass between years could be because different beds are surveyed each year
    h. The biomass time series graphs showed impossible recruitment increases:
        i. For this operating model rendition, anything more than a 15% increase in biomass between years, Blue Matter Science split the time series
        ii. Tom proposed using the most recent biomass number rather than the biomass as a time series given all the issues with the time series data

2. Suggestions on how to use the biomass data:
    a. Tom proposed using the most recent biomass number rather than the biomass as a time series given the above issues denoted in '1. Caveats'.
        i. Have an individual index for each stat area that you have continuous samples for and try to fit a model to all of them. This way you wouldn't have data hole filling issues
        ii. We could have a biomass index per sub-bed. There's ~120 sub-beds in area 7 and that would mean we need a 120 indices to fit the model to if we went that way but it eliminate interpretation issues.
        iii. We could also use the top ten contributory sub-beds to reduce the number of model fits needed.
    b. *The leap we're making with top 10 sub-bed method; these 'top 10 sub-beds' would be indicative of biomass change for everywhere.
        i. It was also suggested that we could do Northcoast, inside, outside areas rather than the top 10 sub beds since these areas or so different.
    c. Tom's problem with that idea is the data holes again. Biomass can't be interpreted back in time because of algorithm for TAC as well as discontinuity in sub-beds.

3. Concerns/questions with the biomass data:
    a. There's a change in biomass in stat area 24 around 2016-2018 possibly due to sampling/survey issues?
    b. We could be losing precision by aggregating sub-beds and calculating CIs on stat area rather than keeping CIs at the sub-bed level
    c. At what precision is sub-beds indicative of stat area biomass?; would we expect that to give us overall idea of biomass;
        - Likely bigger beds would be selected that could bias the data but may on average give an accurate trend
        - Typically sub-beds have been surveyed that are more important to the beds
        - Sea otter beds get avoided in surveys as to not sway biomass estimates lower and cause closures
    d. Tom will only use survey data not extrapolation data.
    e. The fishery operates between 3-20 m and biological surveys don't occur deeper than 20 m. It is known that there are geoducks deeper than 20 m but nothing about their distribution/abundance is known.
    f. Only harvestable area is surveyed (places that are too gravelly to harvest or quality of geoduck is poor are omitted), so biomass estimates are only of vulnerable biomass
    g. Surveys only cover fishable areas, which holds us to higher a standard (we think we have less than we do)

4. Estimating the precision on the biomass data:
    a. Calculation of survey biomass precision by stat area:
        i. Median and 75% CIs were provided by sub beds
        ii. $SD_{stat.area} = \surd(\Sigma SD_{subarea}^2)$
        iii. Standard deviation requires that there's no correlation in the way the sub-beds were calculated. If they're correlated the SD calculation needs another value
        iv. Mean weight variance calculated from catch data
        v. Within discussions it was decided that mean weights are likely independent per beds so the precision/variance calculation wouldn't have conflict with correlation.
        vi. The current estimates give too precise of a biomass estimate

5. Conclusions on biomass data
    a. Based on current and historical info, the catches are so small we wouldn't expect fisheries induced changes in biomass trends. Based on stable population model the biomass trends would be very flat.
    b. We can use the most recent biomass value as a pseudovalue but we can't use the biomass as a time series in its current state.
    c. Based on picking ten top beds; pick top 50% of survey biomass. Estimate model with and without subbed trends. (beds rather than sub-beds= fewer indices, sub-bed data didn't exist until 2006)
    d. The model that's being presented today is assuming the biomass estimates in their current state which aren't realistic (geoduck can't have the giant changes that the biomass data is showing)

An aside about sub-bed data:

1. Harvest data; we only have sub-bed data starting in 2006. This impacts if we want to incorporate landings data, etc.
2. New bed code is assigned when new sub-beds are added
3. The survey method has not changed since mid-1990s (divers visual survey)

Age Composition by Sub-area Data:

1. Age composition is very different between sub-areas
2. There's no size selectivity that would lead to a reduction in the capture of clams as they grew older
3. Tom assumed that there is age structure by sub-area and split them out instead of aggregating them
4. Mean-weight correlation is negligible as geoducks grow so fast it would be less of a problem
5. Age structure has to be fit to individual curves due to the discrepancy in age curves between sub areas.
6. We don't know anything about recruitment from deeper geoducks.
7. **We could calibrate ROV surveys to a dive survey, then survey the deeper habitats with ROV. Then the ROV survey wouldn't have to be accurate it would just have to be relative**

Catch data:

1. Catch curves might be able to estimate M. We can do this with geoduck since we have absolute biomass rather than relative.
2. Catches are assumed to be observed precisely (a CV of 5%).
3. Some areas are fished every year and some annual rotations (north coast area 1-10 on a 3 year rotation since 1989 due to logistics of monitoring phsp, water quality, etc.)
4. Data before 1989 had a disagreeance between fish slip and landings data

Nominal commercial CPUE:

1. Average catches/effort; not an advisable approach because of density differences, seasonality etc.
   a. These would change apparent catch rate without changing abundance
4. **Assumed 50% CV when creating the model as a placeholder which can later be replaced with a better value. **Mackenzie M. et al. working on producing that value.***
5. CPUE is used for trends not values
6. CPUE is market driven;
   a. The fishers might take different amounts of time to fish depending on quota they've been told (i.e. if they need less catch then they might take more time to get higher quality catch). ****This would impact model inputs.**
   b. Change from frozen to live catch in early 1990s impacted the way they were fishing too (change towards fishing for quality). Dom expecting CPUE to drop around 1990 due to this but this was not reflected in Tom's graphs.
   c. Overtime the fishing behavior would be the same post-1990 since they're driven by buyer requests. Therefore market price shouldn't impact CPUE
7. Recruitment, quality, and diggability get incorporated into log book data in log book comments (2006-present). However, this is done on volunteer basis so not going to be available for all beds. As well, the diggability are normally categorical rankings of 2's and 3's which isn't very informative. Bed code might more informative for co-variance.
8. *Tom will test CPUE with and without bed trend*

Work Items still to do and Notes on Tom's end:

1. Work items:
    a. Standardize CPUE
    b. Hierarchical somatic growth estimation (fits one coast wide mean on github- Meghan)
        i. There is a large discrepancy in number of observations between areas. Meghan B found one k coast wide was better as some areas have very little data.
    c. Post-1990 CPUE
    d. Sensitivity with and without CPUE
    e. Fit to final survey biomass value only as opposed to the biomass time series
    f. Explore fitting to bed-specific biomass surveys (longer time series, a cumulative percentage of overall stat area biomass)
    g. Sensitivity with and without bed trend

2. Notes:
    a. Note analyses are focused on biomass available to fishing; unknown abundance deeper than 20 m for example, or in MCA
    b. Surveys include closed fishing areas and fishing quotas is based on this abundance
    c. Survey biomass includes closed areas (contamination closures (marine biotoxins and pollution &sewage etc).
    d. There's likely a 2-year lag between data and quota advice
    e. Some areas are in a 3 year rotation (partly for business planning reasons)

3. Other concluding notes on data and OM future plans:
    a. 1976 was the start of the commercial fishery
    b. How complete are catch data; anything after 1989 when dockside validation was implemented has a high level of confidence. In earlier landings, catch would be assigned to area but might not have bed information
    c. Fishery started in the SOG, expanded to WCVI and then to the North Coast. We wouldn't expect catches from North Coast before 1980
    d. Another way to get CPUE; Look at harvest rates over time and divide by catches
    e. Use inter-annual measure of variability to see if your model is overparameterized.
    Catches/standardized CPUE = Effort
    Catches/index= trend in fishing mortality over time
    $I_y=f(C_y, F_y, 0)$,
    $I={}_qB$
    $C_y/I_y=E_y$

- CPUE: around the mid-1990s they started counting how many geoducks/dive. Biomass index would be better than a numbers index. Diggability available starting 2006 for some beds. Bed code can be used a proxy for diggability. Likely start around 1990 and without diggability to reduce restrictions on data usage.

Mackenzie going to start with; Depth, bed code, diver code. Tom suggests generating a data set and testing it with that. Abundance trend between years shouldn't be irratic. Scale per stat area not coastwide.

Goal (MM); one model per stat area

Results:

1. Inputs:
    a. RCM runs in R and is easy for other people to use. Because it's in R Tom can put wrappers to turn different aspects on and off
    b. Somatic growth and weight-length parameters taken from empirical data
    c. Age- and time-invariant M estimated from a lognormal prior (mean 0.025, cv=0.3)
    d. Commercial selectivity was assumed to be fixed: 5% at 100mm and fully selected and asymptotic from 120mm (ie. anything above 120 mm is going to be caught with equal likelihood).
    e. Tom assumed that it's logistic selectivity and that it follows size limit since he wasn't given age data for the commercial fishery.
    f. Discussion confirmed that age selectivity likely wouldn't be that different between commercial and biological data.
    g. There is no length data since 1980s and maybe 1990s.
    h. Non-compliance on harvesting rules assumed to be minimal.
    i. If the model is parameterized on age and length it doesn't work because of the unusual somatic growth in geoduck.
    j. Biomass survey was split into chunks originally for this presentation of model but not going to do that moving forward.

2. Model fit for stat area 6:
    a. Sharp increase in biomass survey. Won't have this in the next version (not splitting biomass survey into chunks next time)
    b. Composition data is posing challenging:
        i. Two years 1996 and 2007; model can't fit the data to create recruitments this big.
        ii. Lots of noise in the data that the model can't get to.
        iii. Age data is problematic. Fixed logistic has lots of noise but fits the curve quite well. Tom thinks the age data is really problematic (is it recruitment variability or non-independent sampling issues).
            1. Age data hard to interpret due to localized dynamics being very variable. It's posted this is likely due to high variability in recruitment.
            2. Stat area 6 fits the worst for the age data. Only 7 years of data available to work with.
            3. *10 years ago, DFO decided it wasn't worth getting age data from every place they went since they knew that geoducks grow fast. Thus the survey regime changed to re-sampling the same beds over time to get more info on recruitment data. Some beds should have multiple samples because of this shift.
    c. Age data not informing any reference points. Only informing recruitment strength over time and total mortality.
    d. Proposition to simulate localized recruitment impulses; this could be an Operating Model using the variability on the regional scale.

3. Estimates/assumptions from stat area 6 model:

a. Fishing mortality= 1% which is consistent with the goal of <1% catch for that area despite seeming like a low fishing mortality. The absolute maximum fishing mortality is 1.8% but TAC is set much lower.
b. There was a major change in the way the quota were set; until 2006 harvest rate around 1% of virgin biomass and then it changed to slightly higher harvest rate based on current biomass rather than virgin biomass
c. The model shows a pulse in recruitment in 2010 because it's trying to fit an increase in biomass data at that time (which we decided we weren't going to use moving forward)

4. Mortality in all stat areas:
   a. M_MLE (natural mortality) estimate looks reasonable but range don't seem right.
   b. Natural M seems to vary greatly between areas. These big differences in natural M would impact tac greatly.

5. Other notes:
   a. The OMs currently only focus on the areas that produce the most biomass since 22 (stat areas) models is a lot of models.
   b. OMs are currently based on calendar year, but fishery isn't based on a calendar year. This doesn't capture fishing highs in December-January in a fishing year. Also not all 'fishing seasons' are 12 months.
      i. Next model iterations will have harvest rate/ catches switched to season rather than calendar year since biomass is for a season not a calendar year
   c. We haven't talked about maturity yet, Tom not sure what he assumed (Dom says 2-3 years maturity)
   d. M estimation issue, tails too wide
   e. Reference point for many things in Canada is 50% B_0 usually but geoduck is at 25% B_0 ish right now
   f. Model shows grossly underfished right now
   g. Kobe plot: very underfished and underfishing
   h. Suggestion to put localized recruitment variability into the simulations based on the model misfit subareas

6. Reference point results:
   a. All models estimated productive stock size to be very low with respect to unfished (~25%) input due to the unusual growth and maturity of geoduck.
   b. Current estimates of exploitation rate and stock level suggest the stocks are very lightly exploited and close to unfished
   c. Because the stock is so underexploited projections had to be done with quite extreme values to get responses in the biomass

Example uses:
1. Projection of sea otter predation
2. Impact of precision in survey
3. Impact of closures (rebuilding analysis)

1. Sea otter scenario:
    a. Linear relationship between otters and mortality
    b. Non-trivial increases in mortality could occur with large increases in otter populations. How much of this can we control with fishing?
    c. This scenario shows that management applications could be negligible in comparison to environmental impacts in certain situations
    d. A sea otter project might become a CRSF but they need someone not already on a CRSF to go on the proposal
    e. Otter distribution expansion rather than abundance increase in a single area impacts geoducks more

2. Impact of biomass survey precision:
    a. Current harvest rate set to total max 1.8
    b. Current exploitation rate is very low and hence can be expected to have limited impact on biomass outcomes
    c. evaluated four index based management procedures that fish at varying multiples of the current Catch/index ratio:
    $TAC_{y+1}=\Delta \cdot I_y \cdot C_{2022}/I_{2022}$
    (IR10,IR20, IR30, IR40 with Δ values of 1,2,3,4, respectively)
        i. ran these with current index precision and ¼ current index
        ii. There was very little SSB-only impact on variability in catches
    d. Model says we don’t need to increase budget for surveying, if anything it could be reduced
    e. MPs can be designed to better adapt to ‘noisy’ input data. We can use a smooth line rather than the raw data.
    f. Conclusions:
        i. What you do is almost as important as what you know. You can do a lot of things to overcome deficiencies in data and understanding.
        ii. Our current data/model shows that we’d have to fish 4 times as much to see a decline and we still wouldn’t see it approach anywhere near our upper stock reference

3. Superimposition of fine-scale spatial heterogeneity:
    a. See what movement in recruitment between subareas does
    b. Create sub-area viscosity between areas or not; we can simulate movement distributions that are observed. This allows us to see if it impacts management decisions.
        i. Caused a bunch of sub area closures and forced efforts to the other areas.
        ii. Assuming effort redistribution into open areas biomass stays similar but CPUE increases since you’re fishing more time in higher density areas.
1. However, currently in practice, when areas are closed the catch isn’t reallocated to the open areas, the overall harvesting goes down. This management is less favorable to convincing fisherman the pros of closures.

2. Whether closures align with higher or lower density areas would impact whether reallocating closure catch to open areas in an effective idea
    c. We don't yet have larval directional dispersal in the model. Comments from the group is that it's very variable.
    d. Getting around the lack of knowledge around dispersal: we could simulate the extremes (near-zero recruitment between sub-beds and recruitment is at the level stat area) to recognize all the impacts.

More uses for OMs:

1. Mixing extremes (fully mixed, local only)
2. Closures/effort redistribution

3. Freeze catch, with closures for contrast
4. #1MP
5. #2 LRP; fairly arbitrary currently (40% of B_0, but 40% was arbitrary. This is very precautionary)-
    a. A more biologically informed value desired.
6. LRP in response to changing environmental conditions
7. LRP/predators/fishery impacts/serious harm
8. Economic viability
9. Fishery versus economic sustainability
10. Performance metrics relating to stability (MPs)

Other discussion points:

1. Geoducks are going into fish stocks provisions as 1 coast-wide stock so that status will have to be reported based on the whole coast
2. **We need to come up with a definition of what the LRP is before we can come up with a value.**
    a. **What does 'causing harm' look like?**
3. LRPs are biologically based but are impacted by economical abundance to fish. Therefore, LRPs can be at a point that would never be fished anyways because it's not economical to fishermen/industry
4. Fish stock provisions only based on biological state of stock not the fisheries viability. LRPs are supposed to be based on the biological state not on the economically viable to industry.
5. What do we have to do to satisfy regulations and what do we have to do to manage the fishery are not always the same conversation. Meeting the regulation is a smaller box than the management of the fishery

Next steps:

1. Data finalization
2. Hierarchal growth

3. Areas for operating model refinement:
    a. Not putting biomass into blocks anymore
    b. Don't know what to do with age-comp data inconsistencies (great variation between beds)
    c. Tom would like more management options to be sent to him
    d. Standardize CPUE series by management area
    e. Hierarchal estimates of asymptotic length
    f. Evaluation of coast-wide abundance
    g. Developing operating models at varying spatial scales
    h. Superimpose spatial structure (sub-bed heterogeneity for example)
    i. Develop robustness tests
    j. Climate change and growth
    k. We've got a huge amount of variability already between all our 22 models. If we can prove that a target works for all 22 models we can demonstrate the robustness of the management model
    l. What is coast-wide status/status by stat area
    m. We need an LRP coast-wide and by stat area
    n. We want to know the potential biological risk from increasing numbers of predators

4. Robustness tests:
    a. Natural mortality rate
    b. Changes in somatic growth
    c. Changes in recruitment strength

5. Performance metrics:
    a. Yield
    b. Conservation (LRP)
    c. Stability in yield
    d. Economic viability
    e. Accessibility (i.e. in relation to the location of open/closed areas)
    f. Harvest rate (efficiency)

Action Points

1. **We could calibrate ROV surveys to a dive survey, then survey the deeper habitats with ROV. Then the ROV survey wouldn't have to be accurate it would just have to be relative**

2. **Assumed 50% CV for nominal commercial CPUE when creating the model as a placeholder which can later be replaced with a better value.** ***Mackenzie M.** et al. working on producing that value.*

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