Informing Management of B.C. Hand-Harvested Invertebrates: Operating Models, MPs and MSE

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Disclaimer

The following work is preliminary and intended only as tool for eliciting feedback on data, modelling and other aspects of these fisheries.

None of these results are final.

These analyses do not necessarily reflect the point of view of DFO or other funders and in no way anticipate DFO future policy in this area.

Interactive Report

This Technical Report documents the various components of the Invertebrates Decision Framework. However, due to the complexity of all of the underlying components, it was originally designed as an interactive html document with links to the various supporting reports, figures and documents. The interactive version can be found here

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Objective

Establish operating models for at least four species of hand-harvested invertebrates in B.C. for the purposes of informing management decision making including data collection, suitable stock assessment approaches, reference points and harvest control rules.

Project details

Term	April 2022 - March 2023, April 2023 - March 2024, May 2024 - March 2025
Funding body	Canadian Department of Fisheries and Oceans (DFO)
Funding stream	ProServices, Medium Complexity Bid
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Contract No.	4500038008, 4500051010, 4600000482
Project Partners	Blue Matter Science Ltd.
Blue Matter Team	Tom Carruthers, Adrian Hordyk, Quang Huynh
DFO Principal Investigators	Shannon Obradovich, Mackenzie Mazur

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Operating models

An operating model is a theoretical description of fishery and population dynamics used for the testing of management strategies that could include, for example, data collection protocols, stock assessment methods, harvest control rules, enforcement policies and reference points. In fisheries, operating models are used in closed-loop simulation to test management procedures (aka. harvest strategy) accounting for feedback among the system, data, management procedure and implementation. A management procedure is a rule that calculates management advice from data. Management Strategy Evaluation uses closed-loop simulation of management procedures as a core technical component but is a wider process of stakeholder and manager engagement that identifies system uncertainties, performance metrics, viable management procedures, ultimately aiming to adopt an MP for the provision of management advice for an established time period.

Reference Case Operating Models The reference case operating model is used as the single 'base' operating model from which reference set and robustness set operating models are specified. Reference and robustness tests are typically 1-factor departures from the reference case OM, however sometimes reference set OMs are organized in a factorial grid across primary axes of uncertainty.

Reference Set Operating Models Reference set operating models span a plausible range of the core uncertainties for states of nature. These are often the types of alternative parameterizations or assumptions that would be included in a stock assessment sensitivity analysis.

The role of the reference set operating models is to provide the central basis for evaluating the performance of candidate management procedures, for example rejecting badly performing harvest strategies.

Robustness Set Operating Models Robustness set operating models are intended to include additional sources of uncertainty for providing further discrimination among management procedures that perform comparably among reference set operating models.

Robustness operating models often represent system states of nature that are not empirically informed or are hypotheses of a subset of stakeholders.

Geoduck (*Panopea generosa*)

Operating Model Specification Geoduck operating models were constructed assuming that discrete populations occur at the resolution of statistical area (management area). Models were conditioned using the Rapid Conditioning Model (RCM) of openMSE (SAMtool package, Huynh et al. 2023) and fitted to historical catches, standardized catch-per-unit-effort, sub area age composition data, a current estimate of absolute biomass and biomass trends within statistical area based on bed-level survey data. Given an assumption of asymptotic fleet selectivity and the availability of the absolute biomass estimate, it was possible to estimate natural mortality rate from an informative prior.

The Reference Case operating model presented here is for statistical area 14 which had numerous age-composition data.

MSE-style closed-loop projections were undertaken for the current harvest rate (the principal management guideline) and current catch levels.

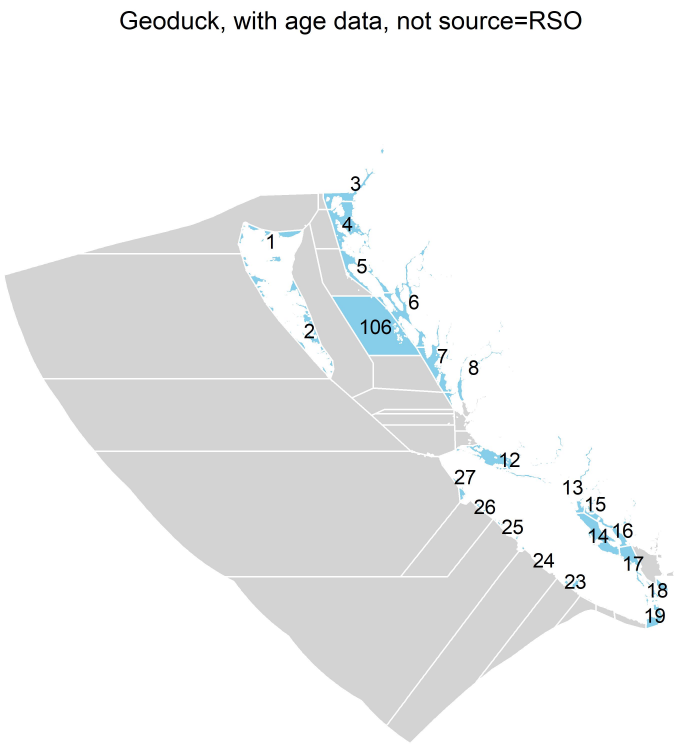

Figure 1: Statistical Areas for which age data were available and RCM operating models were fitted

Reference Case Operating Model Reference Case Operating Model Description (.html)

Comparison of Stat Area Operating Models Across the 22 Stat. areas for which age-data were available and models could be conditioned to data

Stat Area Comparisons (.html)

Table 1a. Geoduck RCM model fits

Area
RCMfit_Stat_Area_1.html
RCMfit_Stat_Area_106.html
RCMfit_Stat_Area_12.html
RCMfit_Stat_Area_13.html
RCMfit_Stat_Area_14.html
RCMfit_Stat_Area_15.html
RCMfit_Stat_Area_16.html
RCMfit_Stat_Area_17.html
RCMfit_Stat_Area_18.html
RCMfit_Stat_Area_19.html
RCMfit_Stat_Area_2.html
RCMfit_Stat_Area_23.html
RCMfit_Stat_Area_24.html
RCMfit_Stat_Area_25.html
RCMfit_Stat_Area_26.html
RCMfit_Stat_Area_27.html
RCMfit_Stat_Area_3.html
RCMfit_Stat_Area_4.html
RCMfit_Stat_Area_5.html
RCMfit_Stat_Area_6.html
RCMfit_Stat_Area_7.html
RCMfit_Stat_Area_8.html

Custom Analyses A summary of the 2024 custom analyses for all species is available here

Some initial closed-loop MSE-type projections were also conducted

Project Status

Table 1b. Project Updates and Progress

Table 1c. Geoduck assumptions and to-do list

Geoduck Meeting Notes etc 2023 Meeting Notes (.pdf)

Manila Clam (*Venerupis philippinarum*)

Operating Model Specification Manila clam operating were conditioned to historical catches from 1999 onwards. The model assumes an equilibrium annual catch equal to 75% of the mean catch from 1999-2003.

Update	Details
Hierarchical growth model	M. Burton (DFO) developed a hierarchical model in TMB / stan for estimating Stat. area growth parameters. MCMC samples are now used in the operating models
Current absolute biomass	Data were updated to 2022 and current absolute biomass estimates (only absolute index) are now used to inform the model
Bed-level trends	Bed-level biomass survey time series are used to inform the trend in recent biomass. This includes up to 10 individual bed indices or those that encompass 80% of surveyed biomass (calculated by the mean value per bed over all years)
Standardized catch per unit effort	Dr M. Mazur (DFO) developed a generalized linear model to standardize commercial catch data according to various variates. The model included temporal autocorrelation to prevent the estimation of large, implausible differences in inferred abundance.
Selectivity parameterized by age	After around age 10, geoduck reach close to their asymptotic length. Parameterizing operating models according to age is necessary to fit the age composition data.
Age composition disaggregated	In order to account for regional variation in age structure, the age composition data are disaggregated by subarea. All are assigned dome-shaped selectivity except the sub area with the highest mean age which is assigned logistic 'flat-topped' selectivity.
Natural mortality prior	Given the absolute biomass survey and age composition data it is possible to estimate natural mortality. This is assigned an informative prior of mean 0.05 with a CV of 15%.
Lognormal likelihood for age data	The model is now fitted to age composition data with a lognormal likelhood function - this reduces the tendency for the model to estimate occasional high recruitments from a single year of data.
Truncated age composition data	Only age composition data after 1990 are used in operating model conditioning

Assumptions	To Do
Stat. Area is the biological unit	Make generic management performance outputs
Commercial Catch CV of 5%	Add correct coords to OM objects by stat area
Annual age data effective sample size of 40	Make a coastwide OM by aggregating data
5% Selectivity at 100mm, full selectivity at 120mm (all Stat Areas)	Test open-closure rules
Informative M prior of 0.05 with CV of 15%	Work on calculation of coast-wide LRP
Absolute biomass estimates are only final historical year	Test efficacy of small-scale spatial closures
Somatic Growth follows a von-B growth equation	Robustness (M, unreported catches, somatic growth, rec strength)
Maturity is from 2003 study	

The model is fitted to a CMA-level annual time series of survey densities. This was calculated by aggregating density estimates from beaches, where the beach-level data include linear interpolation among years with observed data, and constant extrapolation before and after the first and last observed years, respectively.

The model was also fitted to fishery length composition data and survey age composition (annulus data). In both cases the selectivities were assumed to be logistic. The fishery selectivity function was parameterized by length, the survey selectivity was parameterized by age. Somatic growth and weight-length parameters were sampled from a multivariate normal distribution arising from variance-covariance matrix of parameter estimates from an MLE fit to annulus data by Statistical Area.

Since the available data only very weakly inform depletion, the models are configured with an additional prior on current stock depletion for testing robustness of management options to varying levels of stock status.

The operating models were fitted using the Rapid Conditioning Model (RCM) included in the openMSE framework.

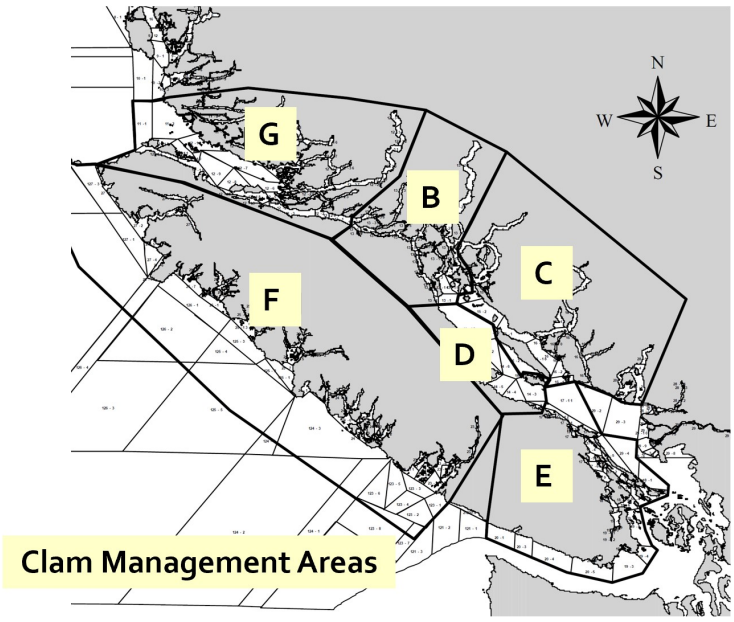

Figure 2: Location of Clam Management Areas.

Comparison of Operating Models Across CMAs Across the 4 Clam Management Areas for which age-data were available and models could be conditioned to data

Stat Area Comparisons (.html)

Table 2a. Manila Clam RCM model fits

Area
RCMfit_Beach_17-19-002.html
RCMfit_CMA_C.html
RCMfit_CMA_D.html
RCMfit_CMA_E.html
RCMfit_CMA_F.html

Reference Case Operating Model Reference Case Operating Model Description (.html)

Custom Analyses An investigation of minimum size limits and rebuilding was conducted and is documented here

Example closed-loop MSE-type projections were also conducted (.html)

Project Status

Update	**Details**
Goes to 2022	All data sources updated to 2022
Includes IFMP survey data	Most recent data points were included which allow for use of the index in simulated projections (as a basis for responsive management)
Age composition data	From annulus data, now included and assumed to be linked to the survey index series.
Placeholder for fishery effort data	Model can be configured to include a metric of exploitation rate based on slip data (effort days).

Table 2b. Project Updates and Progress

Assumptions	To Do
Logistic (length - based) selectivity for the fleet	Investigate use of effort slip data (managers).
Logistic (age-based) selectivity for the survey	Investigate sensitivity to use of somatic growth derived from biological sampling (as opposed to annulus data)
Equilibrium catches are 75% the average of 1999-2003	Sensitivity alternative assumptions about 'spool-up' equilibrium catches.
	Demonstrate robustness of current size limit management (much greater than size at maturity).
	Sketch historical catch patterns (expert judgment)
	Tactical management options at the beach-level. E.g. open/closure rules based on density
	Robustness to winter-kill / summar-kill events
	Develop OMs at varying spatial scales (e.g. beach)
	Investigate possible uses of ICMP and its requirements (precision etc)

Table 2c. Manila clam assumptions and to-do list

Manilla Clam Meeting Notes etc 2023 Meeting Notes (.pdf)

Green Sea Urchin (*Strongylocentrotus droebachiensis*)

Operating Model Specification Green Urchin operating models were constructed assuming that discrete populations occur at the resolution of Statistical Area (Management Area). Models were conditioned using RCM and fitted to historical catches, historical nominal catch-per-unit-effort, a survey relative abundance index and fleet and survey length composition data.

The Reference Case operating model presented here is for Statistical Area 12 which has numerous data and corresponds with a reasonably large harvest of urchin.

MSE-style closed-loop projections were undertaken for the current harvest rate (the principal management guideline) and current catch levels.

Comparison of Stat Area Operating Models Stat Area Comparisons (.html)

Table 3a. Green Urchin RCM model fits

Reference Case Operating Model Reference Case Operating Model Description (.html)

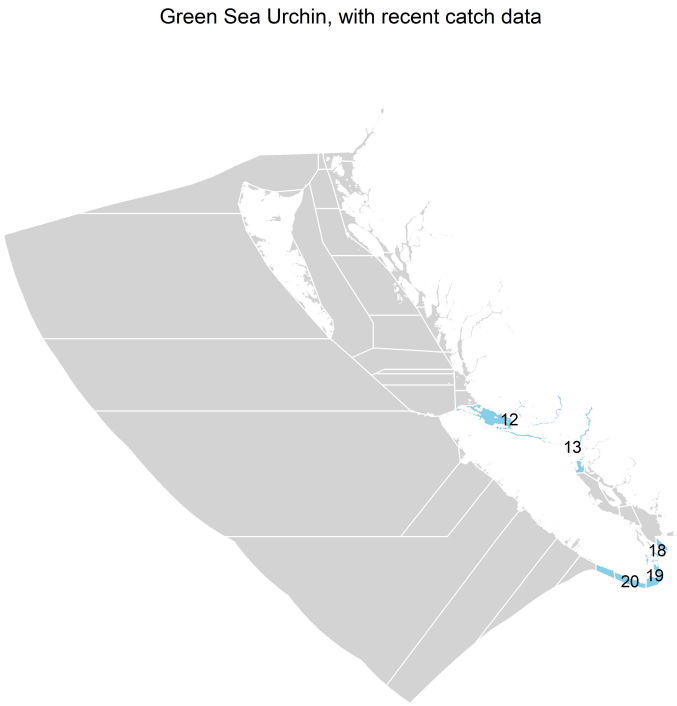

Figure 3: Statistical Areas for which composition data and recent catches were available and RCM operating models were fitted.

Area
RCMfit_North_Area.html
RCMfit_South_Area.html
RCMfit_Stat_Area_12.html
RCMfit_Stat_Area_13.html
RCMfit_Stat_Area_18.html
RCMfit_Stat_Area_19.html
RCMfit_Stat_Area_20.html

Custom Analyses The results of demonstration analyses is documented here

Also conducted were some example closed-loop MSE-type projections (.html)

Project Status Table 3b. Project Updates and Progress

Table 3c. Green urchin assumptions and to-do list

Green Sea Urchin Meeting Notes etc. Feb 2024 Meeting Notes (.pdf)

Update	**Details**
Catches incorporated to inform model scale	Models updated to include catch history
Model includes nominal CPUE	This is a placeholder for standardized CPUE in a revision of the models
Multispecies survey density included	To allow for the testing of density-based management procedures linked to simulated density
Survey relative biomass in legal / sublegal size classes	Two additional indices included that are for legal and sublegal size classes providing information about the population structure and potentially allowing for management procedures that can account for shifts in size composition.
Size composition data included for both fleet and survey	Two sources of size composition data were combined in model conditioning for Stat. areas 12 and 19 that are relatively 'data rich'
Evaluation of alternative spatial definitions	Stat. areas were aggregated into northern and southern areas to evaluate impact on estimates of reference points and stock status.

Assumptions	**To Do**
Stat. Area is the biological unit	Get biomass estimates from Lyanne - relative abundance indices?
Similar diameter-wet weight relationship among Stat areas	How to construct a CPUE index?
	Somatic growth parameter ranges? Currently K comes from red urchin in california and Linf from eye-balling the W-L data
	Distribution for L50 needed (or suitable range)
	Check Harvest header key
	Add correct coords to OM objects by stat area
	Robustness of size limit to changes in predators
	Opening / closures rules based on abundance.

Giant Red Sea Cucumber (*Apostichopus californicus*)

Operating Model Specification Sea cucumber operating models were configured to be numbers-based due to the inability to age sea cucumbers and representatively measure/weigh them. This entails the following working assumptions: knife-edge growth to size / weight 1 at age 2; Recruitment based on a Beverton-Holt S-R relationship calculated from mature numbers (the model includes a fecundity growth parameter k where fecundity follows a cubic relationship); Asymptotic selectivity from a young age class (e.g. age 4-7).

Since harvesting is by diver and highly selective, regulation is by harvest rate and bag-limit, the numbers-based operating model is potentially appropriate for the management regime but requires realistic modelling of the bag-limit impacts on discard rate and size selectivity.

Models were conditioned using RCM and fitted to historical catch in numbers, an estimate of absolute numbers, and a time series of survey density estimates.

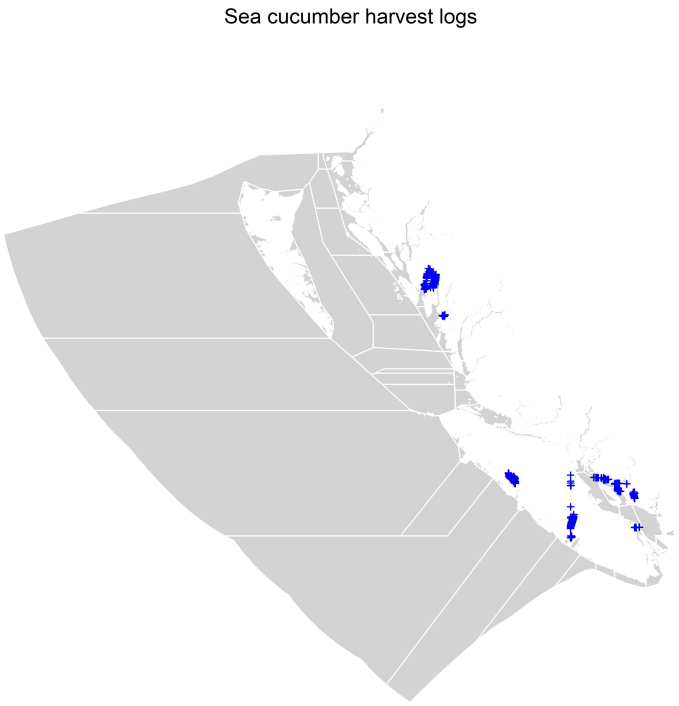

Figure 4: Location of historical Sea Cucumber harvests.

Reference Case Operating Model Reference Case Operating Model Description (.html)

Area comparisons among Subareas (revised for 2024 from QMA) Subarea Comparisons (.html)

Table 4a. Sea cucumber RCM model fits

Area
out.csv
out2.csv
outs Feb 2024.xlsx
RCMfit_12-39.html
RCMfit_15-5.html
RCMfit_4-1.html
RCMfit_6-5.html
RCMfit_6-6.html
RCMfit_6A.html
RCMfit_6C.html
RCMfit_7-12.html
RCMfit_7-17.html
RCMfit_7-9.html
RCMfit_7A.html
RCMfit_7B.html
RCMfit_7C.html
RCMfit_8-16.html
RCMfit_8-4.html
RCMfit_8D.html
RCMfit_QMA_25A.html

Update	Details
Revised to subarea models	Spatial unit changed back to subarea to allow for complete catch, density and biomass reporting for each model.
Top 10 by landings	Ten operating models were configured based on the ten subareas with the most contributory historical landings
Density included for MPs	By including observations of survey density it is now possible to configure management procedures and opening/closing rules based on simulated density observations
Development of responsive management procedures	Allows for the testing of adaptable harvest rate policies and open/closure rules
Rotational closure management procedures	Allows for evaluation of risk equivalency among harvest rates with and without rotational closures

Custom Analyses In 2023, MSE-style closed-loop projections were undertaken for the current harvest rate, current catch levels and six example management procedures that aim for 2.2, 4.2 and 6.7% harvest rates without alternating closures (C_22, C_42, C_67) and also with alternating closures (Alt_22, Alt_42, Alt_67) whereby the QMA is closed and opened every other projection year.

The results of these demonstration analyses is documented here

Project Status Table 4b. Project Updates and Progress

Table 4c. Green urchin assumptions and to-do list

Sea Cucumber Meeting Notes etc Feb 2024 Meeting Notes (.pdf)

Assumptions	**To Do**
Subarea is the biological unit	Managers / scientists to select a range of sub areas that span a range of exploitation, location and environmental conditions
Modedl is numbers based (somatic growth, maturity, length-weight are unknown and variable) rather than biomass-based.	If possible, derive bag limit discarding rate using observations of catch rate and discard rate
Knife edge weight / length at age of 1 at age 2+	If possible, derive a (vague) model for size (age) selectivity given size (age) availability
Density time series CV is 10%	Include density index series to allow for testing of density based opening - closure rules (i.e. based on sea cucumbers per meter of shoreline)
Numbers time series CV is 10%	Dynamic selectivity calculations (might be a better example in urchin / hake)
Model includes a k (growth rate) for fecundity at age (cubic on inplied growht) between 0.3 and 0.5	Add correct coords to OM objects by QMA
	Check management intervals in OM
	Can evalute survey frequency (2 - 4 years currently)
	What density per subarea is indicative of overfishing
	How precautionary are current management approaches?
	What is the conservation benefit of no-take subareas?
	Is the 2.5 C/m shoreline reopening threshold important to conservation?
	Which areas are currently most at risk?
	What is the relative performance of Control points based on unfished density (by subarea) rather than a nominal density (e.g. x c/m-sl)
	What is the relative performance of alternative control points?
	Subarea control points - how well do these achieve overall (summed) LRP performance across multiple areas?
	15 cm 'pencil' effect (is there some other reference that is better for fishermen?)

Software and Code

csrf_hh_data GitHub Repository

openMSE (MSEtool, DLMtool, SAMtool R libraries)

Rapid Conditioning Model (RCM) (Huynh 2023)

Recent Presentations

Geoduck Nov 2023 (.pdf)

Manilla Clam Nov 2023 (.pdf)

Cucumber Feb 2024 (.pdf)

Urchin Feb 2024 (.pdf)

References

DFO 2021 (Anderson et al)

Geoduck IFMP

Green Sea Urchin IFMP

Sea Cucumber IFMP

Intertidal Clam IFMP

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(Green urchin collaborators) Lyanne Curtis, Christine Hansen, Travis Bell;

(Sea cucumber collaborators) Jill Campbell, Christine Hansen, Erin Wylie, Travis Bell;
