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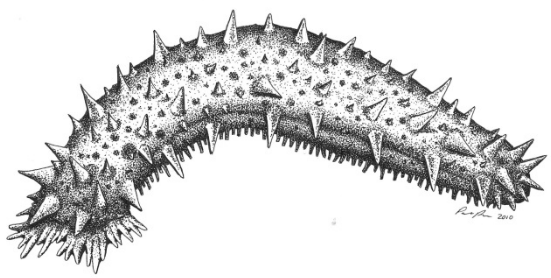
Pacific Region

Canadian Science Advisory Secretariat
Science Advisory Report 2015/026

A SET OF SIMULATION MODELLING TOOLS TO EVALUATE ALTERNATIVE COMMERCIAL NO-TAKE RESERVE NETWORK DESIGNS FOR SHALLOW-WATER BENTHIC INVERTEBRATES IN BRITISH COLUMBIA



Parastichopus californicus, the species used in this case study. Drawing by P. Ridings.

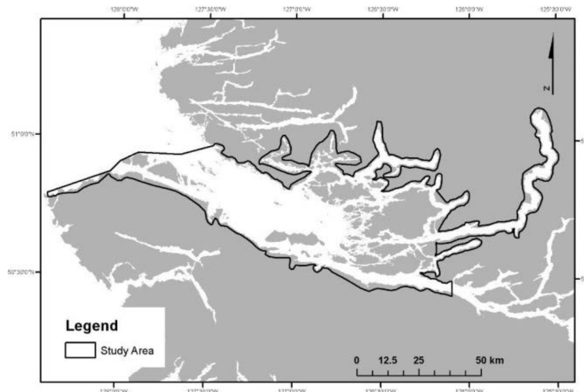


Figure 1. Map of the case study area, Pacific Fisheries Management Area 12.

Context:

Science advice was requested by Fisheries Management (FM) to provide a scientifically-sound, defensible and transparent process for the development of a coast-wide network of commercial no-take reserves for individual species of shallow-water benthic invertebrates. A technical working group was formed in 2012 to identify methods to produce advice, develop tools and apply them to a relatively data-rich area in British Columbia (BC). The criteria for development of such a tool set included: applicability to different regions in BC; flexibility to be applied to a broad range of sedentary benthic invertebrate species; ability to account for multiple sources of uncertainty; and the flexibility to evaluate the effectiveness of alternative reserve designs for meeting multiple fisheries-management objectives and conservation issues. A range of semi-quantitative and quantitative approaches was reviewed and considered. The technical working group agreed that a habitat-based, spatially-explicit, metapopulation-dynamics, simulation modelling tool would provide the most flexibility to evaluate alternative reserve design options for a broad range of benthic species, while explicitly accounting for uncertainties in model parameters and structure. Relatively data-rich populations of the commercially-harvested, low-mobility California Sea Cucumber, Parastichopus californicus, were selected for a case study to develop the set of simulation modelling tools and apply them as a proof of concept.

The simulation-modelling tools, or their outputs, may inform current work that is underway to establish a network of Marine Protected Areas (MPAs) in BC, as per the Canada-BC MPA Network Strategy, and ongoing marine spatial planning processes in Large Ocean Management Areas such as the Pacific North Coast Integrated Management Area (PNCIMA).

This Science Advisory Report is from the October 23 and 24, 2013 meeting on A Simulation Modelling Tool to Evaluate Alternative Fishery Closure Network Designs for Shallow-water Benthic Invertebrates in British Columbia. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Fisheries Management (FM) Branch requested the development of a tool to inform the design of a network of commercial fishery reserves for sedentary benthic invertebrates that would be applicable to a broad range of sedentary benthic invertebrate species, able to account for multiple sources of uncertainty and flexible enough to evaluate the ability of alternative reserve designs to meet multiple fisheries management and conservation objectives.
- A habitat-based, spatially-explicit, metapopulation-dynamics simulation modelling framework coupled with sensitivity analyses was completed. The core component of the simulation modelling framework couples models of habitat suitability, dispersal, metapopulation dynamics and fishing. Methods were described to:
    1. develop the simulation modelling framework;
    2. produce spatial data layers;
    3. estimate input parameters; and
    4. carry out and interpret a global sensitivity analysis.
- The simulation modelling framework was applied as a proof of concept to a baseline model developed for the California Sea Cucumber (*Parastichopus californicus*) in Pacific Fishery Management Area 12 to illustrate how the set of tools could be used together to: predict the distribution of suitable habitat; project population trends over time; carry out a global sensitivity analysis to quantify the relative influence of model parameters and identify research priorities; and evaluate alternative reserve network configurations.
- The next stage of running the simulation tool fully, using a specified location and species, and having the results reviewed by CSAS was recommended.
- The use of the term “Commercial No-Take Reserve” (CNTR) within this document refers to areas where commercial fishing of a particular species is not permitted.

INTRODUCTION

Pacific Region shellfish resource managers requested information and advice on methods and biologically-based criteria that could be used to develop a network of Commercial No-Take Reserves (CNTRs) for a singular, low-mobility, benthic, broadcast-spawning marine invertebrate species (e.g. sea cucumber, sea urchin, bivalves and abalone). However, there is limited knowledge of the life-history parameters – including survival, growth, reproduction and movement patterns – for many commercially-harvested marine invertebrate species in British Columbia (BC). While commercial fisheries for invertebrates are assessed and managed using the precautionary approach (Hand et al. 2009), there is a high level of uncertainty regarding many of the life-history parameters of these species. An additional level of precaution, such as a network of CNTRs, could mitigate some of the risks associated with this uncertainty while allowing aboriginal and recreational fishing to persist in those areas.

A set of tools was developed that can be used independently or together, depending on the management objectives, to aid researchers and resource managers in designing single-species networks of CNTRs for sedentary benthic invertebrates in BC, Canada.

The simulation-modelling framework describes and applies a set of quantitative tools that can be used to provide advice on the number, size and spacing of CNTRs needed to achieve one or more specified management objectives. A key component of the simulation modelling framework is a set of coupled sub-models of habitat suitability, dispersal, metapopulation dynamics and fishing. The tools allow analysts to develop spatial data layers and estimate other input parameters, run simulations and analyze simulation results. These tools are applied to a case study species (California Sea Cucumber, *Parastichopus californicus*) to demonstrate how they might be used to inform decisions on CNTR design. The results show how model sensitivity and scenario analyses can be used to identify priorities for research and evaluate alternative network designs using a range of performance criteria. Finally, there is a discussion of how the set of tools may be applied to address a broad range of spatial management questions for a broad range of species in any area, provided sufficient data and computation power are available.

The terms of reference for this science advisory process were:

1. Assess the performance of the simulation tool's ability to evaluate fishery closure network designs for sea cucumbers that vary in number, size and location, as well as under various scenarios of data availability.
2. Assess the performance of the simulation tool's ability to evaluate alternative fishery closure network designs for sea cucumbers based on a range of performance measures and plausible commercial and First Nations fishery management scenarios.
3. Evaluate uncertainty in parameter assumptions and simulation tool results and, based on sensitivity analysis, provide recommendations for ways to reduce uncertainty.
4. Assess the applicability of the simulation tool to other low-mobility, shallow-water benthic invertebrates.
5. Provide a discussion on the suitability of proxies or alternative methods to identify candidate commercial fishery closure locations for low-mobility benthic invertebrates.
6. Provide recommendations for research and monitoring of biological trends to evaluate their effectiveness in achieving conservation and fishery management objectives.

The set of tools developed for evaluating different CNTR designs include:

- code to develop spatially-explicit predictions of the location of suitable habitat and invertebrate densities;
- code to build baseline models of metapopulation dynamics linked to models of habitat suitability, dispersal and fisheries management;
- customized code to run sensitivity analyses of baseline models; and
- code to collate, analyze and interpret simulation results of interest and evaluate reserve design against performance criteria.

Fisheries managers identified several performance measures they were interested in using to evaluate the effectiveness of alternative CNTR network designs. The performance measures used to evaluate CNTRs were the percent decline in population, the number of Pacific Fishery Management (PFM) Subareas that fell below the limit reference point (LRP; 50% of B_0 for *P. californicus*) and the proportion of years that any PFM Subarea fell below the LRP over 20- and 100-year time horizons.

Together, the set of tools produce predictions of the trends in population abundance, metapopulation occupancy and catch rates. These results allow analysts to evaluate model predictions against conservation and management objectives, such as overall population decline and risk of falling below the LRP.

In sensitivity analyses, model parameters are varied in such a way that allows analysts to quantify the influence of model parameters on predictions of interest. Key model parameters that can be varied within the presented simulation modelling framework include the number, size and location of populations or PFM Subareas that are included in the reserve network. By exploring a range of values for each of these reserve network metrics, analysts can identify attributes of the network needed to achieve one or more specified objectives.

A brief description of these tools and their abilities to provide advice for managers interested in developing a reserve network is provided below.

ASSESSMENT

The following section assesses the ability of the simulation modelling framework to meet each of the Terms of Reference (ToR).

Objective 1: Assess the performance of the simulation tool's ability to evaluate fishery closure network designs for sea cucumbers that vary in number, size and location, as well as under various scenarios of data availability.

Simulation modelling can be used to evaluate management scenarios when empirical studies would be prohibitively costly or time-consuming. To evaluate the performance of network designs that vary in number, size and configuration in relation to defined management objectives, the corresponding parameter values in a baseline model are varied in a sensitivity analysis.

The output from sensitivity analyses can be used to provide science advice on the size, number and configuration of suitable habitat patches to include under different management strategies by examining the relationships between evaluation metrics and simulation results of interest.

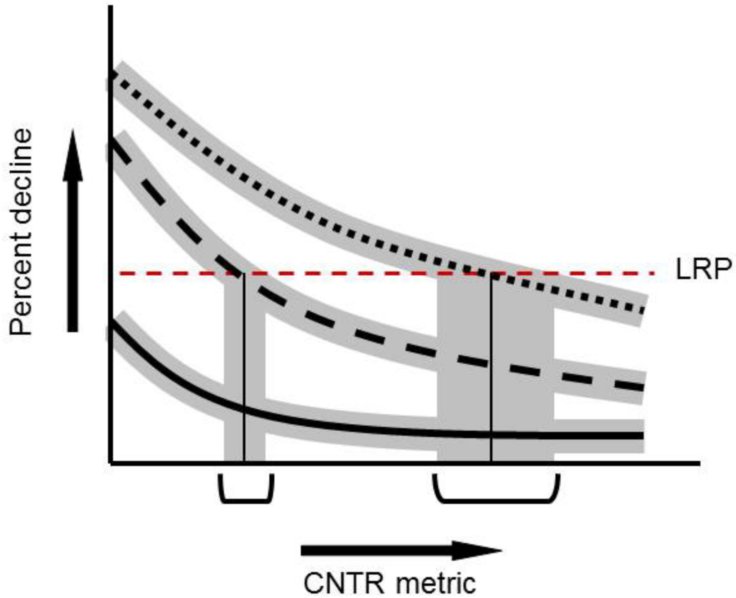


Figure 2. A schematic showing how varying a Commercial No-Take Reserve (CNTR) metric (such as number of Pacific Fishery Management Subareas included in the CNTR or total area of the CNTR) can be related to a model prediction of interest (in this case percent decline in population abundance) under three management scenarios (e.g. low, medium and high exploitation rates represented by solid, hashed and dotted lines, respectively; the grey shadow represents variability of these curves). When models are fitted to the relationships, their intersection with a specified management objective (e.g. remaining below a limit reference point, LRP) can be used to predict the value of the CNTR metric needed to ensure the objective is met.

In Figure 2, percent decline in population abundance is plotted as a function of an unspecified CNTR metric and three hypothetical relationships between the two variables are plotted. In all cases, there is an influence of the CNTR metric (e.g. number of populations in the CNTR network or total area of the CNTR network) on percent decline, but the forms of the relationships differ. The dotted and dashed lines represent two cases in which the relationship between percent decline and the CNTR metric intersect a specified management objective, in this case a LRP. Those relationships, along with confidence intervals, can be used to provide science advice on the attributes of the CNTR network required in order to prevent populations from falling below the LRP. Those attributes might be the number of populations, or total habitat area or shoreline length needed in the CNTR design to prevent populations from falling below the LRP. By contrast, the solid line represents a situation in which populations never fall below the LRP regardless of the level of the CNTR attribute.

The required number, size and configuration of habitat patches needed to meet conservation or fishery management objectives depend not only on the strength and form of the relationships between these metrics and the likelihood of achieving the objectives, but also on interactions among variables and on the objectives themselves. In the example presented in Duprey et al.[1] (unpublished manuscript), if the LRP were set at 5 or 10% declines in the population's biomass, the relationships would likely intersect the LRP and allow the provision of quantitative advice on

[1] Duprey, N.M.T., Curtis, J.M.R., Finney, J., and Hand, C.M. Simulation modelling tools to evaluate alternative fishery closure area network designs for shallow-water benthic invertebrates in British Columbia.

the CNTR attributes required to achieve objectives. Based on simulation results, increases in commercial and other harvest rates would change the form of the relationship between percent decline and CNTR attributes such that they could intersect the LRP. However, a broader range of harvest rates was not fully analyzed. In addition, the baseline scenarios were run using the assumption that fishing mortality was spatially uniform and other fishing patterns were not explored. Different fishing patterns could have a significant effect on the results. It is also important to consider the interactions among variables and the impact the nature of the conservation or fishery management objectives could have on the science advice that could be provided. Also, it should be noted that if the methods and tools were applied to other populations, or other species, the general conclusions could differ.

Objective 2: Assess the performance of the simulation tool's ability to evaluate alternative fishery closure network designs for sea cucumbers based on a range of performance measures and plausible commercial and First Nations fishery management scenarios.

The performance measures used to evaluate alternative fishery closure network designs were the percent decline in the population, the number of PFM Subareas that fell below the LRP and the proportion of years that any PFM Subarea fell below the LRP at set intervals (20 and 100 years in this case). The code used in the tools is designed to record population occupancy and probability of extinction, as well as cumulative harvest over time. In addition to these presented metrics, the code is flexible and can allow users to evaluate alternative CNTR designs based on any performance measure that can be calculated from the predicted/simulated distribution and abundance patterns over space and/or time. There is the potential to build in other types of indicators, but these would need to be assessed in terms of their ability to be included in the simulator.

The code allows users to simulate a variety of plausible commercial and other fishery management scenarios. It can incorporate up to two types of harvest (e.g. commercial and other harvest rates) and those harvest rates can be applied to any stage at any frequency and across any spatial scale that is equal to or larger than the population scale (e.g. populations, PFM Subareas, PFMAs). Harvest can be applied as a proportion of the population or at a fixed number of individuals throughout time.

Objective 3: Evaluate uncertainty in parameter assumptions and simulation tool results and, based on sensitivity analysis, provide recommendations for ways to reduce uncertainty

Several parameters used in the presented tools were unknown for *P. californicus* and therefore are uncertain. The sensitivity analysis is a tool to quantify the relative influence of variables on model results. The presented methods describe the degree of uncertainty in the variables used in the simulation tool. One important source of uncertainty that was not considered is the role of interactions between variables in model outcomes. There was insufficient time to test the variables used in the sensitivity analyses for interactions in the presented analysis. This step is especially important, as interactions between variables can be strong and could change the relative influence they have on simulation results. If the presented suite of tools was to be used in a full CNTR network analysis, interactions between variables should be fully explored. This would reduce the uncertainty in parameter influence and make a synthesis of parameter influence more defensible. Nevertheless, the set of simulation tools allows users to produce the results needed to evaluate the interactions among variables.

Research priorities can be developed from the outputs of these tools by comparing the relative influence parameters have on management indicators (areas of suitable habitat, population density and size, percent population decline, populations remaining above the LRP, etc.) and ascertaining the certainty of the parameter. Reducing the uncertainty in some of the parameters may be possible through research, while research into other parameters may be cost/time prohibitive.

Objective 4: Assess the applicability of the simulation tool to other low-mobility, shallow-water benthic invertebrates.

The presented suite of tools can be used for a variety of low-mobility, shallow-water, benthic invertebrate species in BC (e.g. Geoduck (*Panopea generosa*) and Red Sea Urchin (*Strongylocentrotus franciscanus*)). The predicted habitat suitability models and predicted density models could be constructed for many species of low-mobility, benthic invertebrates as long as biologically-relevant environmental, population and species data exist for the area of interest. The environmental data used in the present study were highly detailed due to the extensive research that has focused on the Broughton Archipelago. Sensitivity analysis in the habitat suitability and density models explored different resolutions of environmental data and found that there was no significant difference in the performance of the model for PFMA 12. Similar models can be built at a variety of resolutions for any coastal area where environmental data exist.

The metapopulation dynamics model could easily be re-parameterized for a different species by programming the life-history parameters specific to the target species. In fact, some species may have less uncertainty than sea cucumbers in some of the parameters used in the model, which could reduce uncertainty in the results. The dispersal model is a basic model that, again, could be fine-tuned for another species, incorporating any known information on larval pelagic duration, behaviour and movements.

Finally, the fisheries management model can be re-written to incorporate the management regime used for the target species. In summary, these tools could be fully replicated and customized for another benthic invertebrate species, either in part or in full, but only if there was the expertise available to complete these tasks. It is important to note that while these are valuable tools, they cannot be re-tuned to other species nor re-run for *P. californicus* unless the users have expertise in spatial analysis, simulation modelling (including knowledge of good practices for verifying and validating model performance and interpreting results), the R programming language, RAMAS software and assessing model results for robustness.

Objective 5: Provide a discussion on the suitability of proxies or alternative methods to identify candidate commercial fishery closure locations for low-mobility benthic invertebrates

The suitability of proxies or alternative methods for identifying candidate CNTRs depend first and foremost on the management objectives. For example, if the management objective of a CNTR is simply expressed as a desired proportion of suitable habitat (e.g. 50% of available habitat is within CNTR), a map-based approach would be sufficient. Map-based approaches could range in complexity from simply plotting known habitat to modelled predictions of suitable habitat, as was done in the presented methods. Alternative site-selection tools such as MARXAN could be used to optimize the placement of closed areas when there are also other objectives, such as minimizing cost(s). The benefit of using these alternative approaches is that they are relatively straight-forward to apply so long as the appropriate data are available. One key disadvantage is that the solutions they provide cannot be evaluated in terms of their ability to achieve the management objectives specified by DFO FM Branch. Moreover, these alternative methods typically only provide a snapshot of what is, in fact, a very dynamic system.

When objectives are expressed in terms of the change of distribution or abundance of a species over time, more sophisticated tools are required. These tools must have the capability to account for dynamic processes over time, as well as methods to account for uncertainty. The strength of the presented set of tools is that they can be applied in either scenario. The component parts can be used individually or as a combined tool. The main drawback in using the presented simulation approach is the high level of expertise and time required to carry out the analysis.

Objective 6: Provide recommendations for research and monitoring of biological trends to evaluate their effectiveness in achieving conservation and fishery management objectives.

This Objective was not addressed.

Sources of Uncertainty

- Application of this simulation tool to large areas may be constrained by computational power if there are greater than approximately 500 discrete populations.
- The trial runs of this simulation tool, on *P. californicus*, highlighted many knowledge gaps that are likely important parameters in one or more of the sub-models used in the simulation tool. Some of the uncertain parameters identified as particularly important include: substrate type maps, the amount of landings occurring in the First Nation Food Social and Ceremonial and Recreational fisheries and several life-history parameters (e.g. dispersal, larval behaviour and survival). Expert advice was used to fill in these gaps in knowledge (except substrate type which was not used in the creation of habitat/density models) for example runs. However, the tool can easily be updated and re-run should new data/experiments/knowledge provide better species-specific values for these parameters.
- There is uncertainty in how incorporating spatially-explicit and/or non-uniform fishery dynamics, in the fisheries dynamics model, may affect model outcomes and related science advice.

CONCLUSIONS AND ADVICE

The next stage of running the simulation tool fully, using a specified location and species, and having the results reviewed by CSAS to review the application and types of advice stemming from these tools was recommended. This suite of tools could also be used for a broad range of low-mobility, shallow-water, benthic invertebrate species in BC (e.g. Geoduck and Red Sea Urchin) using data and parameters appropriate to the species of interest, subject to computational constraints.

The present simulation tools work well for the intended purposes (species and area), but various proxies or alternative sub-model methods may be available for other areas and/or species and these should be assessed for their inclusion in future simulations. One of the strengths of the presented simulation tool is that sub-models can be replaced with better models of reality should they be available for a different species, different areas or as new information becomes available.

It is recommended that at a minimum the first application of the simulation tool be reviewed through CSAS so that the outputs and performance of the tool can be thoroughly evaluated. The following specific conclusions and advice were provided with respect to the application for sea cucumbers, other benthic invertebrate species, as well as approaches for validation and future research:

When using the simulation tool*:*

1. For each sub-model, use the best data available and validate the data (when possible) using the best expertise available.
2. Predictive power of habitat suitability and density sub-models should be assessed, and presented transparently along with model results, if they are used.
3. Examine the effect interactions between variables have on predicted variables.
4. Assess the importance of substrate type, other benthic factors and exposure on outcome in future runs of the habitat suitability and density models, if data become available for the area of analysis.
5. Assess the effect of including a range of habitat patches on the outcome.

SOURCES OF INFORMATION

This Science Advisory Report is from the October 23 and 24, 2013 meeting on A Simulation Modelling Tool to Evaluate Alternative Fishery Closure Network Designs for Shallow-water Benthic Invertebrates in British Columbia. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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