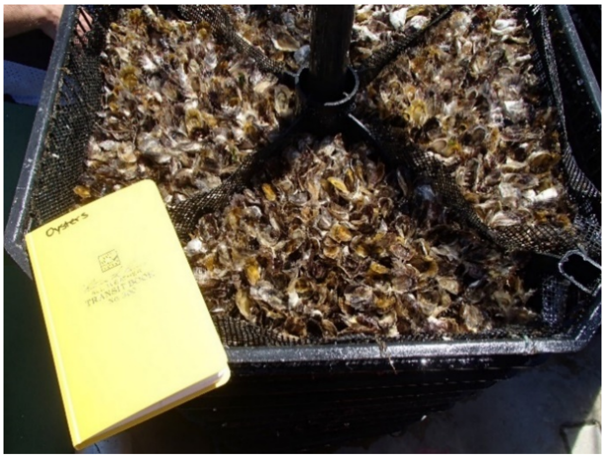
MODELLING AND MONITORING METHODS APPROACH TO EVALUATE ECOLOGICAL BIVALVE CARRYING CAPACITY IN BAYNES SOUND, BRITISH COLUMBIA



Oyster culture tray in Baynes Sound (Photo courtesy of Terri Sutherland).

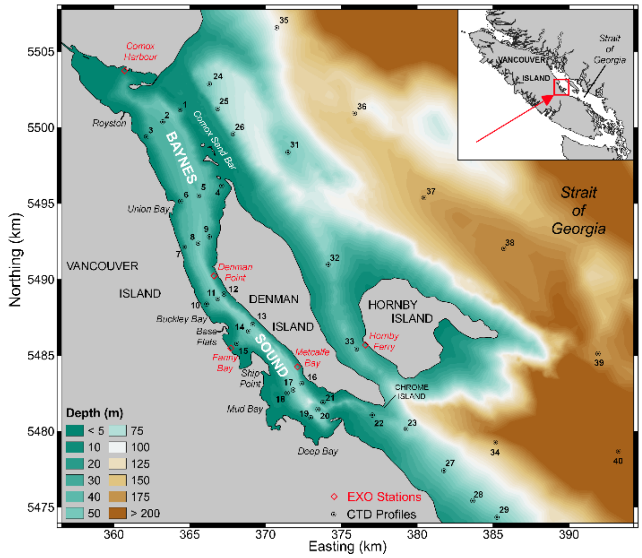


Figure 1. Map of Baynes Sound (British Columbia) including bathymetry and hydrodynamic stations.

Context:

In British Columbia (BC), shellfish culture is located primarily on the west coast of Vancouver Island and the Strait of Georgia, with the most prolific production sites associated with Baynes Sound, Cortez Island, and Okeover Inlet. Although the culture of shellfish was developed over 100 years ago in BC, little research exists pertaining to the ecological capacity of shellfish production in these prolific, sheltered bays. Shellfish production is influenced by a balance of water quality, hydrodynamics, and food supply (plankton). A carrying capacity assessment is required to assess this balance and identify any bay-wide limitations due to a potential competition for resources or shift in ecosystem functioning. Fisheries and Oceans Canada (DFO) Fisheries Management- Aquaculture has requested that Science Branch 1) assess the ecological carrying capacity for shellfish aquaculture in Baynes Sound at a bay wide scale using a high-resolution, spatially-explicit hydrodynamic-biogeochemical coupled model (Finite Volume Community Ocean Model [FVCOM])- Bivalve Culture Ecosystem Model [BiCEM]), and 2) recommend monitoring methodologies including field and laboratory protocols for use by regulatory, industry, and science personnel.

This Science Advisory Report is from the March 8-12, 2021 Regional Peer Review on Modeling and monitoring approaches to evaluate the ecological carrying capacity for shellfish aquaculture. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.

SUMMARY

- Ecological carrying capacity assessments are typically investigated using mathematical models that integrate complex interactions including physical and biological factors. Due to the significant influence of local environmental conditions on ecosystem functioning, carrying capacity studies are site specific. These models are done on a site specific basis and are validated using observational data.
- This assessment used two numerical models to integrate these complex interactions using a 4D high-resolution model. The Finite Volume Community Ocean Model (FVCOM) was coupled with a Bivalve Culture Ecosystem Model (BiCEM) including the Dynamic Energy Budget (DEB) to simulate bivalve physiology and their interactions with the ecosystem.
- This carrying capacity model focused on the biogeochemistry and lower trophic pelagic ecosystem (plankton and organic seston) and their interaction with cultured bivalves, with a focus on the extent to which bivalves utilize these food resources. The model incorporated cultured Pacific oysters and wild and cultured Manila clams as representative of a wider diversity of the bivalve population.
- Five scenarios were considered to assess model-predicted changes in water properties outlined above: 1) No Aquaculture (leases removed); 2) Current conditions (2016-2017 aquaculture production); 3) Current conditions plus max production of all leases; 4) Expansion (new applications); and 5) Expansion plus max production of all leases.
- The scenarios provided model predictions of changes in the pelagic ecosystem (Chlorophyll-a, Net primary productivity, Particulate organic carbon, Particulate organic nitrogen, and Zooplankton) due to cultured bivalve populations in Baynes Sound based on natural variation and 1/3 of primary production. Thresholds for unacceptable changes are defined by management taking into account local setting.
- Under each scenario including Scenario 5 (Expansion plus max production), the ecological carrying capacity of Baynes Sound for bivalves would not be exceeded. Model results indicate that existing shellfish and potential future increases in shellfish aquaculture leases can be supported ecologically in Baynes Sound, but should proceed gradually and in conjunction with monitoring, focusing on areas where a high density of aquaculture already exists (Mud, Fanny, and Deep bays).
- Indicators and supporting variables to assess changes in shellfish population and the surrounding ecosystem are presented, along with monitoring methodologies for collecting field samples and carrying out congruent laboratory analyses (separate research document). These tools are intended to inform the development of future monitoring programs.
- The modelling was based on a 2016-2017 data set that reflected an anomalously warm year relative to historical data. Enhanced water-column mixing and phytoplankton production can be mitigated by 1) increasing horizontal resolution of the model grid in the areas of steep topography and 2) including additional river inputs. Additional information on bivalve densities and zooplankton data would improve model accuracy.
- The individual parameterization and subsequent coupling of FVCOM-BiCEM models was a novel approach providing a 4D high-resolution, spatially-explicit hydrodynamic-biogeochemical coupled model, resulting in an efficient approach to assessing ecological carrying capacity of shellfish aquaculture.

- This modelling approach of coupling physics and biology is recommended as a methodology to assess aquaculture management ecological carrying capacity at other potential locations considered for aquaculture applications on a site specific basis.

INTRODUCTION

Baynes Sound is one of the most productive farming areas for bivalves in British Columbia (Figure 1). Shellfish production is influenced by a balance of water quality, hydrodynamics (e.g., bay flushing, mixing, etc.), and food supply (plankton). The Sound covers an area of 90 km^2, which includes sheltered bays, intertidal mud- and sand-flats, marshes, and rocky substrates. While the majority of the subtidal area is between 20-30 m in depth, the upper reach consists of a wide, deep basin (40-80 m) and the lower reach widens into Mud and Deep bays, upstream of the restricted southern entrance. A diverse intertidal zone borders the shoreline and dominates the western shore with wide mud- and sand-flats that experience a 4-metre (spring) tidal range. The Courtenay River provides the largest input of freshwater runoff, while both the northern and southern restricted entrances provide water exchange between Baynes Sound and the Strait of Georgia (SoG) as tidal jets.

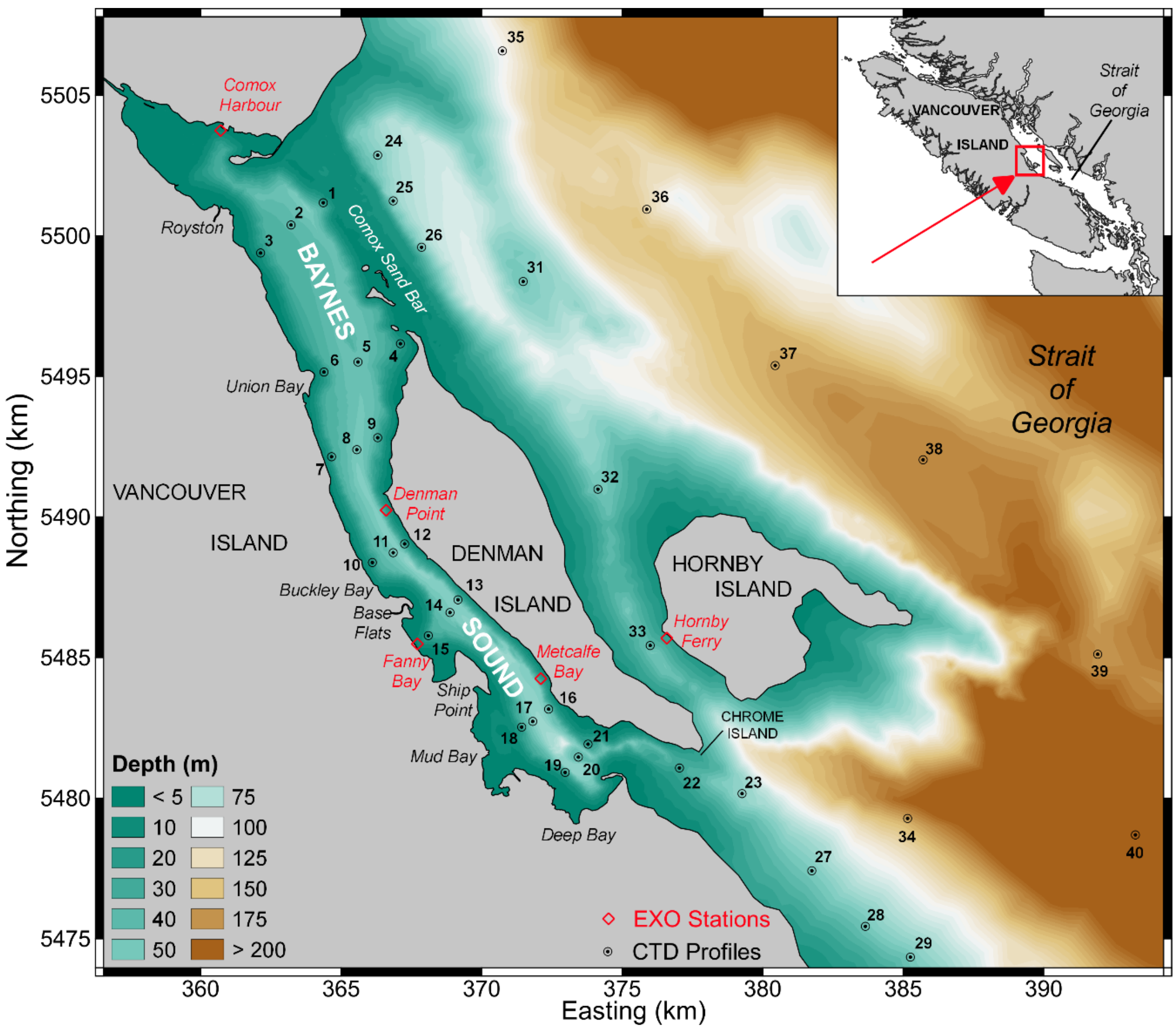


Figure 1. Map of Baynes Sound (British Columbia) including bathymetry and hydrodynamic stations as well as local areas of interest.

Both carrying capacity assessments and potential management thresholds and indicators are bay specific, reflecting the relevance of bay-scale hydrodynamics and characteristics on ecosystem functioning. Indices based on the comparison of key oceanographic and biological processes have been used as proxies for the carrying capacity of bivalve aquaculture sites. These indices compare the energy demand of bivalve populations (based on filtration rates) and the ecosystem's capacity to replenish these resources. Additionally, monitoring methodologies associated with potential carrying capacity indicators can provide a baseline for a future ecosystem monitoring program. Based on the information collected from long-term monitoring programs, regulatory management thresholds for ecological indicators could be established.

Modelling approaches to shellfish carrying capacities were reviewed as part of a similar assessment conducted in the Gulf Region (DFO 2015, Filgueira et al. 2015). The result of the 2015 Canadian Science Advisory Secretariat (CSAS) peer review was the identification of a high-resolution, spatially-explicit model as the most efficient approach to assess ecological carrying capacity of shellfish aquaculture.

ASSESSMENT

Ecological Carrying Capacity (ECC) is defined as the magnitude of aquaculture activity in a given area that can be supported without leading to unacceptable changes in ecological processes, species, populations, communities, and habitats in the aquatic environment (DFO 2015). ECC calls for the analysis of the full range of ecosystem-level interactions, but according to the Ecosystem Approach to Aquaculture guiding principles (Soto et al. 2008), ECC is usually assessed by focusing on the bivalve-phytoplankton interaction. Most models used to assess ECC in bivalve aquaculture have focused on the coupling of a hydrodynamic model with a lower trophic model representing the nutrient, phytoplankton and zooplankton dynamics in addition to a bivalve component (Pete et al. 2020). Bivalve species, indigenous and cultivated, are an integral component of marine ecosystems and, coupled with hydrodynamic processes, can have both direct and indirect effects on various other biotic communities (DFO 2006). Due to the significant influence of local environmental conditions on ecosystem functioning, carrying capacity studies are ecosystem-specific.

In the Pacific Region, the Finite Volume Community Ocean Model (FVCOM) was coupled with a Bivalve Culture Ecosystem Model (BiCEM), which resorted to the Dynamic Energy Budget (DEB) to simulate bivalve physiology and its interactions with the ecosystem. This combination resulted in a 4D, high-resolution, spatially-explicit biogeochemical model that provided bay-wide and local assessments integrated over depth and designated time periods.

The individual parameterization and subsequent coupling of FVCOM and BiCEM is the first of its kind, providing a novel approach with its first application in the Pacific Region (Baynes Sound). Since DFO Aquaculture Management identified Baynes Sound as a priority site in 2009 due to its production status, DFO Science followed up by acquiring relevant research data to support a carrying capacity assessment. Accordingly, this modelling approach focused on the traditional core ECC variables (nutrient-phytoplankton-zooplankton-shellfish loop) with the addition of a bivalve sub-model. The inclusion of other commercial, recreational and aboriginal (CRA) fishery components and/or a benthic assessment would require a broader food web and benthic model. This approach would increase the complexity and uncertainty of the outcomes that are relevant for shellfish, and, thus were outside the scope of this advice.

Modelling Approach to Baynes Sound

Baynes Sound is a coastal embayment in the SoG, with a restricted renewal entrance at the southern end and a surface exchange associated with a large sandbar at the northern entrance

(Figure 1). The northern Strait of Georgia, that overlaps with the model domain, has a relatively high source of nutrients and flagellate phytoplankton concentrations along the Baynes Sound northeastern border (Olson et al. 2020). In order to conduct the ecosystem modelling, a number of parameters to support the bivalve ecological carrying capacity assessments were collected with varying frequency and spatial resolution. The physical oceanographic conditions were simulated using FVCOM. Applications of FVCOM have been previously developed to help address aquaculture issues in the Broughton Archipelago and Discovery Islands regions of BC.

This spatial model solves the three dimensional (3D) primitive equations for velocity and surface elevation in combination with the 3D transport/diffusion equations for salinity and temperature in the presence of turbulent mixing. Variables including temperature and salinity as functions of depth were field collected to initialize the model and provide boundary forcing during the model simulation. FVCOM approximates the region of interest with a grid of triangles with varying resolution and orientation in the horizontal and layers in the vertical.

The present study also relies on the off-line coupling of FVCOM with a biogeochemical component, the Bivalve Culture Ecosystem Model (BiCEM, Figure 2). Briefly, BiCEM simulates the Nitrogen cycle, considered as the limiting element for Baynes Sound productivity, through inorganic nutrients, phytoplankton, non-living suspended organic matter, zooplankton, and wild and cultivated bivalves. Bivalve eco-physiology is addressed with specific Dynamic Energy Budget (DEB) models in the BiCEM structure. Hence, the coupled FVCOM-BiCEM model provides a dynamic and spatially-explicit representation of the ecosystem resulting from the interactions between all variables.

The procedure for the coupled FVCOM/BiCEM simulation was to first run FVCOM and store these outputs of temperature, salinity, velocity and mixing, (in 20 min intervals) for use of these values for BiCEM. Since the largest biological data collection period spanned between 2016 (May) to 2017 (April), this date was selected to initialize and evaluate the BiCEM.

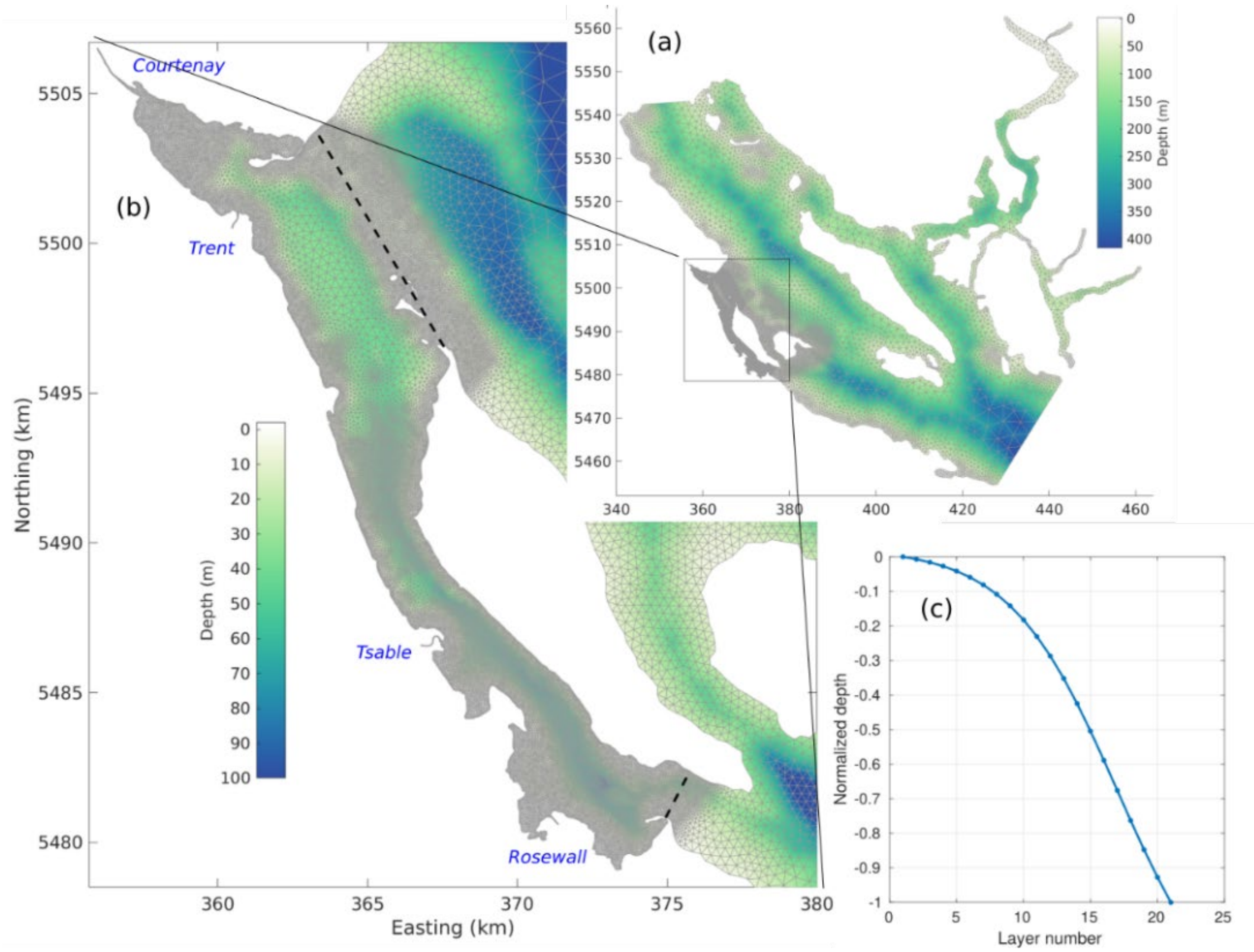


Figure 2: Triangular grid and bathymetry for the coupled model: (a) for the entire model domain, (b) close-up view of Baynes Sound area with the Courtenay, Trent, Tsable, and Rosewall rivers included in the model, and (c) bounds of the model vertical layers.

Does the model do a good job at approximating the hydrodynamics in Baynes Sound?

Comparisons between hydrodynamic output and data observations primarily collected in 2016-2017 were used to evaluate model accuracy. Several parameters including i) temperature and salinity, ii) currents; and iii) sea surface elevation were used to validate the model as these parameters are the physical variables that most affect shellfish aquaculture. Temperature time-series were taken at five separate areas in addition to the Chrome Island lighthouse for a portion of or all of 2016-17. Salinity was collected from conductivity-temperature-depth (CTD) profiling stations at fixed time periods, while acoustic Doppler current profilers (ADCP) were used to collect water currents between the BC Ferries docks (mid-channel between Buckley Bay and Denman Island) and also at Union Bay (Figure 1).

Overall, the FVCOM model performed well for temperature with an overall discrepancy of less than 1 degree C. While the near-surface salinity was in reasonable agreement, the model was slightly too salty at depth, especially at the southern entrance of Baynes Sound. This could be a result of inaccuracies of mixing, bathymetric smoothing of the seafloor necessary to avoid spurious currents, and/or exclusion of several river systems south of Baynes Sound. Overall the root mean square salinity differences for the entire 2016-2017 model year simulation were 1.46

psu (practical salinity unit) at Chrome Island. Estimating current accuracy was challenging due to the paucity of available current meters. Although four current-meter profilers were originally deployed in Baynes Sound, two were not usable due to a malfunction for a portion of deployment. However, two of the four ADCPs were successful in collecting data from the BC Ferries site (Feb 25-April 12 2012) and the Union Bay site (June 15-Aug 30 2016). These upward-facing bottom-mounted ADCPs collected hourly observations from 38.5 to 1.5 m in 1 m intervals. Overall, the model was found to represent the hydrodynamics of Baynes Sound with reasonable accuracy.

Are there enough resources to sustain existing and proposed increase in shellfish aquaculture in Baynes Sound?

Carrying capacity for shellfish aquaculture of a specific body of water is commonly evaluated by comparing the bivalve food renewal rate through primary productivity and the exchange of water and food consumption rates by the entire cultured bivalve population in the study area (Dame and Prins, 1998). Hay and Co (2003) used this approach for their Baynes Sound carrying capacity estimate, considering the whole Sound as a single homogenous body of water and using model outputs to derive average (both in space and time) food renewal rates and limited experimental data to provide the bivalve filtration rate. In the present study, the same conceptual approach of rate comparison was applied through a spatially-explicit framework. This integrated modelling approach provides spatial fine scale outputs to further explore the response of Baynes Sound pelagic ecosystem and wild and cultured bivalves to various scenarios of aquaculture development. Figure 3 shows how the BiCEM model integrates the various parameters.

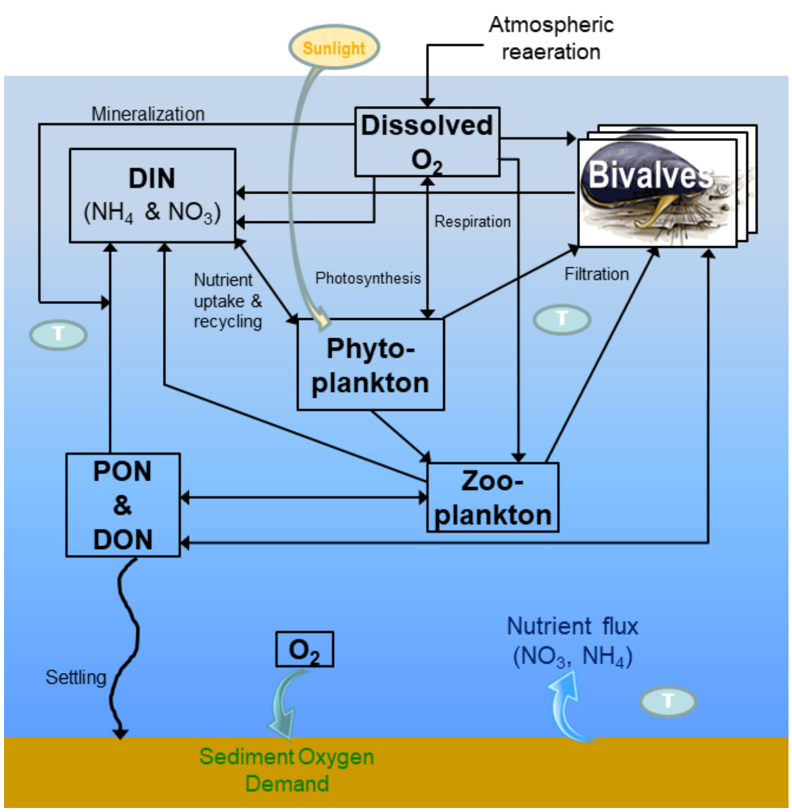


Figure 3: Trophic structure of the Bivalve Culture Ecosystem Model (BiCEM); DIN: dissolved inorganic nitrogen, PON/DON: particulate/dissolved organic nitrogen.

Model outputs were analysed to assess the ecological carrying capacity of Baynes Sound (BS) for shellfish aquaculture based on 5 specific scenarios:

- **Current:** meant to be as representative as possible of BS conditions in 2016-2017.
- **No aquaculture:** all shellfish farms are removed from the Current scenario. This scenario served as a reference to compare all other scenarios.
- **Current - Max:** all existing farms in the Current scenario operate at a maximum stocking density that was derived from the maximum production criteria provided by the Aquaculture Management Directorate (AMD) at DFO, which corresponded to 50 t ha^{-1} for bottom culture and 200 t ha^{-1} for culture in suspension.(~6% surface area in BS).
- **Expansion:** farms that were not included in the Current scenario either because they did not exist in 2016-17 or existed but did not report any production in 2015 and 2016. This scenario includes new applications currently (as of December 2020) under review by AMD.
- **Expansion - Max:** combines the two previous scenarios by considering all farms (existing + new) at maximum stocking density (increase to ~9% surface area for BS).

The ecological carrying capacity assessment was based on the comparison of model outputs for the above mentioned scenarios and two distinct criteria. The first criterion compared predicted reductions in phytoplankton biomass with the natural variability of this parameter (Grant & Filgueira 2011), while the second evaluated the fraction of net phytoplankton primary productivity consumed by the cultured bivalve population (ASC 2019).

A relative change index for pelagic variables including phytoplankton, particulate organic nitrogen, and zooplankton was conducted for each aquaculture scenario. A summary for the most relevant variables is shown in Table 1.

Table 1. Summary table of model outputs for each Scenario focusing on Phytoplankton (Phyto) and net Primary Productivity

	net Primary Productivity	**Relative Change (%)**		**Phyto uptake by cultured bivalves**	
Scenario	(gC m^{-2})	netPP	Phyto	(gC m^{-2})	% netPP
No Aquaculture	329.48	-	-	-	-
Current	328.61	-0.26	-3.27	0.90	0.28
Current-Max	328.34	-0.35	-3.03	1.43	0.44
Expansion	326.07	-1.04	-5.58	1.47	0.45
Expansion-Max	324.96	-1.37	-5.61	2.17	0.67

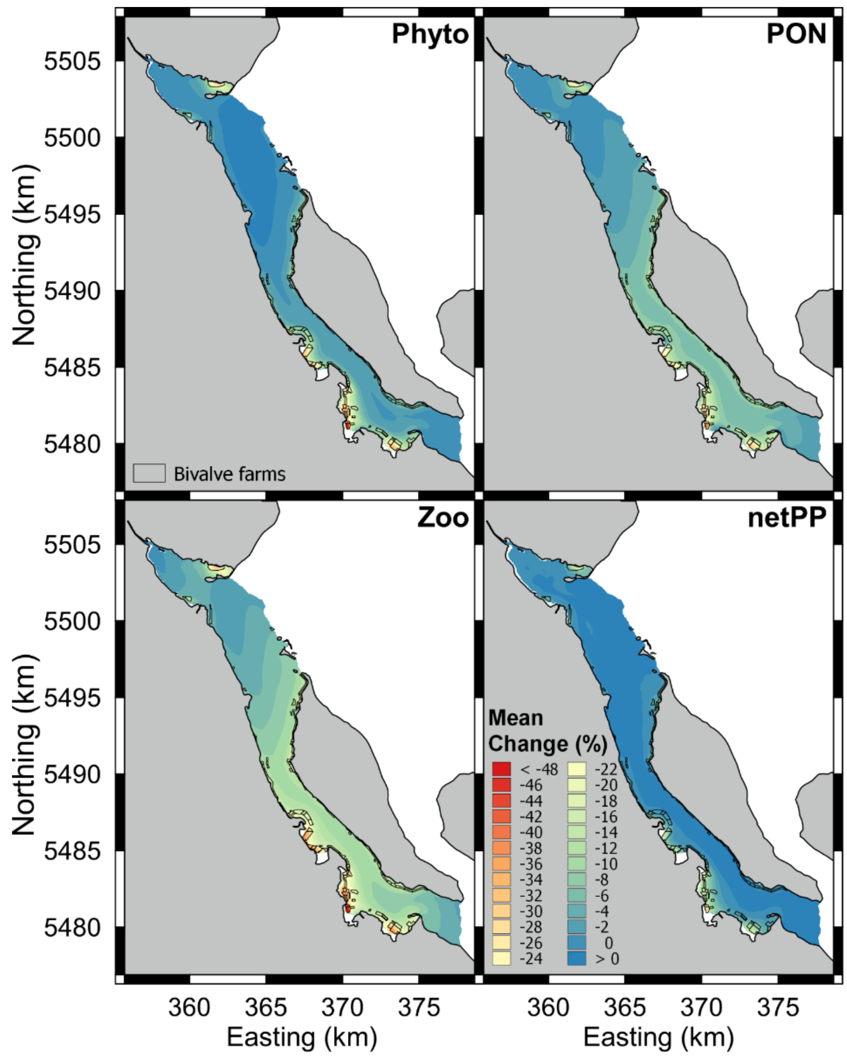


Figure 4. Summary of model results for Current scenario (2016-2017) as mean reduction maps of phytoplankton biomass (Phyto), particulate organic nitrogen concentration (PON), zooplankton biomass (Zoo), and net primary productivity (netPP).

The effects of cultured bivalves on primary productivity are limited to the very nearshore areas with a slight prominence in the lower Sound. Small shallow areas like Mud Bay can reach up to 30% reductions as shown in Figure 4. Phytoplankton reduction remains below 2% for most of the open water areas and below 15-20% in the nearshore with the exception of a few limited areas in Mud Bay (up to 30% reduction). When averaged over Baynes Sound, the model predicts a relative phytoplankton primary productivity decrease of ~4% for the current (2016-2017) aquaculture levels.

The scenarios tested in this study were to evaluate the response of the BS pelagic ecosystem to potentially increase spatial coverage and increased stocking density of shellfish aquaculture. The assessment of the biogeochemical model suggest culture bivalves exert a very limited influence with overall reductions of phytoplankton biomass (<6%) and productivity (<1.5%) for each of the scenarios. Under the highest stocking densities the uptake of plankton (primary food source) is less than 1% of the primary productivity for Baynes Sound. The Aquaculture Stewardship Council (ASC 2019) have a proposed criterion of no more than one third of phytoplankton primary productivity should be used for cultured bivalves. The prediction for

Baynes Sound as a whole is below this but smaller areas such as Mud Bay may approach these levels at a smaller scale and would require monitoring.

Localized effects of new farms on food availability and ultimately farm production was considered in the BICEM model by comparing Current to Expansion scenarios. There is inter-annual variability observed in wild and cultured shellfish populations. Under the max expansion scenario near Comox Harbour the max phytoplankton reductions were ~20% and a corresponding decrease in shellfish growth of ~0.3% (relative change in shell length). In the mid sound, in general there are slower water renewals and a maximum reduction in plankton ~8% and predicted growth reductions for clams (max 0.25%) and oysters (max 1.1%). Largest impacts are predicted in the lower sounds where the largest part of new farm coverage is planned with an increase of ~190 ha of which ~168 ha are concentrated in the Mud Bay/Deep Bay region. Small areas can see reductions in phytoplankton as high as 30%.

What monitoring tools and variables/indicators can be used to describe changes associated with shellfish aquaculture?

The Pacific DFO Aquaculture Management Division requested monitoring methodologies along with associated field and laboratory protocols that can be used by regulatory, industry and science personnel when carrying out ecosystem assessments. The sampling methods are intended to support a wide variety of approaches ranging from general area-based monitoring programs or local emerging issues associated with a significant knowledge gap. A suite of environmental variables that support bivalve aquaculture assessments was selected based on the following: 1) recommendations arising from government advisory processes and/or the scientific community; and 2) the ability of the indicator to detect potential shifts in ecosystem conditions and processes. Each ecosystem variable had a literature review establishing the monitoring relevance of each variable/indicator and available management thresholds.

Detailed field collection and lab analytical techniques are presented for three habitat regimes 1) benthic soft substrates (sediment texture, organics, sulfide/redox, trace elements, fauna, bivalve and eelgrass, 2) benthic hard substrate (video/camera surveys) and 3) pelagic ecosystem (water properties, seston, plankton, nutrients). Relevant bivalve attributes include cultured and wild density, diversity, and condition indices. The pelagic and bivalve indicators represent a nutrient-seston-plankton-bivalve loop that can support a high-resolution, spatially-explicit, hydrodynamic-biogeochemical coupled model capable of evaluating ecological bivalve carrying capacity. In general, the recommended variables can be used in any combination depending on the monitoring objectives, nature of the estuary, and localized settings. Table 2 outlines environmental variables that would support different environmental monitoring theme assessments. Bivalve carrying capacity assessments of aquaculture-laden bays would incorporate a suite of pelagic variables that make up the nutrient-phytoplankton-seston-bivalve loop required for the application of a hydrodynamic-biogeochemical model (Filgueira et al. 2015). These monitoring variables may not have significance to a general ecosystem objective if measured in isolation of the other pelagic variables.

This document does not provide prescriptive monitoring design advice as sampling design is site specific and objective of interest. Future research is required to 1) further validate management regulatory thresholds surrounding mat-forming indicators, such as, sulfide-oxidizing bacteria and Opportunistic Polychaete Complex in a variety of substrates and settings; 2) establish thresholds for key indicator variables; and 3) examine multiple stressors in a cumulative effects environmental setting.

Table 2. Benthic and pelagic sampling variables classified according to ecosystem monitoring themes. ECC = Ecological carrying capacity, BOE = Benthic organic enrichment, PE = Pelagic eutrophication, SH = Sensitive habitat, PI = Physical installations.

VARIABLES/INDICATORS	BIVALVE MONITORING THEMES/OBJECTIVES				
	Ecological carrying capacity	Benthic organic enrichment	Pelagic eutrophication	Sensitive habitat (eelgrass)	Physical installations (net, raft)
Soft-substrate variables					
Sediment grain size	-	BOE	-	SH	PI
Sediment porosity/organics	-	BOE	-	SH	PI
Sediment trace-elements	-	BOE	-	SH	PI
Sediment porewater sulfide	-	BOE	-	SH	PI
Sediment redox	-	BOE	-	SH	PI
Sediment nutrient influx/eflux	ECC	BOE	-	-	-
Sulfide-oxidizing bacteria	-	BOE	-	SH	PI
Opportunistic polychaete complex	-	BOE	-	SH	PI
Macrofauna (>0.5 mm)	-	BOE	-	-	PI
Meiofauna (0.063 - 0.5 mm)	-	BOE	-	SH	PI
Bivalve abundance/diversity	ECC	BOE	-	-	PI
Bivalve recruitment (Intertidal)	ECC	BOE	-	-	PI
Bivalve condition index	ECC	BOE	-	-	PI
Macroalgae	-	BOE	PE	-	PI
Eelgrass	-	BOE	PE	SH	PI
Hard-substrate variables					
Substrate composition	-	BOE	-	-	PI
Epifaunal abundance	-	BOE	-	-	PI
Sulfide-oxidizing bacteria	-	BOE	-	-	PI
Opportunistic polychaete complex	-	BOE	-	-	PI
Pelagic methods variables					
Temperature, salinity, oxygen	ECC	-	PE	SH	PI
Suspended particulate matter	ECC	-	PE	SH	PI
Phytoplankton production	ECC	-	PE	-	-
Phytoplankton primary productivity	ECC	-	PE	-	-
Dissolved nutrients	ECC	-	PE	SH	-
Zooplankton	ECC	-	PE	-	-
Water currents	ECC	-	PE	SH	PI

Sources of Uncertainty

- The model parameterizations and coefficients calculated a higher than measured mixing of the vertical water column which can result in an over prediction of phytoplankton in the BICEM model. The overmixing is also confounded by the bathymetry and forced flattening of the basin.
- Three rivers were not factored into the model (Englishman, Big/Little Qualicum) and do represent a portion of low salinity water entering through the southern entrance. Overall a low impact to the BiCEM modelling is expected, but their inclusion would likely have improved the measured versus modeled salinity values within Baynes Sound.
- In general more information on the bivalve densities would improve model accuracy, in particular when it comes to wild and bottom cultured Pacific oysters.
- Uncertainty results from the inability of the model to accurately capture some features of phytoplankton dynamics, i.e. vertical distribution and fall bloom.
- Additional zooplankton data, in particular temporal coverage, would help better constrain this model variable. It is to be noted that by design this variable is the least realistic of all model variables. The model zooplankton reflects the amount of energy in the system available to be transferred to higher trophic levels other than wild and cultured bivalves, rather than trying to simulate any specific actual zooplankton group or community dynamics.
- The data set used to calibrate the model was from an anomalously warm year (2016-2017).

CONCLUSIONS

- Spatial models are useful tools for exploring ecological carrying capacity. In this case, two models FVCOM and BICEM-DEB were selected to model components of the benthic and the pelagic ecosystem. The integration of these two models was desirable as they provide an accurate description of a very complex hydrodynamic area with biogeochemistry. The hydrodynamics in Baynes Sound are complex with two main connections to the SoG. One narrow deep entrance to the south and one flat wide entrance to the north. Various data and observations were collected for a one year period (2016/2017) along with other longer term data sets (i.e., tidal stations) to calibrate and validate the model. There was good agreement between hindcasts in the model and observations from data collected in the field. The models were able to hindcast the hydrodynamic conditions and biological conditions across the entire bay and at a more local scale such as Fanny and Mud Bays. This resolution is integrated in the ecological carrying capacity for the entire bay and at the more local scale.
- The Current aquaculture level (Scenario 2) has not exceeded the capacity of Baynes Sound to support bivalve aquaculture based on an analysis of phytoplankton depletion and primary productivity. The values simulated for Baynes Sound are well below the thresholds for carrying capacity from the literature in terms of phytoplankton depletion and primary productivity model and uncertainties would not affect the overall conclusion on the ecological carrying capacity of Baynes Sound.
- The Expansion - Max aquaculture level (Scenario 5) would not exceed the ecological carrying capacity. The fraction of resources already exploited varies within Baynes Sound and is largest in Fanny, Deep, and Mud Bays. The current performance of cultures could be impacted at a local scale if maximum expansion scenarios in these areas are considered. Therefore, a cautious approach would be recommended in case of pursuing the expansion,

including a gradual allocation of new leases and monitoring of bivalve performance under this hypothetical scenario.

- The review of methods covers benthic and pelagic monitoring variables that are associated with ecological bivalve carrying capacity and other ecosystem impact assessments. The monitoring methods included techniques for hard and soft bottom sediments and a limited collection of pelagic methodologies using a variety of monitoring devices. The methods also include a field collection and management regulatory thresholds and analyses techniques. Threshold values were provided for many parameters from literature reviews. The document is comprehensive in its methodologies but is not prescriptive on study design, such as, sample size, reference locations etc. Users need to be clear on the objective of the monitoring effort to propose a detailed site specific study design.

CLIMATE CHANGE CONSIDERATIONS

Analyses of long time-series and results from forecast models suggest that bivalve cultures in Baynes Sound will be impacted by climate change (Masson and Cummins 2007; Amos et al. 2015). The potential faster bivalve growth and increased production due to an increase in water temperatures could be hindered by an overall decrease in the Sound's carrying capacity, following the increased pressure on phytoplankton resources. In addition to an increase in mean water temperature, climate change could potentially lead to temporal shifts in the temperature seasonal cycle and planktonic communities (Mackas et al. 2011, 2013; Allen and Wolfe, 2013; Filgueira et al. 2015). Such shifts may affect the phenology of different species or group of species in different ways and lead to new match/mismatch between supply and demand for pelagic resources. Climate change may also produce possible harmful trends in ocean acidification and hypoxia (Ianson et al. 2016, Evans et al. 2019). As for any climate-driven change, further research is warranted to understand the ultimate consequences of these shifts on coastal ecosystems in general and their carrying capacity for bivalve aquaculture.

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SOURCES OF INFORMATION

This Science Advisory Report is from the March 8-12, 2021 Regional Peer Review on Modeling and monitoring approaches to evaluate the ecological carrying capacity for shellfish aquaculture. 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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THIS REPORT IS AVAILABLE FROM THE:

Centre for Science Advice (CSA)
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ISSN 1919-5087
ISBN 978-0-660-38322-4 Cat No. Fs70-6/2021-012E-PDF

Correct Citation for this Publication:

DFO. 2021. Modelling and Monitoring Methods Approach to Evaluate Ecological Bivalve Carrying Capacity in Baynes Sound, British Columbia. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2021/036.

Aussi disponible en français :

MPO. 2021. Approche des méthodes de modélisation et de surveillance pour évaluer la capacité de charge écologique des bivalves dans le détroit de Baynes (Colombie-Britannique). Secr. can. de consult. sci du MPO. Avis sci. 2021/036.