Information Request Package 3 from the Review Panel for the Roberts Bank Terminal 2 Project Environmental Assessment: Responses

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PART 1
ECOSYSTEM MODELLING
(IR3-01 TO IR3-24)

Information Request Package 3 Preamble in Support of Responses to IR3-01 to IR3-24 – Roberts Bank Ecosystem Model

1.0 Introduction

In this document, the Vancouver Fraser Port Authority (VFPA) responds to IR3-01 through IR3-24 of the Panel's information requests (IRs) in Package 3 (issued February 10, 2017) related to the Roberts Bank ecosystem model (RB model[1]).

The RB model supports the VFPA's overall conclusions about potential effects of Roberts Bank Terminal 2 (RBT2 or Project), including the following:

- Changes in productivity from the terminal and causeway footprint are relatively small, especially in the context of the Strait of Georgia basin;
- Before mitigation (including offsetting), the Project increases overall productivity within Roberts Bank;
- Primary losses in productivity, as determined by the RB model are in the subtidal (and this is intuitive given the terminal is primarily located in the subtidal region); and
- The Strait of Georgia's environment (e.g., currents, water quality, species distribution/abundance) will continue to influence the Roberts Bank ecosystem, with or without RBT2.

To provide further context and background to the VFPA's IR Package 3 responses on the RB model, additional information is summarised below.

2.0 Ecosystem-based Management and the Productivity Approach: Roberts Bank Terminal 2 Alignment with Federal Principles

Ecosystem-based management is a holistic approach in which decisions are made based on an understanding of the whole ecosystem rather than individual species or communities. The environmental assessment of RBT2 marine biophysical valued components is founded on this ecosystem-based approach.

In recent years, federal agencies have increasingly adopted this management approach to support planning and decision making. For example, Environment and Climate Change Canada (ECCC) identified employing ecosystem and multi-species approaches as part of its Report on Plans and Priorities 2013-2014 (ECCC 2013).

[1] Note the Panel has used the term 'RB EwE model' in reference to the Roberts Bank ecosystem model. To remain consistent with past documents and communication, the VFPA uses the short form 'RB model' to reference the Roberts Bank ecosystem model in its responses to IRs in this package.

An ecosystem approach is aligned with new guidance from Fisheries and Oceans Canada (DFO), which has shifted focus towards assessing productivity of ecosystems and key fisheries, and ensuring continued capacity for productivity within that ecosystem during construction of and following the implementation of a project (DFO 2013).

The ecosystem approach continues to build momentum in resource management. Recommendations were recently made from the Standing Committee for Fisheries and Oceans Canada to "take an ecosystem approach to protection and restoration of fish habitats so that the entire food web is preserved for fish" and "fund more research dedicated to ecosystem science" (House of Commons Canada 2017).

Studies undertaken to support the environmental assessment of RBT2 were initiated (2011) prior to changes in the *Fisheries Act* (2013) and were aligned to achieve the then (2011) guiding principle of "no net loss of the productive capacity of habitats" (1999).

To help meet these policy goals and objectives, the VFPA convened the Productive Capacity Technical Advisory Group (TAG; see **Section 3.0** below for additional details) in 2012. Scientific experts on birds, fish, and invertebrates contributed (via the Productive Capacity TAG) to the selection of a method to define 'productive capacity' and identified the species that should be included in studies on productive capacity at Roberts Bank.

A key recommendation by the Productive Capacity TAG was to focus on an ecosystem level approach (and model) and use productivity as the primary metric to analyse changes in productive capacity; this recommendation led to the development and use of the RB model.

Subsequently, the *Fisheries Act* changed (2013) and the ensuing Fisheries Protection Policy Statement (2013) placed further emphasis on a productivity-based approach (the goal of which is "to provide for the sustainability and ongoing productivity of commercial, recreational and Aboriginal fisheries").

Hence, Productive Capacity TAG recommendations, the RB model, and RBT2 environmental assessment of marine biophysical valued components (and identification of mitigation measures using the RB model) are aligned with federal legislation and related policy targets, and their focus on an ecosystem and productivity approach.

3.0 Productive Capacity Technical Advisory Group Process

As indicated earlier, observational field studies to support the RBT2 environmental impact statement (EIS) were initiated in 2011 and were designed to support an assessment underpinned by the then-*Fisheries Act* primary guiding principle of 'no net loss of the productive capacity of habitats' (DFO 1999).

Though there have been numerous efforts to develop methods to quantify fish habitat *productive capacity* (e.g., see Smokorowski and Derbowka 2008), no single standard metric or methodology exists. To select an appropriate approach to defining productive capacity (see above) at Roberts Bank, the VFPA sought input from a diverse group of experts through the TAG process (described in EIS Section 7.1). In total, nine TAG members (including scientific

representatives from ECCC and DFO) participated in a Productive Capacity TAG. A summary report of the Productive Capacity TAG is provided as **Appendix IR3-A**.

The Productive Capacity TAG was convened to solicit input on suitable methods for analysing and reporting changes to productive capacity that were scientifically defensible and relevant to the RBT2 regulatory process. Importantly, the Productive Capacity TAG was tasked with recommending an appropriate quantitative modelling methodology. The TAG explored many modelling approaches (following a detailed literature review of all known methods) and, based on the most suitable options, weighed and considered in detail three quantitative models as part of their discussion: habitat suitability index, index of biotic integrity, and Ecopath with Ecosim and Ecospace (EwE) [2]. Criteria developed by the Productive Capacity TAG for selection of the modelling approach for RBT2 is presented in **Table IR3-1**.

Table IR3-1 Criteria for the Selection of a Productive Capacity Measurement Methodology

Criteria	Description
Applicable to Roberts Bank system	Is the method applicable to the Roberts Bank system (marine, estuarine), and is it able to address the species/habitats of concern?
Scientifically defensible	Is the method scientifically defensible and peer reviewed?
Practical	Is the method practical in terms of input data requirements (e.g., timelines, cost, and technical feasibility)?
Understandable	Can the method produce summary statements that are understandable for the regulatory review process?
Describes net changes	Can the method describe expected net changes in productive capacity? In other words, can it aggregate across species groups to produce a summary statement about overall change in net productivity?
Describes key trade-offs	Can the method describe key trade-offs among individual components of productive capacity? In other words, can it ensure that gains and losses across species or species groups are transparent?
Incorporate uncertainty	Can the method estimate or characterise uncertainty and the range of possible outcomes given uncertainty?
Applicable to mitigation and offsetting	Can the method produce results that inform the evaluation of mitigation and compensation options?
Robust to regulatory changes	Is the method robust to changes in the regulatory review process?

Source: Abstracted from the Productive Capacity Technical Advisory Group Summary Report (see **Appendix IR3-A**).

With several hundreds of species at Robert Bank, it would not be technically feasible or effective to model all species and their productivity. The Productive Capacity TAG was also tasked with identifying 'focal species': species that are ecologically linked to many components of the ecosystem, and thus able to provide an indication of changes in productive

[2] EwE is short form for Ecopath with Ecosim and Ecospace. In other documents, 'Ecopath with Ecosim' has been the long form for 'EwE'. All three reference the same suite of modelling software.

capacity for a broader number of species. By keying in on focal species at Roberts Bank, the RB model is able to forecast changes to the wider ecosystem. Criteria developed by the Productive Capacity TAG for selection of focal species used in the RB model is presented in **Table IR3-2**.

Table IR3-2 Criteria for the Selection of a Focal Species

Criteria	Description
Societal Perspective	Species of social importance
	Species of cultural or Aboriginal importance
	Species of economic importance
Ecological Perspective	Species is a good indicator of change in productive capacity
	Species of ecological importance
	Species is ecologically dependent on Roberts Bank
	Species will "capture /represent" species with similar ecological requirements
	Species at risk
	Species traditionally used in monitoring
	Species contributes to the ongoing productivity of a fishery
	Species for which management objectives have been defined
	Species that is consistently present in relatively high numbers
	Species for which there are good historical data

Source: Abstracted from the Productive Capacity Technical Advisory Group Summary Report (see **Appendix IR3-A**).

4.0 Selection of the EwE Model for RBT2

Ultimately, the Productive Capacity TAG participants unanimously selected the EwE model as the preferred modelling method to analyse changes in productivity at Roberts Bank. In addition, participants identified 28 focal species to be representative of the Roberts Bank ecosystem[3].

The EwE model matched well with the selection criteria employed by the Productive Capacity TAG and was recognised as a state of the art modelling tool. The EwE methodology is well documented in the scientific literature and has been widely used to quantitatively describe marine food webs, fisheries policy exploration (regulatory decisions on managing fisheries),

[3] Based on the input from the Productive Capacity TAG, the modelling team also incorporated other species that use Roberts Bank into the model in order to represent predator-prey relationships of potential importance to the 28 focal species. To reduce the complexity of the model, species with similar ecological characteristics were aggregated into functional groups. In total, the RB model incorporates 58 functional groups, including focal species.

and ecosystem-based fisheries management (see CEAR Document #547[4], question 2.12 for a broad list of such applications). The model had also been used in a joint B.C.–Canada environmental assessment in the Site C Dam project and in various Salish Sea studies (see for example Preikshot et al. 2013).

The VFPA retained the University of British Columbia's Fisheries Centre (now the Institute for the Oceans and Fisheries), a leader in ecosystem modelling and the key developer of the EwE approach, to adapt the EwE model for Roberts Bank, tailoring the approach, technique, and study design to the complexities of the site. At its core, the RB model connects physical abiotic and biological model inputs to evaluate changes in productivity with and without the Project for the species or groups of species. Inputs for the model include data from the VFPA's fieldwork efforts conducted from 2011 to 2014, as well as the results of geomorphic modelling (which itself is based on field sampling).

The RB model was one of several tools used by the VFPA to inform the environmental effects assessment of marine biophysical valued components as described in the EIS. Effects assessment conclusions were based on numerous lines of evidence (e.g., other models, field studies, professional opinion, and literature) and did not rely solely on RB model results.

5.0 Agency Engagement Post EIS Submission

Following submission of the EIS in March 2015, engagement with agencies continued during the completeness review of the environmental assessment process.

Follow-up Questions on Coastal Geomorphology and Ecosystem Modelling (CEAR Document #547)

The VFPA has actively responded to questions about the application of the RB model, including through completeness information request responses (see Information Request #6 (IR-7.31.15-06) in CEAR Document #314[5]) and in separate, agency-specific engagement.

DFO and Natural Resources Canada (NRC) provided written questions to the VFPA based on a preliminary review of the EIS on November 19, 2015, ahead of an in-person meeting on November 23, 2015. The meeting included representatives from the VFPA, NRC, DFO, ECCC, and other federal agencies.

Following this large-scale engagement, a series of more topic-specific meetings were held with individual and/or combinations of agencies through December 2015 and February 2016. Involving DFO, NRC, ECCC, and the VFPA, the meetings provided clarity on topics such as

[4] CEAR Document #547 From the Vancouver Fraser Port Authority to the Review Panel re: Answers to preliminary technical questions submitted during the completeness phase from Fisheries and Oceans Canada, Natural Resources Canada, and Environment and Climate Change Canada, concerning the ecosystem modelling to support the Roberts Bank Terminal 2 Project environmental review (NOTE: Updated September 28th, 2016).

[5] CEAR Document #314 From Port Metro Vancouver to the Canadian Environmental Assessment Agency re: Completeness Review - Responses to Additional Information Requirements (See reference document #271) for the Environmental Impact Statement.

hydrology, sediment modelling, and ecosystem modelling questions posed by the agencies. The VFPA provided a cumulative submission of responses to the agencies in March and May 2016, and these questions and responses were posted to the Canadian Environmental Assessment Agency's registry on September 28, 2016 (CEAR Document #547).

DFO Science Branch Review (CEAR Document #900)

In December 2016, the Canadian Science Advisory Secretariat of the DFO Science Branch released its review of the RB model (CEAR Document #900[6]). Numerous federal experts conducted the review, including from DFO and the Canadian Wildlife Service[7,8].

While some questions on the RB model were identified in the DFO Science Branch review (many of which have been included by the Panel in this IR Package 3 submission) the general conclusions of the review support how the model was established and agreed that input parameter estimates were adequate for the Roberts Bank ecosystem.

Importantly, the DFO Science Branch (with input from NRC[7]) concluded "the EwE model, as implemented in this project and reviewed here, is a useful first-order framework to organize information and derive initial estimates of how the system may respond to perturbations" (CEAR Document #900, p.20).

6.0 Overview of Topics in Panel Information Request Package 3: Roberts Bank Ecosystem Model Responses

Since submission of the EIS, a number of common topic themes have emerged regarding questions posed during the completeness phase of the environmental assessment process and now during Panel sufficiency review regarding the assessment of the RB model. **Table IR3-3** summarises additional clarification and analyses that have been undertaken since submission of the EIS to address these questions.

[6] CEAR Document #900 From the Review Panel Secretariat to the Review Panel re: Technical Review of Roberts Bank Terminal 2 Environmental Assessment: Section 10.3 - Assessing Ecosystem Productivity - by Fisheries and Oceans Canada.
[7] Authors of the report include Ian Perry, DFO Science; Alida Bundy, DFO Science; Terri Sutherland, DFO Science; Robert Elner, ECCC, Canadian Wildlife Service; and Andrew Robinson, ECCC, Canadian Wildlife Service.
[8] NRC was involved in joint and separate meetings on the RB model as explained on page 3 of CEAR Document #900.

Table IR3-3 Clarification and Analyses Undertaken Since Submission of the EIS

Reference	Details		Related Information Request Package 3 Response	Related Topics from CEAR Document #314
CEAR Document #547, questions 2.1 to 2.18	2.1 Model Scale	Clarification was provided on model scale in context of exchanges between modelled and external systems (e.g., tidal exchanges, seasonal animal migrations) using annual averages, diet imports, and dispersal rates.	IR3-05	n/a
	2.3 Dispersal Rates	Clarification was provided on how dispersal rates were used to account for movements between cells, including sub-daily movements.	IR3-14	n/a
	2.4 Tug Basin	Clarification was provided on why the tug basin was omitted from the model.	IR3-02	n/a
	2.7 Use of Confidence Limits in RB Model	Clarification provided on how the pedigree approach used was appropriate to capture the level of confidence in input parameters.	IR3-22	Information Request #6 (IR-7-31-15-06), Section 2.0 (Response to IR6a)
	2.9 Model Balancing	Clarification was provided on the model balancing process in general, and illustrated using three worked up examples.	IR3-16; IR3-17	Information Request #6 (IR-7-31-15-06), Section 3.0 (Response to IR6b)
	2.10 Balance Sheet	Provision of unbalanced and balanced input and output values for various parameters to provide context for model results.	IR3-19	n/a
	2.13 Vulnerability and Sensitivity	Presents analysis of a broader range of vulnerability values.	IR3-23	Information Request #6 (IR-7-31-15-06), Section 8.0 (Response to IR6g)

Reference	Details		Related Information Request Package 3 Response	Related Topics from CEAR Document #314
	2.15 Goodness of Fit	Justification provided for use of the percent correct classification method and presentation of sensitivity and specificity as additional goodness of fit metrics.	IR3-21	Information Request #6 (IR-7-31-15-06), Section 7.0 (Response to IR6f)
	2.16 Fixed Selectivity	Clarification on the 'fixed selectivity' concept for diets.	IR3-08	n/a
	2.17 Time Steps	Clarification on time steps and whether annual time steps used in the model captures variability at finer temporal scales.	IR3-13	n/a
CEAR Document #547, questions 3.1 to 3.7	3.2 Normalising of Input Parameters into Annualised Averages	Clarification and rationale for normalising input parameters to create annual averages and discussion of implications for seasonal species.	IR3-13	n/a
	3.7 Use of Greater Confidence Limits	Clarification on whether the model can be run with broader confidence limits to increase uncertainty.	IR3-22	n/a

Many of these themes were anticipated by the Productive Capacity TAG and largely formed the basis for the model selection rationale. In other words, the Productive Capacity TAG advised the selection of the EwE approach because it was the best tool available to address such anticipated topic themes. Hence, such topic themes (that have been identified since submission of the EIS by reviewers, and as summarised below) were considered by the Productive Capacity TAG in advance of the RB model selection and development, and as indicated recently by the DFO Science Branch (CEAR Document #900), the RB model did the "best job possible of comparing the biomass and productivity of the Roberts Bank ecosystem with and without the Project" (p.20).

Additional analyses requested and conducted (during completeness and sufficiency review to date) have confirmed the findings reported in the EIS, strengthening the confidence in the conclusions of the assessment. For context, the key topics and findings are summarised below.

Addressing Uncertainty

As advised by the Productive Capacity TAG, the RB model results described in the EIS addressed uncertainty in several ways and on several levels, as described below.

Model Validation and Accuracy

The VFPA undertook specific model validation and accuracy studies to evaluate the performance of RB model results. Both a visual validation (EIS Appendix 10-C) of model forecasts and the percent correct classification (PCC) accuracy statistic were presented (CEAR Document #547). Both the visual validation and PCC analysis indicate the model is robust and accurately forecasts the present distributions of habitat forming species at Roberts Bank.

In response to questions posed by DFO (CEAR Document #547), the VFPA undertook additional accuracy studies on the RB model (IR3-21). These additional accuracy studies also demonstrate that the model is robust and accurately forecasts productivity at Roberts Bank.

Inclusive of the validation method presented in IR3-21 of this package, four separate validation and accuracy analyses were performed by the VFPA on the RB model, all of which demonstrate the model is robust at forecasting productivity at Roberts Bank, and this provides high confidence in RB model results.

Sensitivity Analyses

Sensitivity analysis is the mechanism the EwE model uses to address potential uncertainty. Numerous sensitivity analyses were undertaken in the RB model and all are included in EIS Appendix 10-D.

Sensitivity analyses were designed to evaluate how potential uncertainty within input variables may affect model results. In summary, a 'key run' of the model was developed (which identified changes in productivity with and without the Project) and evaluated using model sensitivity analyses that included the following:

i. Sensitivity to vulnerability setting;
ii. Sensitivity to inclusion of abiotic factors;
iii. Sensitivity to abiotic factor over/under-estimate; and
iv. Sensitivity to input assumptions (Monte Carlo analyses where the model is run thousands of times using randomly different values for biotic variables).

The sensitivity analyses show the RB model forecasts are robust to uncertainty in various input data.

In response to earlier concerns on confidence limits used in the EIS, the VFPA (CEAR Document #547, question 2.7) increased the confidence limits in the RB model and as indicated by the DFO Science Branch (CEAR Document #900, p.20): "the model may be robust to wide ranges of uncertainty in the input variables and parameters".

Multiple Lines of Evidence

The RB model was used to inform the effects assessment of marine biophysical valued components. However, this model was only one line of evidence used in these assessments; other sources of information, including field study results, other models, precedents from prior projects, and literature sources were also used to draw conclusions.

Capturing Migratory Species Spatial Dynamics and the Roberts Bank Ecosystem Model Study Area

The Productive Capacity TAG used a structured, criteria-based decision-making process for selecting analytical methods. One selection criterion was the ability to incorporate open systems, including consideration of both resident and migratory populations (see Section 3.2.1 of **Appendix IR3-A**). Productive Capacity TAG members noted that EwE had advantages over other potential assessment methods (e.g., habitat suitability index, index of biological integrity) with respect to treatment of migratory species.

The RB model forecasts changes in biomass, with and without the Project, for functional groups—including migratory species—by normalising seasonal input parameters to create annual averages. Annual averages are typically employed over seasonal ones because seasonal data for all parameter inputs (e.g., biomass, consumption, diet, environmental preferences, environmental conditions) do not exist due to onerous collection requirements; in fact, no fully seasonal EwE model has been developed because such models are required to describe the ecosystem as a whole, rather than a seasonal sub-component. Therefore, annual averages are used to account for seasonal and spatial restrictions, and are considered a standard metric for ecological questions within the context of an ecosystem level assessment (Harvey et al. 2012, Mackinson and Daskalov 2007, Preikshot 2013).

It is important to note that the objective of the RB model is not to provide an assessment of Project impacts for each functional group at a fine temporal scale (i.e., a specific migratory window), but to estimate changes in productive potential, with and without the Project, at the ecosystem level.

The EIS effects assessment of migratory functional groups incorporated multiple lines of evidence, using other modelling approaches as well as literature and precedent from other assessments, that are more suitable to determine fine temporal scale changes (e.g., Technical Report - Shorebird Foraging Opportunity during Migration (EIS Appendix 15-B)). Conclusions described in the EIS did not always rely on RB model outcomes.

The VFPA has received information requests on the topic of RB model study area and the proportion of open boundaries to closed boundaries in the model (for example see CEAR Document #900, p.20). While the RB model study area is small in comparison to the entire Strait of Georgia and model domains of some other EwE models (many of which are used for large scale fisheries resource management), the VFPA considers its size appropriate for the following reasons:

- The RB model study area was deliberately designed to capture direct and (potentially farther reaching) indirect biotic and abiotic effects (i.e., scour, wave heights, etc.) from terminal and causeway footprint placement;
- Indirect effects from terminal and causeway footprints, as determined by the RB model, were informed by incorporating the hydrodynamic model, which also included areas outside of the RB model study area (see EIS Section 9.5); the hydrodynamic model did not identify hydrodynamic changes outside of the RB model study area (direct effects from terminal and causeway placement are spatially restricted to these components and are included in the RB model);
- Hence, potential indirect effects from terminal and causeway footprint placement outside of the RB model study area are not forecasted (as determined by both the RB model and the hydrodynamic model);
- Therefore, areas outside of the RB model study area are assumed to be the same with and without the Project (terminal and causeway placement);
- To meet the objectives of the RB model (to identify with and without terminal and causeway footprint productivity changes) it is therefore not necessary to include 'external processes' from areas outside of the RB model;
- The RB model accounts for biological influence from outside of the RB model study area via the use of the import function (see CEAR Document #547, question 2.1 for further details) and annualised biomass estimates for migratory or mobile species; and
- Other EwE models with similar or smaller study areas to the RB model study area have been developed (e.g., Alexander et al. 2016, Heymans and Pitcher 1995, Ruiz and Wolff 2011, Wabnitz et al. 2010, Xu et al. 2011).

Confidence in Diet

Several questions received from reviewers relate to the validity or appropriateness of diets of the functional groups used in the RB model. It seems there is some confusion in questions related to how, or where, information on diets was obtained. The following describes the methodology used to determine diets and the steps taken to address potential sources of uncertainty in such data/information.

Diet matrix parameters and ranges of uncertainty were derived using a step-wise approach, including use of literature, the 'fixed selectivity principle', use of data quality pedigrees, and indirectly using Monte Carlo sensitivity studies.

The first step involved extracting diet composition information from the literature, giving preference to quantitative information on diet preferences (i.e., percent contribution of prey in the diet of a predator), where possible. Because site-specific quantitative diet data were not available for any of the functional groups, published diet preferences from nearby similar systems were considered, which were adjusted to account for local availability of prey (or lack thereof).

In the second step, diet preferences were transcribed in the diet matrix using qualitative information available in the literature, in the absence of quantitative data. Qualitative diet descriptions were converted into quantitative data by applying the 'fixed selectivity principle' (see Section 2.6.2 of EIS Appendix 10-C, CEAR Document #547, question 2.16, and IR3-08).

In general, fixed selectivity is an objective approach for populating a diet matrix that enables qualitative prey preferences to be quantified based on the relative productivity of the prey (as typically determined by field study related abundance information from Roberts Bank).

The third step is specific to functional groups consisting of multiple species, where diet was averaged for each species and then adjusted for biomass of the species in the functional group.

Lastly, the fourth step is specific to functional groups that have large migratory ranges, are highly mobile, and have widely distributed prey (e.g., baleen whales, salmon), and involved classifying elements of their diet as import (i.e., originating from outside the study area boundaries).

Following the above step-wise approach, the range of uncertainty in the diet matrix was evaluated with the implementation of a pedigree. Depending on the origin of the information, diet input for each functional group was assigned a pedigree category and associated confidence interval (see Table 3.1 of EIS Appendix 10-C; for pedigree definitions as they pertain to diets of functional groups, see Table 2.4 of EIS Appendix 10-C).

7.0 Conclusions

The RB model and the related sensitivity analyses support the following technical conclusions:

- Changes in productivity from terminal and causeway footprint are relatively small (and robust to uncertainty in underlying model data); this conclusion is intuitive given the relatively small area of the Project (1.79 km^2) in relation to the RB model study area (54.58 km^2);
- The primary losses in productivity (as demonstrated by RB model results) are subtidal in nature; this reflects the subtidal nature of the Project in that the terminal is sited in the subtidal zone;
- The influence of the Strait of Georgia (currents, water quality, species distribution/abundance) before the Project will be the same with the Project and that, as indicated by the CEAR Document #900, "it could be argued that an ecosystem which is open to frequent exchanges of water and organic matter from beyond its boundaries [such as the case at Roberts Bank] might be more robust to local disturbances such as the Project" (CEAR Document #900, p.9);
- Before mitigation (including offsetting), the Project increases net productivity (all functional groups combined) within Roberts Bank; this is primarily due to forecasted changes to tidal currents, wave energy, and salinity related to the terminal and resulting in improved conditions for biological growth for many of the functional groups studied; and
- With the Project, the Roberts Bank ecosystem will continue to function like it does presently (as a large source of primary productivity which attracts species from higher trophic levels).

The RB model was a tool selected, developed, and appropriately used in the RBT2 environmental assessment. The VFPA sought feedback on the model approach specifically

through the Productive Capacity TAG, ensured developers of the RB model were appropriately qualified, ensured the data input were of the highest quality, and used sensitivity analysis to rigorously address various uncertainties in the model input data and model parameters.

The VFPA continued to engage with regulatory agencies during the completeness phase, providing further clarification as well as conducting additional analyses as requested to address questions raised (CEAR Document #547). The scientific review conducted by the DFO Science Branch supported the modelling approach and noted the model served its function (CEAR Document #900).

The VFPA has responded to these IRs in this submission. Additional analyses provided also re-iterate the key findings presented in the EIS and summarised above.

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Appendices

Appendix IR3-A Productive Capacity Technical Advisory Group Summary Report

APPENDIX IR3-A
PRODUCTIVE CAPACITY TECHNICAL ADVISORY GROUP SUMMARY REPORT

Roberts Bank Terminal 2

Technical Advisory Group (TAG) Process Report

Productive Capacity – Final Report

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Acronyms

CCIP	Container Capacity Improvement Program
Compass	Compass Resource Management
EA	environmental assessment
EwE	Ecopath with Ecosim
HEP	Habitat Evaluation Procedure
HSI	Habitat Suitability Index
HUI	Habitat Utility Index
IBI	Index of Biotic Integrity
IPCC	Intergovernmental Panel on Climate Change
NOAA	National Oceanic and Atmospheric Administration
PC	productive capacity
PMV	Port Metro Vancouver
PPRFFA&Ss	past, present, and reasonably foreseeable future actions and stresses
RBT2	Roberts Bank Terminal 2
TAG	technical advisory group
SRKW	Southern Resident Killer Whales
TEU	twenty-foot equivalent units
VEC	valued ecosystem component

1 Introduction

1.1 Purpose and Background

The Roberts Bank Terminal 2 (RBT2) project is a proposed new three-berth container terminal in Delta, BC that would expand existing port facilities by 2.4 million twenty-foot equivalent units (TEUs) of container capacity. The project is part of Port Metro Vancouver's (PMV) Container Capacity Improvement Program (CCIP), a long-term strategy to meet anticipated growth in demand for container capacity. The proposed RBT2 project entails the construction of a new three-berth marine terminal and associated road and rail infrastructure alongside the existing Westshore and Deltaport terminals at Roberts Bank. PMV has a mandate to support the growth of Canadian trade with other countries, and current demand forecasts anticipate container traffic to triple by 2030. Subject to regulatory approvals, the RBT2 project could be operational by the mid-2020s. Further information on the proposed RBT2 project can be found on the project's website, www.robertsbankterminal.com.

Figure 1. Artist's rendering of the proposed RBT2.

Image courtesy of PMV.

The proposed RBT2 project is subject to environmental assessment (EA) under federal and BC provincial laws. EA is a process whereby the potential effects of proposed projects on the environment are examined through a public process. While the scope and nature of the EA for RBT2 has not yet been determined by regulators, PMV expects the EA to be some form of joint review process. The proposed RBT2 project could potentially cause a variety of environmental effects, some of which are reasonably well understood, and some of which are less well understood due to their complexity and based on the current state of scientific knowledge.

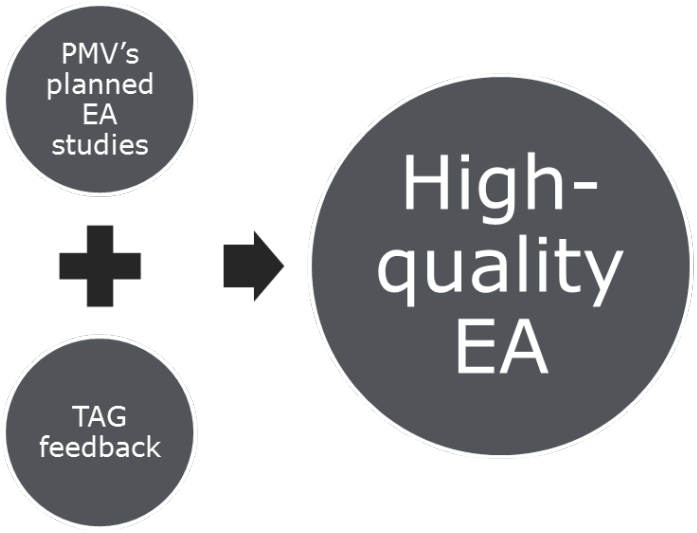
PMV has contracted Hemmera, a consulting firm specializing in EA, to conduct the EA studies for the proposed RBT2 project. Some of these studies, such as baseline studies that characterize the environment pre-construction, are currently underway. As part of its pre-EA work, PMV initiated a Technical Advisory Group (TAG) process to gather input from outside experts on four separate topics.

This report is written by Compass on behalf of the Productive Capacity TAG and summarizes the proceedings and recommendations of that TAG.

1.2 Overview of the Technical Advisory Group Process

The purpose of the TAG process was to pro-actively gather input from scientific and technical experts prior to the formal initiation of the EA for RBT2 so as to enhance the relevance, quality, and rigour of EA studies for the project (Figure 2). Experts were invited from regulatory agencies, academia, First Nations and key non-government organizations based on their ability to contribute to technical discussions pertaining to the identified EA studies.

Figure 2. Role of TAG process in ensuring high-quality EA of the proposed RBT2 project.



The TAG process involved four separate TAGs:

1. Biofilm and Shorebirds;
2. Southern Resident Killer Whales (SRKW);
3. Coastal Geomorphology; and
4. Productive Capacity of Roberts Bank habitat.

The four TAGs each addressed topics that were considered by PMV and its consultants to require additional preliminary scoping in order to satisfy EA requirements.

Biofilm, shorebirds, and SRKW are likely to be recognized in the forthcoming EA as topics of particular importance to stakeholders and thus of the forthcoming EA process. These topics are discussed in companion reports on each of the individual TAGs.

Coastal geomorphology—the physical features and processes in the vicinity of the proposed project area at Roberts Bank—was chosen because any project-related geomorphic and physical oceanographic changes are expected to be the primary driver for marine biological and ecological changes. RBT2 infrastructure may cause changes to tidal currents and water movement associated with wind-generated waves, which could affect sediment settling and re-suspension, and which in turn could cause changes to local marine habitats, such as biofilm and eelgrass beds. This topic is explored in a companion report on the Coastal geomorphology TAG.

Similarly, the ability of habitat to support species of particular interest to stakeholders is critical to the health of those species. PMV sees merit in entering into technical dialogue on how the productive capacity of habitat is most appropriately defined at Roberts Bank. This topic is explored here.

Despite the different topic matter of each of the four TAGs, all four had a similar set of objectives:

- build a common understanding of the potential effects of RBT2 based on the best available information;
- provide input on appropriate methods for assessing potential adverse effects and their significance;
- identify priority information needs and related studies; and
- identify opportunities for collaboration.

Each TAG met face to face three or four times between November 2012 and May 2013. Meetings were held in Vancouver over full day periods. Each individual TAG process was designed and led by Compass, who acted as an external facilitator. In each meeting Compass and PMV consultants led discussions with TAG members. In addition, for all TAGs except Coastal Geomorphology, focus groups were created to investigate particular topics in greater depth with an additional set of experts relevant to each field.

1.3 Participants and Roles in the TAG Process

There were five main parties identified as potential participants in the TAG process: technical experts from government agencies, academia, non-governmental organizations, PMV and PMV consultants, and First Nations. First Nations did not participate in the TAG process, however PMV has committed to share TAG information and obtain input through a separate process.

TAG members were tasked with:

- providing input on current and planned EA studies;
- providing input on potential effects of the project on the environment;
- providing input on impact assessment methods;
- helping prioritize and scope key issues; and
- providing input from their organization.

PMV consultants, Hemmera, were tasked with:

- preparing material for TAG meetings, such as pre-reading packages, presentation slides, and discussion materials;
- managing schedules, scope, and budget for the TAG process;
- explaining current study plans to the TAGs;
- ensuring integration of people and discussions across TAGs where relevant;
- organizing meeting logistics; and
- where relevant, having representatives participate as TAG members in TAG meeting discussions.

PMV was tasked with:

- providing resources and meeting logistics;
- providing communications with TAG participants and the public;
- providing information about the proposed RBT2 project; and
- observing TAG meetings and considering input from each TAG.

The TAG process was *advisory* in nature, and so PMV sought to gather advice through the process in terms of how best it and its consultants conduct specific EA studies for RBT2.

Compass was tasked with:

- designing the TAG process and advising on implementation;
- facilitating TAG meetings;
- advising on how discussions and outputs of individual TAGs might be used by other TAGs;
- summarizing input, including areas of agreement and disagreement, in meeting notes; and
- producing a record of the process in this summary report.

1.4 About This Report

This report reviews the discussions and outputs of the Productive Capacity TAG. This report does not attempt to follow the chronological order in which items were discussed during the meetings, but rather provides a thematically-organized synthesis of discussions that occurred over the course of the TAG meetings. The next section provides more background information in terms of what meetings were held, who was involved, and what specific topics were explored. Section 3 examines methods for assessing impacts on productive capacity and designing mitigation and offsetting programs. Section 4 examines several related issues that were less prominent in the TAG process. The reader is encouraged to review the reports for the other three TAGs to have a complete understanding of the RBT2 TAG process.

2 Background on Productive Capacity TAG

The proposed Roberts Bank Terminal 2 (RBT2) project will introduce changes to the productive capacity (PC) of the marine environment. Productive Capacity is defined by Fisheries and Oceans Canada (1986) as the maximum natural capability of habitats to produce healthy fish, safe for human consumption, or to support or produce aquatic organisms on which fish depend. While PC assessment has been conducted widely in Canada in a fisheries context, there is no single universally accepted approach. Further, Roberts Bank is an open estuary system with many species, and there are few precedents for the assessment of PC in such an environment. Nonetheless, it will be necessary in the EA context to determine whether the RBT2 project results in a net gain or loss in PC, and what kinds of trade-offs may be involved across different components of PC.

The PC TAG was convened to solicit input on suitable methods for assessing and reporting changes to PC that are scientifically defensible, relevant to the regulatory process, and relevant to the Roberts Bank area. The PC TAG discussed how the RBT2 project might affect PC at Roberts Bank at a species level, how PMV and its consultants might assess these effects (suitable assessment methodologies), and potential offsetting concepts and mitigation that could be considered. This chapter summarizes the input provided by the PC TAG and Focus Group. It provides a thematically-organized synthesis of discussions over the course of four TAG meetings.

2.1 TAG Meeting Summary

The PC TAG met four times between November 2012 and May 2013 to discuss a number of topics as summarized in Table 2.1.

Table 2.1: Dates and key topics of PC TAG meetings

Meeting #	Meeting Date	Key Topics Covered
1	November 6, 2012	• TAG process • RBT2 project overview • Context for Assessing PC at Roberts Bank • Key Issues in assessing PC • Discussion on criteria, indicators and methods • Focal Species: criteria for selection and initial list of species • Priorities and work plan for PC TAG
2	January 8, 2012	• Review of assessment methodologies (primary productivity, habitat utilization index, energy index) • Application of selected methods to biofilm, Dungeness crab and foraging fish, and shorebirds ("straw dog" examples) • Review and refinement of focal species list • Decision to convene Focus Group to provide expert input on focal species • Work plan and next steps
3	February 27, 2013	• Presentation and discussion of Focus Group results • Further refinement of focal species list • Discussion of limiting factors for focal species • Further review and discussion of PC assessment methodologies • Considerations for evaluating offset opportunities • Work plan and next steps
4	May 2, 2013	• Confirmation of focal species • Review of short-listed PC assessment methodologies (HSI, IBI, EwE) • Evaluation and selection of preferred PC assessment methodology • TAG wrap-up and key messages

2.2 TAG Participants

In total, nine TAG members participated in the PC TAG discussions, and eight observers attended without active participation. Table 2.2 presents participants of the PC TAG and their affiliation.

Table 2.2: Participants in the Productive Capacity TAG

Name	Affiliation	Role	Participation
Juergen Baumann	Baumann Environmental Services Ltd.	TAG member	Meetings 1, 2, 3, 4 (morning)
Sean Boyd	Environment Canada	TAG member	Meetings 1, 3, 4
Rob Butler	Independent	TAG member	Meetings 1, 2, 3
Carson Keever	Hemmera	TAG member	Meetings 1, 2, 3, 4
Patrice Leblanc	SENES	TAG member	Meetings 1, 2, 3, 4
Steve Macdonald	Fisheries and Oceans Canada	TAG member	Meetings 2, 3, 4
Brian Naito	Fisheries and Oceans Canada	TAG member	Meetings 1, 2, 3
Scott Northrup	Hemmera	TAG member	Meetings 1, 2, 3, 4
Terri Sutherland	Fisheries and Oceans Canada	TAG member	Meeting 2
Jody Addah	PMV	Observer	Meeting 2
Eriko Arai	Hemmera	Observer	Meetings 1, 2, 3, 4
John Parker-Jervis	PMV	Observer	Meeting 1
Kyle Robertson	PMV	Observer	Meetings 3 and 4
Andrew Robinson	Environment Canada	Observer	Meeting 2
Ben Wheeler	Hemmera	Observer	Meetings 1, 2, 3, 4
Laura White	Hemmera	Observer	Meeting 4
Marina Winterbottom	Hemmera	Observer	Meetings 1, 3, 4
Christian Beaudrie	Compass	Facilitator	Meetings 1, 2, 3, 4
Chris Joseph	Compass	Support	Meeting 1

2.3 Focus Group Participants

Given the diverse background required to inform specific questions raised by the PC TAG, a Focus Group consisting of individuals with expertise in the broad areas of birds, fish, invertebrates, marine vegetation, and marine mammals that utilize the Roberts Bank area was convened (Table 2.3). Members of the Focus Group were engaged through a web-based survey. Through the use of the Delphi method, experts provided independent input initially, and then were given an opportunity to review the survey results and provide additional feedback.

Table 2.3 Participants in the Productive Capacity Focus Group

Name	Affiliation
Juergen Baumann	Baumann Environmental Services Ltd.
Jim Boutillier	Fisheries and Oceans Canada
Sean Boyd	Environment Canada
Mark Drever	Environment Canada
Jason Dunham	Fisheries and Oceans Canada
Cynthia Durance	Precision Identification
Edward Gregr	University of British Columbia
David Lank	Simon Fraser University
Moira Lemon	Environment Canada
Colin Levings	University of British Columbia
Steve Macdonald	Fisheries and Oceans Canada
Kimberley Mathot	Max Planck Institute for Ornithology
Brigid Payne	Fisheries and Oceans Canada
John Reynolds	Simon Fraser University
Gary Williams	GL Williams and Associates
Ron Ydenberg	Simon Fraser University
7 anonymous participants	Various

21 experts in total from academic institutions, government (NOAA, Department of Fisheries and Oceans), non-governmental organizations, and private consulting participated in the Focus Group.

2.4 Selection of TAG Topics and Priorities

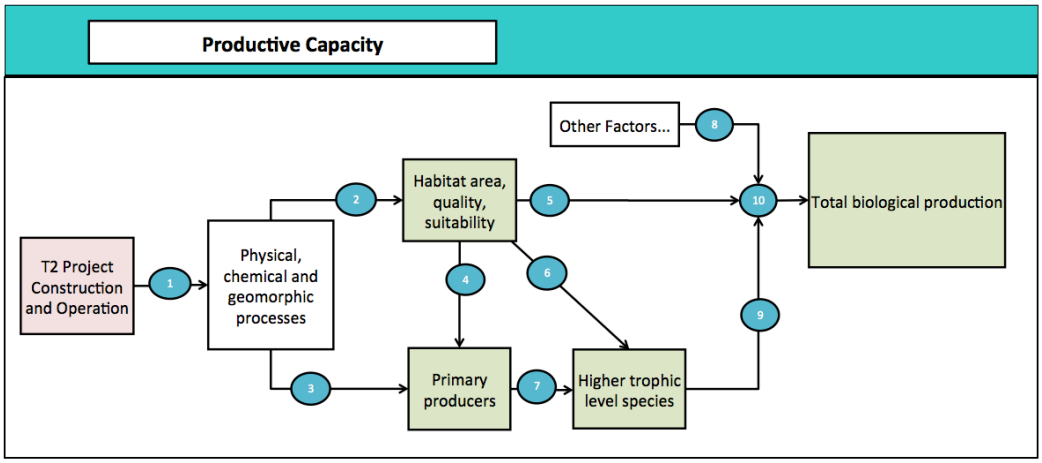
At the onset of the TAG process, Hemmera identified a number of key areas for guidance, and tasked the TAG members with:

- providing input on potentially appropriate method(s) for assessing PC in the context of the proposed RBT2 project;
- providing input on the species and habitat types to consider;
- providing input on information needs and study priorities associated with assessing PC;
- discussing broad implications for the identification and evaluation of mitigation/compensation options; and
- providing input where possible on the evolving regulatory context.

These topics served to guide the development of agendas for the four PC TAG meetings.

To further help identify high-priority topics for exploration, the PC TAG reviewed potential pathways of effects between the proposed RBT2 project and PC in the Roberts Bank area (Figure 2.1). This pathway of effects diagram is not intended for use in quantitative modeling or analysis, but as an organizing framework to structure PC TAG discussion about effects, uncertainties, and studies.

Figure 2.1 Pathways of effects on productive capacity



The possible cause-effect relationships (or hypotheses) summarized in Figure 2.1 were as follows:

1. The construction and operation of the proposed RBT2 project will affect a number of physical, chemical, and geomorphic processes in the Roberts Bank area.
2. Changes in physical, chemical, and geomorphic processes will affect the area and quality/suitability of habitat.
3. Changes in habitat area or quality will affect primary productivity.
4. Changes in physical, chemical, and geomorphic processes will affect primary productivity.
5. Changes in habitat area or suitability lead to changes in species composition, distribution, and biomass/abundance.
6. Changes in habitat lead to changes in productivity at individual higher trophic levels.
7. Changes in primary productivity lead to changes in productivity at individual higher trophic levels.
8. Other factors beyond this project may also play a role in affecting total biological production.
9. Changes in individual higher trophic level species may play a role in affecting total biological production
10. The project, in combination with other ecosystem attributes and stressors, could affect species abundance, distribution, and biomass, as measured/reported on selected focal species.

Changes in PC could be reported with reference to any or all of the green boxes in Figure 2.1: changes in habitat area or suitability (hectares or suitability-weighted hectares), changes in primary productivity (e.g., standing biomass of primary producers), productivity (biomass, distribution, diversity) at higher trophic levels, or total biological production (e.g., change in biomass, distribution and diversity of the entire Roberts Bank community).

The PC TAG discussed how the project's construction and operations might translate into effects at each pathway, and discussed suitable approaches for assessing effects on PC. The

PC TAG identified several key components of a suitable PC assessment, monitoring, and mitigation strategy:

- define a representative set of *focal species* or communities that can serve as indicators of changes of PC for all affected species in the Roberts Bank area;
- develop an approach for assessing both *net changes* and *trade-offs* among species or guilds, and for evaluating the effectiveness of offsetting methods;
- define spatial and temporal bounds for assessing PC;
- develop methods for addressing uncertainty;
- conduct monitoring and evaluation to verify offsets; and
- identify adaptive management options (that facilitate responses to changes over time).

These key components provided a basis for PC TAG discussion. The next section summarizes TAG discussion and recommendations around three topics encompassing these components: the selection of focal species, the selection of an appropriate PC assessment methodology (including the definition of spatial and temporal bounds, and methods for addressing uncertainty), and the selection of mitigation and offset strategies.

3 Assessing Effects on Productive Capacity

3.1 Focal Species

The selection of focal species involved the development of selection criteria and a preliminary list of focal species by TAG members, followed by additional examination through a focus group process to solicit input from additional experts. Several rounds of review and revision were conducted, leading to the final selection of focal species. The selection criteria, process, and results are presented here.

3.1.1 Criteria for selecting focal species

For the purpose of the PC TAG, "focal species" are defined as those species that are ecologically linked to many components of the ecosystem, and thus able to provide an indication of changes in PC for a broader number of species. The assumption is that by studying changes in PC at Roberts Bank for these focal species it is possible to understand changes to the wider ecosystem. PC TAG members defined a set of criteria for the selection of focal species based on both societal and ecological perspectives. The selection criteria are summarized in Table 3.1.

Table 3.1 Criteria for the selection of a Focal Species

CRITERIA	DESCRIPTION
Societal Perspective	Species of social importance
	Species of cultural or First Nations importance
	Species of economic importance
Ecological Perspective	Species is a good indicator of change in PC
	Species of ecological importance
	Species is ecologically dependent on Roberts Bank
	Species will "capture /represent" species with similar ecological requirements
	Species at risk
	Species traditionally used in monitoring
	Species contributes to the ongoing productivity of a fishery
	Species for which management objectives have been defined
	Species that is consistently present in relatively high numbers
	Species for which there are good historical data

3.1.2 Process for selecting focal species

The process for selecting focal species involved developing a preliminary list of focal species with the PC TAG first, and using it as a basis for engagement with a focus group of 21 experts covering each of the broad species categories: birds, fish, invertebrates, marine vegetation, and marine mammals. Using a web-based survey, each focus group participant was asked to complete three tasks:

- select suitable 'focal species' for assessing changes to PC at Roberts Bank, from one or more of the following biological groups: birds, fish, invertebrates, marine vegetation, and marine mammals;
- indicate the importance of the selected focal species from a social and biological perspective; and
- specify the species for which the focal species are suitable indicators.

The list of potential focal species were then scored based on the number of times that a species was selected as an appropriate indicator by focus group members, and through consideration of the rationale for selection. The results of the focus group served as a preliminary list of focal species for further consideration by PC TAG members, with *highest scoring* focal species highlighted as recommended species. PC TAG members reviewed the resulting focal species list and made a number of recommendations on additional species to include, or alternative species where focus group results did not indicate strong support for a particular species.

3.1.3 Focus Group results

Table 3.2 summarizes the focal species selected based on the results of the PC Focus Group and discussion within the PC TAG.

Table 3.2 Selected Focal Species

Broad Category	Sub-Category	Selected Focal Species
Birds	Shorebirds	western sandpiper (*Calidris mauri*)
		dunlin (*Calidris alpina*)
	Fish Eating Birds	great blue heron (*Ardea herodias fannini*)
	Predators / Raptors	bald eagle (*Haliaeetus leucocephalus*)
	Waterfowl	American wigeon (*Anas americana*)
		brant (*Branta bernicla*)
Fish	Salmonids	chum (*Oncorhynchus keta*)
		chinook (*Oncorhynchus tshawytscha*)
	Flatfish	starry flounder (*Platichthys stellatus*)
	Forage Fish	sand lance (*Ammodytes hexapterus*)
	Reef Fish	lingcod / rockfish (*Ophiodon elongatus and Sebastes*)
		shiner perch (*Cymatogaster aggregata*)
Invertebrates		Polychaetes
		Dungeness crab (*Metacarcinus magister*)
		macrofauna
		bivalves (including filter and deposit feeders)
Marine Vegetation		native eelgrass (*Zostera marina*)
		non-native eelgrass (*Zostera japonica*)
		Ulva
		kelp / *Fucus*
		salt marsh species (*Distichlis*, *Sarcocornia*, *Bulboschoenus*, *Schoenoplectus*, *Carex*)
		diatoms, dinoflagellates, cyanobacteria

The topic of productive capacity with respect to marine mammals was not discussed in detail by the TAG given the lack of subject expertise among the invited experts.

The complete list of focal species, ecologically linked species, and rationale for selection are available in Appendix A.

3.1.4 PC TAG Recommendation

The PC TAG recommended that the design assessment and monitoring methodologies consider the focal species listed in Table 3.2 above. Furthermore, PC TAG members advised PMV to assess both diversity or community structure and biomass or abundance when assessing PC for these focal species. It is important that the focal species approach does not lose sight of the importance of species assemblages, community structure, and diversity. Further, there is a need to select control areas to assess abundance and diversity before and after the construction of the proposed RBT2.

3.2 PC Assessment Methods

3.2.1 Process for Selecting Assessment Methods

The selection of appropriate methodologies for assessing PC at Roberts Bank involved a review of a long-list of potential methodologies to create a short-list of suitable methodologies for in-depth review, the development of appropriate selection criteria, and a structured selection process involving PC TAG input to select an appropriate methodology.

In evaluating what is needed in an assessment methodology, the PC TAG discussed the treatment of trade-offs among species or species groups in detail. They noted that a useful assessment method must be able to evaluate changes at the level of species, species groups, and trophic levels. It should also provide a structure for making judgments about net changes in PC. However, the PC TAG noted that such judgments embed value judgments about the relative importance of losses and gains in different species groups. The assessment methodology should ensure that gains and losses for particular species, species groups, or trophic levels are transparent, but leave judgment about the acceptability of estimated gains/losses to decision makers.

The PC TAG also discussed the need for the method to facilitate the evaluation of PC both before and after RBT2, as well as after offsetting is implemented, to enable consideration of net gains and losses. Since offsetting could occur at sites that are spatially or temporally distinct from Roberts Bank, this criterion had a meaningful effect on the evaluation.

Table 3.3 illustrates a hypothetical example of how the results of a PC assessment could be reported to ensure that both trade-offs among species and judgments about net effects are captured. In this example, changes in PC for each focal species (or species group) are estimated before and after the development of the RBT2 project and after offsets are taken into consideration. For illustrative purposes, boxes in grey indicate no net change, boxes in green indicate an increase in PC, and boxes in red indicate a net decrease in PC. In this hypothetical example, Species B and C are predicted to experience losses in productive capacity post-construction, while Species D experiences a gain. Offsets are identified and evaluated, and PC is re-assessed. Now, with offsets, Species A and B experience net gains, but Species C is still projected to experience a loss. Assessment methods might produce a judgment that, overall, there is a net gain in PC. The PC TAG, however, emphasized that reporting key trade-offs (losses and gains in key species) should be transparent.

Table 3.3 Hypothetical results using a transparent PC assessment methodology

	Before	**After**	**After** (With Offsets)
Species A			
Species B			
Species C			
Species D			
Total			

Key challenges highlighted by the PC TAG in selecting and applying assessment methods include:

- understanding the relationship between habitat changes and species or community changes
- finding methods that *predict* change, as opposed to just measuring it

- dealing with open systems, including consideration of both resident and migratory populations

Long- and Short-List

Hemmera conducted a literature review in December 2011 of the rationale and methods used to estimate productive capacity in Canada and abroad, in order to create a list of potential methods and indices for assessing PC at Roberts Bank. A copy of the literature review is available in Appendix B. The Minns et al. (2011) paper is provided in Appendix C. The document provides a review of the rationale and methods used to estimate productive capacity in Canada and abroad. The literature was surveyed for methods and models to estimate productive capacity. This included Habitat Suitability Index (HSI), Habitat Utilization Index (HUI), abundance, Energy Index, Index of Biotic Integrity (IBI), and ecosystem based approaches. Next, recent development projects that estimate habitat productive capacity were evaluated to determine their methodology. Finally, additional insights were outlined and expert resources for the estimation of productive capacity were recommended.

Overall, ten methods of quantification of productive capacity are described in this review. Of these models, nine have been successfully implemented in Canada, while the one method (Biomass Size Distributions) has been primarily used in Europe. One especially well documented model, the Habitat Evaluation Procedure (HEP), was developed by the US Fish and Wildlife Service (1980) but has been adapted several times by Canadian researchers. A total of 10 development projects, 7 Canadian and 3 US are also described, with an emphasis on the nature of the project, its social and biological relevance, the method used to estimate productive capacity and the rationale provided to justify the estimate.

Recommendations for enhancing estimates of productive capacity are outlined, specifically, the importance of incorporating controls in the estimation of habitat productive capacity for habitat compensation, the importance of incorporating uncertainty into calculations of species productivity and habitat productive capacity, the need for cumulative effects monitoring and, finally, the disparity between marine and aquatic projects in their estimation of productive capacity in Canada.

PC TAG members reviewed literature and worked examples of these approaches as applied to bird, fish, invertebrates, marine vegetation, and marine mammals, to evaluate their suitability as assessment methodologies. PC TAG members made the following observations:

- Habitat, species, and ecosystem methods may be more relevant than methods based on assessment of effects on individuals.
- Focusing on habitat area alone will limit the range and extent of offsetting options that can be considered, and will limit our scientific understanding of changes in the system.

Based on PC TAG feedback, the consultants focused on HSI methods, and prepared worked examples of how PC could be assessed for sample species. PC TAG members generally supported the approach and provided useful input; however, they expressed interest in exploring more ecosystem-based approaches that could better account for community structure and relationships among species. As a result, three methods were short-listed for further review (Table 3.4): HSI, IBI, and an ecosystem approach using the Ecopath with Ecosim software package.

Table 3.4 Description of short-listed PC assessment alternatives

METHOD	DESCRIPTION
HSI	The HSI method was developed to quantify available and usable habitat for a species or functional group of interest, allowing biologists to link taxa with specific environmental variables within the habitat being studied. The index ranges from 0 to 1, where 0 indicates totally unsuitable habitat and 1 represents optimal habitat where species have maximum productivity.
IBI	The IBI method is unique in that it was developed to assess the quality or integrity of an area based on the species occupying the area (Karr et al. 1986). The IBI uses information such as diversity, abundance, ecological role (native/invasive, or tolerance), trophic structure, and biomass from species or communities within the area or scale of interest to estimate the ecological status of the area.
Ecopath with Ecosim (EwE)	Ecosystem modeling using Ecopath with Ecosim (EwE) is a trophic model that follows energy transfer through the food web, and can do so in space and time. This method is unique relative to the HSI and IBI in that it incorporates multiple species and ecological variables into a single model for the ecosystem of interest. While the model itself uses information from all trophic levels, the outputs of the model can be species or taxon-specific so that impacts on specific species of interest can be tracked.

Criteria for selecting Assessment Methods

PC TAG members identified criteria to be considered in the assessment of PC assessment methodologies (Table 3.5). These criteria served as the basis for evaluation of the short-listed assessment methodologies.

Table 3.5 Criteria for the selection of a Productive Capacity Assessment methodology

CRITERIA	DESCRIPTION
Applicable to Roberts Bank system	Is the method applicable to the Roberts Bank system (marine, estuarine), and is it able to address the species/habitats of concern?
Scientifically defensible	Is the method scientifically defensible and peer reviewed?
Practical	Is the method practical in terms of input data requirements (e.g. timelines, cost and technical feasibility)?
Understandable	Can the method produce summary statements that are understandable for the regulatory review process?
Describes net changes	Can the method describe expected net changes in PC? In other words, can it aggregate across species groups to produce a summary statement about overall change in net productivity?
Describes key trade-offs	Can the method describe key trade-offs among individual components of PC? In other words, can it ensure that gains and losses across species or species groups are transparent?
Incorporate uncertainty	Can the method estimate or characterize uncertainty and the range of possible outcomes given uncertainty?
Applicable to mitigation and offsetting	Can the method produce results that inform the evaluation of mitigation, compensation and banking options?
Robust to regulatory changes	Is the method robust to changes in the regulatory review process?

Scoring Exercise

PC TAG members participated in an exercise to score the shortlisted methods against the nine selection criteria using a 5-point scale from '1: does not meet this criterion' to '5: fully meets this criterion'. The shortlisted methods were also directly ranked from one to three, in order of preference for use in assessing PC at Roberts Bank. The results of these initial scoring and ranking exercises provided the basis for discussion. Differences in experts' scores for each criterion were compared and contrasted. PC TAG members discussed their initial scores, focusing in particular on reasons for outlier scores. They were offered an opportunity to modify their scores after the discussion.

3.2.2 Findings

Figure 3.1 illustrates the group average scores for each of the three methods (HSI, IBI, and EwE) across each of the nine assessment criteria, considering the input of five PC TAG members who were available for the scoring exercise. Average EwE scores for each of the assessment criteria are indicated by green diamonds, IBI scores are indicated by blue triangles, and HSI scores are indicated by red circles. The lines drawn between average scores indicate the spread in scores between the highest and lowest scoring method for each criterion. The group agreed that the average scores are a good representation of the relative suitability of the three methods. Individual score breakdowns for each of the three methodologies are available in Appendix D. Results indicate that EwE outperforms both HSI and IBI on seven of nine criteria, while IBI shows the lowest performance of the three methods.

Figure 3.1 Average scores for all three methods

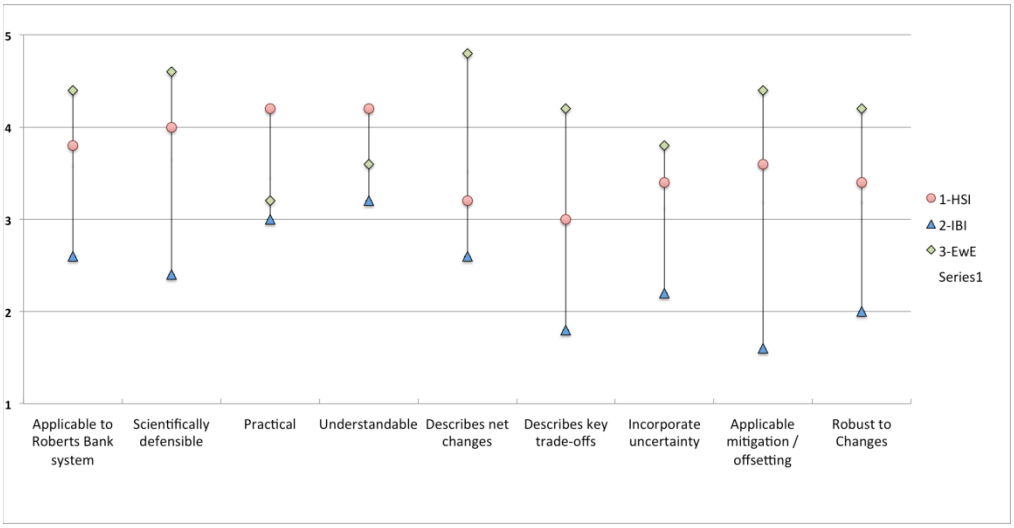


Figure 3.2 summarizes the same results from Figure 3.1 in the form of a consequence table, to facilitate the comparison of averages between methods for each of the scoring criteria. This presentation helps to clarify trade-offs among the methods and show how each alternative performs relative to another. In this image, EwE is selected as a basis for comparison to HSI and IBI, and is shown in PURPLE. Reading row by row, cells shown in GREEN indicate that the method performs better than EwE for the criterion in that row; while cells in RED indicate that the method performs worse than EwE. Cells that are WHITE indicate that the method performs about the same as EwE (< 10% difference).

Figure 3.2 Consequence Table

Obj.	Sub Objective	Criteria / Units	Dir	HSI	IBI	EwE
	Applicable to Roberts Bank system	#	H	3.8	2.6	4.4
	Scientifically defensible	#	H	4.0	2.4	4.6
	Practical	#	H	4.2	3.0	3.2
	Understandable	#	H	4.2	3.2	3.6
	Describes net changes	#	H	3.2	2.6	4.8
	Describes key trade-offs	#	H	3.0	1.8	4.2
	Incorporates Uncertainty	#	H	3.4	2.2	3.8
	Applicable mitigation / offsetting	#	H	3.6	1.6	4.4
	Robust to changes	#	H	3.4	2.0	4.2

Legend
Better than selected
Worse than selected
Selected

From Figure 3.2, it is apparent that IBI is dominated by EwE – that is, EwE outperforms it on every criterion with the exception of "practicality", in which case they are tied. EwE also outperforms HSI on all criteria except "understandability" and "practicality". Whether EwE is preferred over HSI or not depends on the weight assigned to understandability and practicality relative to the other criteria.

PC TAG members were asked to discuss what the key benefits and losses in choosing HSI and EwE were for each of the criteria. Insights from discussion included clarification of definition, or interpretation of some of the criteria, and sharing of perceptions and judgments about the performance of each method, which led to learning and deeper understanding of the trade-offs between the methods. Some changes in scores were made as a result of the discussion[1].

In discussing the key strengths and weaknesses of the methods, TAG members summarized their considerations overall for each of the three methods across all nine performance measures. A summary of key strengths and weaknesses for HSI, IBI, and EwE is shown in Table 3.6.

[1] While several TAG members indicated that they would likely adjust several of their individual scores based on what was learned during the discussion, the TAG did not take that additional step in interest of time. Everyone agreed that the average scores accurately reflected the relative performance of the methods.

Table 3.6 Key Performance Considerations

EwE	**Applicable to Roberts Bank System**: addresses community structure, has some advantages with respect to treatment of migratory species **Scientifically Defensible**: high, many applications in similar situations, transparency in input judgments **Practical**: some concern about data requirements; however it was noted that many of the same data are required for HSI **Understandable**: understandable to scientists, but may be less easily interpreted by some regulators **Describes Net changes**: facilitates assessment of "net" effects across species and trophic levels; many assumptions are explicit in the model **Describes Trade-offs:** facilitates assessment for focal species and trophic levels **Incorporates Uncertainty**: sensitivity analysis is built in and can be customized **Applicable to Mitigation and Offsetting**: can be readily used at other sites and compared with Roberts Bank to produce an assessment net of offsets **Robust to Change**: most robust would be to use multiple methods
HSI	**Applicable to Roberts Bank System:** has some limitations with respect to migratory species and temporal changes **Scientifically Defensible:** high, has been applied widely **Practical**: good; data requirements are reasonable **Understandable**: familiar to regulators and understandable to the public **Describes Net Changes**: this is a weakness of HSI; method of aggregating across species needs work and may be difficult/controversial **Describes Trade-offs:** shows gains/losses by species (but difficult to compare across species) **Incorporates Uncertainty**: sensitivity analysis can be done **Applicable to Mitigation and Offsetting**: can be used to evaluate offsets **Robust to Change:** most robust would be to use multiple methods
IBI	**Applicable to Roberts Bank System**: questionable, few precedents **Scientifically Defensible**: low, not used for PC, not used in predictive context for EA **Practical**: good; data requirements are reasonable **Understandable**: familiar to regulators and understandable to the public **Describes Net Changes**: is designed to report aggregate change to the community **Describes Trade-offs**: not designed for species specific assessments **Incorporates Uncertainty**: may be able to apply sensitivity analysis; no known precedents **Applicable to Mitigation and Offsetting**: would be difficult to use IBI to assess offsets and integrate the results with the base assessment because of site-specific nature of IBI **Robust to Change**: most robust would be to use multiple methods

While the selection process was designed to facilitate a structured criteria weighting exercise to facilitate comparison of methods across numerous criteria, given the relative simplicity of the trade-offs involved this exercise was not necessary. PC TAG members were asked instead to rank the methods directly to obtain their overall impression of the performance of each of the three short-listed PC assessment methodologies. The results of the direct ranking exercise (Figure 3.3) are consistent with the results of the scoring exercise—EwE was ranked the highest, HSI second, and IBI third by all five participants.

Figure 3.3 Direct Ranking

	HSI	IBI	EwE
Expert A	**33%**	**22%**	**44%**
Expert B	**38%**	**21%**	**42%**
Expert C	**36%**	**18%**	**45%**
Expert D	**38%**	**21%**	**42%**
Expert E	**40%**	**10%**	**50%**

Note: Scores are normalized, with percentages summing to 100% for each TAG member

3.2.3 PC TAG Recommendation

PC TAG members selected EwE as the preferred method and endorsed it as a conceptually sound approach to assessing changes in PC at Roberts Bank resulting from the implementation of RBT2.

HSI is considered acceptable by the TAG. If detailed evaluation of EwE shows it to be impractical with respect to timelines, budgets or data requirements, the TAG indicated that the HSI method could be accepted. The TAG noted, though, that one key disadvantage of HSI is that it would be difficult to assess "net" effects on PC (aggregated across species). In comparison, EwE enables assessment both of net effects and trade-offs between effects on different species and different trophic levels.

The TAG viewed IBI as the least favourable method for this application for a number of reasons. In particular, the lack of a precedent (has not been used to assess productive capacity and is not used predictively) suggests that its defensibility would be questionable. Its utility in assessing incremental gains associated with offsets was also questioned due to its site-specific nature.

While PC TAG members agreed that this approach is conceptually sound, they noted that, ultimately, acceptability of the final analysis is subject to the quality of data and analysis, and the assumptions made.

PC TAG members emphasized a number of points for PMV and its consultants to consider as the productive capacity assessment is carried out. They are:

- It is important that both the public and regulators understand the methods and results of the PC assessment; in particular, if EwE is used, the method may be unfamiliar to regulators and difficult for the public to understand.
- If EwE is selected, one risk is that the use of the method and interpretation of the results may rely on a particular expert or consultant with specific experience or expertise in the EwE software platform. PMV and its consultants should guard against the associated risks (e.g., budget, schedule, transparency, etc.).
- The assessment methodology must be capable of both estimating the effectiveness of mitigation and offset projects and monitoring, whether that mitigation has worked or not. PMV must be able to demonstrate to regulators and the public that mitigation efforts are effective.
- It is important to consider temporal challenges in the assessment of PC. Some effects will occur immediately, while others will occur over time.
- In dealing with uncertainty, sensitivity or scenario analyses should be performed in place of statistical analyses.
- Consideration must be given to the treatment of cumulative effects.

3.3 Mitigation and Offsetting

3.3.1 Key Issues

Mitigation

Overall, PC TAG members agreed that mitigation and compensation can be used to offset some losses in PC due to the proposed RBT2 project. Assessment methods should enable a measure of how offsets contribute to PC for individual species and net PC overall, evaluate which species win or lose, and make the trade-offs transparent. There is, however, a lack of guidance available for designing and assessing mitigation programs, including how to evaluate

the relative contribution of mitigation efforts that are conducted at a distance from the area of disturbance. Additionally, it was noted that, since project planning is in a relatively early stage, evaluation of specific mitigation or offsetting projects would be premature. PC TAG members focused instead on providing guidance for the selection of mitigation or compensation options once potential impacts from the RBT2 development are better known.

PC TAG members endorsed the use of two key hierarchies for the selection of mitigation or compensation options:

A) Impact management hierarchy:

1. *Avoid impacts*
2. *Mitigate or minimize impacts that cannot be avoided*
3. *Compensate (offset) only for impacts that you cannot avoid or mitigate for*

B) Hierarchy of compensation options:

1. *Create or increase the PC of **like-for-like** habitat in the same ecological unit*
2. *Create or increase the PC of **unlike** habitat in the same ecological unit*
3. *Create or increase the PC of habitat in a **different** ecological unit*
4. *As a last resort, use artificial production techniques to maintain a stock of fish, deferred compensation, or restoration of chemically contaminated sites*

Further, in considering compensation or offsetting projects, PC TAG members suggested a number of additional points to consider, including:

- spatial trade-offs -- local versus regional applicability of methods;
- species trade-offs -- consider relative impacts between species, life history stages, and trophic levels;
- temporal losses -- some effects may take longer than others to occur
- consider habitat banking options ; and
- consider compensation alternatives, as such conservation allowances to fund beneficial conservation projects.

Selection of Control Areas

TAG members noted that control studies will be critical in evaluating changes to PC due to RBT2, and in evaluating the effectiveness of mitigation programs. Possible control locations for biofilm, for example, include the Sturgeon Bank and Boundary Bay areas, and distant sites such as Cowichan. One PC TAG member recommended that the design of baseline studies should be informed by the selection of assessment methodologies in the PC TAG. Some baseline studies are currently underway, and PC TAG input will further inform the development of baseline studies.

Other considerations

If independent valued ecosystem component (VEC) assessments require modeling, the TAG suggested that consideration be given to the use of the EwE approach for those as well to streamline the assessment and ensure comparability of results.

4 Other Topics Explored by Productive Capacity TAG

4.1 Changing Legislation

Changes to federal legislation that may affect the assessment methodologies used for evaluating PC in the Roberts Bank area are expected. PC TAG members highlighted a need to continue dialogue with regulators as the EA progresses. The best approach at this stage is to identify all considerations for the assessment of PC and selection of mitigation programs, discuss these with PC TAG members and regulators to understand their point of view, and obtain their endorsement on what things need to be considered (such as trade-offs).

4.2 Linkages to other EA work

Each VEC to be considered in the EA will have its own assessment independent of the PC assessment. The EwE approach could potentially be integrated into the modeling required for individual VEC assessments under other TAGs.

5 Conclusion and Future Opportunities

The Productive Capacity TAG met four times over 2012 and 2013 to provide PMV and its consultants with feedback on appropriate methods to assess the potential effects of the proposed RBT2 project on the productive capacity of Roberts Bank. This report catalogues this TAG process and the key findings and outputs of the process. At this point, PMV and its consultants are continuing their EA studies with this additional guidance in mind. Looking forward, PMV and its consultants will complete their EA studies, engage the provincial and federal governments in the formal EA process, and continue to consult with stakeholders and First Nations.

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Appendix A - Productive Capacity Focus Group Summary

This document summarizes the responses from 21 survey participants in a Productive Capacity Focus Group Survey, with expertise in the following areas:

- *behavioural ecology of shorebirds emphasizing reproductive and anti-predator strategies*
- *ecologist with broad experience*
- *fisheries resource management; aboriginal policy, program and negotiation*
- *foraging behaviour with a focus on birds (both shorebirds and passerines)*
- *marine classification and habitat suitability assessment*
- *monitoring, marine, freshwater, ordination techniques*
- *ornithologist with emphasis on coastal birds, especially herons and shorebirds*
- *professional wetland scientist specializing in estuarine habitat and mitigation/restoration*
- *salmon ecology, avian ecology*
- *coastal marine ecology*
- *invertebrate biology, crustaceans and bivalves, marine mammals*
- *shorebird and biofilm ecology*
- *shorebird ecology, numerical methods, avian demography*
- *a sea grass scientist who has studied sea grasses throughout British Columbia for over 30 years, and has had projects studying the Roberts Bank eelgrass almost continually since 1982*
- *scientist addressing issues and providing advice to resource managers related assessment of marine invertebrates and development of tools for the implementation of tools for delivery of ecosystem approaches to management*
- *applied biologist with environmental assessment focus and reasonably good knowledge of habitat in EA context, but not an expert in habitat per se*
- *project review from a fish and fish habitat perspective; mainly involves review of consultant reports that assess fish habitat at and near project sites, determine project impacts to fish habitat, propose mitigation measures to minimize impacts to fish and propose fish habitat compensation to offset fish habitat impacts*
- *surveys of birds in marine and wetland habitats in British Columbia - focusing on shorebird migration studies, migrating and wintering waterfowl; and seabird colony population surveys*
- *winter ecology of arctic geese and sea ducks; migration ecology of these taxa; estuarine/marsh ecology*
- *designed and managed research in the field of fish habitat in both fresh and marine areas on both the east and west coasts of Canada*
- *ecology of fishes and invertebrates in estuaries, including ecosystem components such as algae and vascular plants; specialization in juvenile salmonids in estuaries*

Findings from this survey of experts will help inform the assessment methodology for the proposed Port Metro Vancouver Roberts Bank Terminal 2 Project.

In short, each participant was asked to complete three survey tasks:

1. To select suitable 'indicator species' (*heretofore referred to as 'focal species'*) for assessing changes to productive capacity at Roberts Bank, from one or more of the following biological groups: birds, fish, invertebrates, marine vegetation, and marine mammals

2. To indicate the selected focal species' importance from a social and biological perspective, and

3. To specify the species that the focal species are suitable indicators for

The criteria provided for evaluating species' importance are summarized in Table 1, along with additional criteria suggested by survey respondents. A summary of the *highest scoring* focal species based on participant input are summarized in Tables 2 through 5, along with the criteria considered in their selection and the species identified as 'ecologically linked' with each focal species. Focal species were scored based on both the number of times that a species was selected as an appropriate indicator, and consideration of the rationale for selection.

Definitions:

> *Productive Capacity, defined as the maximum natural capability of habitats to produce healthy fish, safe for human consumption, or to support or produce aquatic organisms on which fish depend, is an important component of the Canadian directive on fish habitat (DFO 2010). The term productive capacity implicitly assumes a quantity with which fish habitat can be measured and net loss, or gain can be calculated. Since the publication of the 1986 DFO directive, biologists have been striving toward a quantitative measurement of productive capacity that can be used to achieve no net loss of fish habitat in Canada (Minns 2009, Minns 2011).*
>
> *Focal Species are those species that are ecologically linked to many components of the ecosystem, and thus can provide an indication of changes in productive capacity for a number of species.*

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Table 1: Focal Species selection criteria

Criteria for Selection of Focal Species		Description of Criteria
Societal Perspective	Species of social importance	*Indicates that the species is valued for its importance to society, broadly speaking*
	Species of cultural or First Nations importance	*Indicates that the species is culturally important, or is important to First Nations specifically. Note: This is not a definitive indication of First Nations importance - First Nations will be consulted directly in the selection of appropriate focal species*
	Species of economic importance	*Indicates that the species is important from an economic perspective, as part of a fishery or other economic activity*
Ecological Perspective	Species is a good indicator of change	*Indicates that the species can provide insight into changes in productive capacity in the Roberts Bank ecosystem. The species may (for example) be relatively more sensitive to changes in physical or biological parameters than others, and so by monitoring changes in this species it is possible to gain insight into how productive capacity as a whole is changing*
	Species of ecological importance	*Indicates that the species plays an important ecological role in the Roberts Bank area*
	Species is ecologically dependent on Roberts Bank	*Indicates that the species requires the use of the Roberts Bank area during its life time*
	Species will "capture /represent" species with similar ecological requirements	*Indicates that changes observed in this species (e.g. increase/decrease in populations) can provide insight into changes in other species as well. As such, the species can be studied (as a 'focal species') to understand changes to a number of other species ('ecologically linked' species)*
	Species at risk	*Indicates that the species is listed as a species at risk, or that its population is significantly stressed/strained and may not deal well with changes in the Roberts Bank area*
	Species traditionally used in monitoring	*Indicates that this species is commonly studied/monitored within the Roberts Bank area or elsewhere*
	Species contributes to the ongoing productivity of a fishery	*Indicates that the species plays an important role in supporting a fishery (in the Roberts Bank area or elsewhere)*
	Species for which management objectives have been defined	*Indicates that specific management objectives have been defined for this species in the Roberts Bank or Fraser River Estuary region*
	Species that is consistently present in relatively high numbers	*Indicates that the species is present in large numbers, and for relatively long or well-defined time periods, resulting in sufficient statistical power to determine whether or not (or the degree to which) any change has occurred*
	Species for which there are good historical data	*Indicates that there is a wealth of historical data for the species, both in the project area and in other areas, resulting in spatial and temporal controls*

Additional suggested criteria include:

- *Biological importance, general ecosystem status, ecologically important but data deficient*

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Table 2: Focal Species selection criteria - Birds

FOCAL SPECIES			ECOLOGICALLY-LINKED SPECIES	RATIONALE FOR SELECTION
Broad Category	Sub-Category	Selected Focal Species		
BIRDS	Shorebirds	**western sandpiper** (*Calidris mauri*)	biofilm dunlin (*Calidris alpina*) western sandpiper black bellied plover (*Pluvialis squatarola*) rock sandpiper (*Calidris ptilocnemis*) least sandpiper (*Calidris minutilla*) black turnstone (*Arenaria melanocephala*) other shorebirds / small shorebirds invertebrates (in general)	Species of social importance Species is a good indicator of change Species of ecological importance Species is ecologically dependent on Roberts Bank Species will "capture /represent" species with similar ecological requirements Species traditionally used in monitoring Species that is consistently present in relatively high numbers Species for which there are good historical data
		dunlin	biofilm dunlin black bellied plover rock sandpiper least sandpiper black turnstone other shorebirds / small shorebirds invertebrates (in general)	Species of social importance Species is a good indicator of change Species of ecological importance Species is ecologically dependent on Roberts Bank Species will "capture /represent" species with similar ecological requirements Species traditionally used in monitoring Species that is consistently present in relatively high numbers Species for which there are good historical data
	Fish Eating Birds	**great blue heron** (*Ardea herodias fannini*)	small mammals fish eating birds (in general) great blue heron cormorants loons grebes western grebe (*Aechmophorus occidentalis*) small fish spp (incl. eelgrass fishes - gunnels, sticklebacks, sculpins, sea perch)	Species of social importance Species of cultural or First Nations importance Species is a good indicator of change Species of ecological importance Species is ecologically dependent on Roberts Bank Species will "capture /represent" species with similar ecological requirements Species at risk Species traditionally used in monitoring Species that is consistently present in relatively high numbers Species for which there are good historical data
	Predators / Raptors	**bald eagle** (*Haliaeetus leucocephalus*)	peregrine falcon (*Falco peregrinus*) bald eagle short-eared owl (*Asio flammeus*) northern harrier (*Circus cyaneus*) snowy owl (*Bubo scandiacus*)	Species of social importance Species of cultural or First Nations importance Species for which management objectives have been defined Species for which there are good historical data

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FOCAL SPECIES			ECOLOGICALLY-LINKED SPECIES	RATIONALE FOR SELECTION
Broad Category	Sub-Category	Selected Focal Species		
		peregrine falcon	bald eagle western sandpiper dunlin	(added after TAG and focus group feedback) Significant predators for shorebirds (western sandpipers and dunlin) traditionally used in productivity assessments there is very good historical data on their presence in the area
	Waterfowl	**American wigeon** (*Anas americana*)	American wigeon american wigeon snow goose (*Chen caerulescens*) surf scoter (*Melanitta perspicillata*) mallard (*Anas platyrhynchos*) green winged teal (*Anas crecca*) northern pintail (*Anas acuta*) trumpeter swan (*Cygnus buccinator*) bufflehead (*Bucephala albeola*)	Species of social importance Species is a good indicator of change Species of ecological importance Species is ecologically dependent on Roberts Bank Species will "capture /represent" species with similar ecological requirements Species traditionally used in monitoring Species that is consistently present in relatively high numbers Species for which there are good historical data
		Brant (*Branta bernicla*)	brant	Species of social importance Species of economic importance Species is a good indicator of change Species of ecological importance Species is ecologically dependent on Roberts Bank Species traditionally used in monitoring Species that is consistently present in relatively high numbers Species for which there are good historical data"

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Table 3: Focal Species selection criteria - Fish

FOCAL SPECIES			ECOLOGICALLY-LINKED SPECIES	RATIONALE FOR SELECTION
Broad Category	Sub-Category	Selected Focal Species		
FISH	Salmonids	**chum** (*Oncorhynchus keta*)	pink (*Oncorhynchus gorbuscha*) coho – juvenile (*Oncorhynchus kisutch*) sockeye – juvenile (*Oncorhynchus nerka*) semelparous anadromous salmonids (juveniles/adults) other salmonids eulachon (*Thaleichthys pacificus*) stickleback sculpin skates spiny dogfish (*Squalus suckleyi*) green sturgeon (*Acipenser medirostris*) steelhead (*Oncorhynchus mykiss*) amphipods copepods isopods	Species of social importance Species of cultural or First Nations importance Species of economic importance Species is a good indicator of change Species of ecological importance Species is ecologically dependent on Roberts Bank Species will "capture /represent" species with similar ecological requirements Species contributes to the ongoing productivity of a fishery Species for which management objectives have been defined Species that is consistently present in relatively high numbers Species for which there are good historical data
		chinook (*Oncorhynchus tshawytscha*)	chinook coho - juvenile sockeye - juvenile eulachon southern resident killer whales	Species of social importance Species of cultural or First Nations importance Species of economic importance Species is a good indicator of change Species of ecological importance Species is ecologically dependent on Roberts Bank Species will ""capture /represent"" species with similar ecological requirements Species contributes to the ongoing productivity of a fishery Species for which management objectives have been defined Species that is consistently present in relatively high numbers Species for which there are good historical data
	Flatfish	**starry flounder** (*Platichthys stellatus*)	zoobenthos nearshore flatfish linked to sediment other groundfish / flatfishes and benthic species (english sole (*Parophrys vetulus*), sculpins) english sole sanddab	Species is a good indicator of change Species of ecological importance Species is ecologically dependent on Roberts Bank Species will "capture /represent" species with similar ecological requirements Species that is consistently present in relatively high numbers

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FOCAL SPECIES			ECOLOGICALLY-LINKED SPECIES	RATIONALE FOR SELECTION
Broad Category	Sub-Category	Selected Focal Species		
	Forage Fish	**sand lance** (*Ammodytes hexapterus*)	pelagic larvae fishes forage fish nearshore forage fish linked to sediment other pelagic foraging species (herring, smelts) eulachon surf smelt (juveniles only) (*Hypomesus pretiosus*)	Species of ecological importance Species is ecologically dependent on Roberts Bank Species contributes to the ongoing productivity of a fishery
	Reef Fish	**lingcod / rockfish** (*Ophiodon elongatus and Sebastes*)	copper rockfish (*Sebastes caurinus*) quillback (*Carpiodes cyprinus*) lingcod schooling rockfish	Species of ecological importance Species for which management objectives have been defined
		shiner perch (*Cymatogaster aggregata*)	shiner perch	Species of ecological importance Species will ""capture /represent"" species with similar ecological requirements Species that is consistently present in relatively high numbers

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Table 4: Focal Species selection criteria - Invertebrates

FOCAL SPECIES			ECOLOGICALLY-LINKED SPECIES	RATIONALE FOR SELECTION
Broad Category	Sub-Category	Selected Focal Species		
INVERTEBRATES		**polychaetes**	forage fish infauna	Species is a good indicator of change Species of ecological importance Species is ecologically dependent on Roberts Bank Species will "capture /represent" species with similar ecological requirements Species that is consistently present in relatively high numbers Indicates changes in substrate oxygen levels and organic matter which may affect other infauna
		Dungeness crab (*Metacarcinus magister*)	harvest crabs / other crabs scavenger various life stages red rock crab sea pen	Species of social importance Species of cultural or First Nations importance Species of economic importance Species is a good indicator of change Species of ecological importance Species is ecologically dependent on Roberts Bank Species traditionally used in monitoring Species contributes to the ongoing productivity of a fishery Species for which management objectives have been defined Species that is consistently present in relatively high numbers Species for which there are good historical data Indicates health of a valuable fishery *Note: Dungeness crab larvae may recruit from the Roberts Bank area or from outside of the delta, therefore fluctuations in crab abundance on the delta may not necessarily reflect something happening locally, but rather broader environmental conditions*
		macrofauna	juvenile fish infauna habitat forming organisms coral(which include sea pens) sponges and bryozoans amphipods copepods isopods *Pandalus*	Species of social importance Species is a good indicator of change Species of ecological importance Species will "capture /represent" species with similar ecological requirements Species traditionally used in monitoring Species that is consistently present in relatively high numbers
		***Pandalus* (shrimp)**	macrofauna	Shrimp trawl fishery located at Roberts Bank

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FOCAL SPECIES			ECOLOGICALLY-LINKED SPECIES	RATIONALE FOR SELECTION
Broad Category	Sub-Category	Selected Focal Species		
		bivalves (including filter and deposit feeders)	cockles butter clam (*Saxidomus gigantea*) littleneck clam (*Mercenaria mercenaria*)	Species of social importance Species of cultural or First Nations importance Species is a good indicator of change Species is ecologically dependent on Roberts Bank Species that is consistently present in relatively high numbers

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Table 5: Focal Species selection criteria – Marine Vegetation

FOCAL SPECIES			ECOLOGICALLY-LINKED SPECIES	RATIONALE FOR SELECTION
Broad Category	Sub-Category	Selected Focal Species		
MARINE VEGETATION		**native eelgrass** *(zostera marina)*	great blue heron brant wigeon fish / fish communities ichhtyofauna harvest crabs / other crabs marine vascular plants eel grasses	Species of social importance Species of cultural or First Nations importance Species is a good indicator of change Species of ecological importance Species is ecologically dependent on Roberts Bank Species will "capture /represent" species with similar ecological requirements Species traditionally used in monitoring Species contributes to the ongoing productivity of a fishery Species that is consistently present in relatively high numbers Species for which there are good historical data
		non-native eelgrass *(zostera japonica)*	great blue heron wigeon fish / fish communities zoobenthos harvest crabs / other crabs marine vascular plants macroinvertebrates eel grasses	Species is a good indicator of change Species of ecological importance Species is ecologically dependent on Roberts Bank Species that is consistently present in relatively high numbers Species for which there are good historical data
		Ulva	macroalgae (*Fucus*, *Ulva*, kelp)	Species of social importance Species of cultural or First Nations importance Species is a good indicator of change Species of ecological importance Species contributes to the ongoing productivity of a fishery
		kelp / *Fucus*	macroalgae (*Fucus*, *Ulva*, kelp)	Species of social importance Species of cultural or First Nations importance Species is a good indicator of change Species of ecological importance Species contributes to the ongoing productivity of a fishery

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FOCAL SPECIES			ECOLOGICALLY-LINKED SPECIES	RATIONALE FOR SELECTION
Broad Category	Sub-Category	Selected Focal Species		
		Sarcocornia pacifica	salt marsh species (*Disctichilis*, *Sarcocornia*, *Bulboschoenus*, *Schoenoplectus*, *Carex*) stickleback	Species of social importance Species of cultural or First Nations importance Species of economic importance Species is a good indicator of change Species of ecological importance Species is ecologically dependent on Roberts Bank Species will ""capture /represent"" species with similar ecological requirements Species contributes to the ongoing productivity of a fishery Species that is consistently present in relatively high numbers Species for which there are good historical data
		bulrush	trumpeter swan (*Cygnus buccinator*) snow geese waterfowl (i.e. mallard)	Species of social importance Species of cultural or First Nations importance Species is a good indicator of change Species of ecological importance Species is ecologically dependent on Roberts Bank Species will "capture /represent" species with similar ecological requirements Species traditionally used in monitoring Species contributes to the ongoing productivity of a fishery Species for which management objectives have been defined Species that is consistently present in relatively high numbers Species for which there are good historical data
		salt marsh species (*Disctichilis*, *Sarcocornia, Bulboschoenus, Schoenoplectus, Carex*)	*Bulboschoenus* *Sarcocornia pacifica*	Species of social importance Species of cultural or First Nations importance Species is a good indicator of change Species of ecological importance Species is ecologically dependent on Roberts Bank Species will "capture /represent" species with similar ecological requirements Species traditionally used in monitoring Species contributes to the ongoing productivity of a fishery Species for which management objectives have been defined Species that is consistently present in relatively high numbers Species for which there are good historical data

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FOCAL SPECIES			ECOLOGICALLY-LINKED SPECIES	RATIONALE FOR SELECTION
Broad Category	Sub-Category	Selected Focal Species		
		phytoplankton		NOTE: Hemmera consultants to perform a literature review to determine if there is any correlation between the amount of microphytobenthos (biofilm) and phytoplankton. If there is known to be a link then just using one or the other as a focal species is probably sufficient. If there is no evidence for the linkage between biofilm and phytoplankton then it may be necessary to include both on the focal species list.
		epibenthic (diatoms, dinoflagellates, cyanobacteria)	biofilm western sandpipers waterfowl (in general) sediment microflora diatoms, dinoflagellates, cyanobacteria	Species of social importance Species is a good indicator of change Species of ecological importance Species is ecologically dependent on Roberts Bank Species will "capture /represent" species with similar ecological requirements Species contributes to the ongoing productivity of a fishery Species that is consistently present in relatively high numbers

SUMMARY OF COMMENTS:

BIRDS:

Comments on Focal Species Selection:

- I've chosen species that are sufficiently common either on the water or along the shore in that region to allow comparisons over time. Glaucous-winged gulls might be OK too.
- I don't agree with the statement that a suite of species can't be included. If the method is counting, then all species can be tallied at the same time. There might be some interactions that would be missed if you are too selective. Bald eagle and herons, and falcon and sandpiper are two examples.
- Changes in habitat structure associated with this project: adjacent land, road and rail links, the pad itself, ship traffic, current outflow from the Fraser etc. will favour some species over others. While I acknowledge that drastic change might radically reduce or improve capacity for all, there will more likely be shifts in abundance. I suggest that a community ecology approach would be better suited than finding a suit of 'indicator species'. The area involved is not large, and regular systematic surveys could be conducted. If pressed, I suppose one could construct a set of species 'representing' guilds. But practically by definition, each species occupies a unique hyper dimensional niche space, and therefore its presence/abundance indicates habitat suitability for itself alone. A list of guild representatives would be long, and at that point one might just as well be comprehensive, in my opinion. This survey crashed on my when I tried to go further without picking a species, and I lost the better crafted text I had written here, with more or less the same advice given above. To prevent this from happening again, I will therefore force myself to choose top avian predators as answers to this question.
- The above species are ones that have been consistently use the Roberts Bank area and they should have reasonably good baseline data.

Additional Criteria suggested:

- Social importance for birdwatching, tourism, hunting.
- Cultural importance for festivals and future festivals.
- Economic for hunting, and birding.
- City of Vancouver is planning a Bird Agenda to heighten awareness of conservation of birds.

Comments on Criteria:

- "Species traditionally used in monitoring" applies through Coastal Waterbirds Survey. I haven't looked them up, but I expect them all to be fairly well represented in historical surveys.
- There might be new management plans for species at CWS. There were plans for all bird groups a decade ago.

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FISH

Comments on Focal Species Selection:

- I don't know which specific species make most use of this area. I've ticked sturgeon because of the ongoing tagging project on them in the Fraser River, and because of their COSEWIC "threatened" status.
- Need resident species, abundant, low trophic levels; salmonids not good indicators, although usually singled out by stakeholders. Surf smelt least reliable of my list
- Salmonids: chinook and chum likely show longest residency and are representative of semelparous salmonids. Dolly varden char - representative of iteroparous salmonids. Sand lance - direct connection to sediment ecosystem and is a salmonid forage fish. Herring direct connect to pelagic ecosystem and is a salmonid forage fish. Stickleback - direct connection to vegetation and is a salmonid forage fish. Starry flounder and English sole- direct connection to sediment ecosystem.
- The key to choosing species is: a) abundance (I guessed at this above), b) covering a range of habitat use (I tried to cover the available habitats).
- The 3 salmonids (and not pinks) because the juveniles are present reliably every year, but all 3 to accommodate population variables not associated with Roberts Bank. Surf smelt because spawning habitat may vary on the bank (and with development), and lingcod because they require reef habitat that is an artifact of port development on the bank (not naturally present). PREVIOUS RESPONSE: [I pick the above species as indicators of productive capacity. I chose chinook, chum and coho (juveniles) because they're present every year, and all three because they vary individually, subject to factors outside of the estuary. I didn't select some of the above even though they're present (e.g., sand lance) because I'm not sure how population changes could be related to changes in productive capacity. Also, additional species should be monitored for indicators of general environmental problems pre and post construction (not just change in productive capacity).]

Comments on Criteria:

- All are in recreational and commercial (except perhaps surf smelt) fisheries. The salmonids are particularly important culturally.
- Starry flounder is a common species that uses a variety of salinities, found in the area, used for contaminant burden work, common on soft sediment habitat
- good monitoring species are rarely of societal importance nor SARA listed
- This question is difficult to answer because there is no definition of what mean by societal perspective. Also societal importance to First Nations can only be assessed by a FN person. Sand lance, herring and sticklebacks are of economic importance because they are major food items in fish species of economic importance.
- I'm not sure how much they use Robert's Bank but tagging by the Fraser River Sturgeon Conservation Society shows that some individuals do leave the river, so this could be important. Numbers might be too small to provide strong baselines or statistical power, but this should be checked. Karl English or Troy Nelson could help.
- "There use of Dungeness crab as an indicator may be confounded by natural fluctuations in stock abundance and the impacts of fisheries withdrawals. COMMENT BY EMAIL: [I don't have sufficient knowledge of the relative life histories of non-fisheries targeted species in the area to say that I was

comfortable identifying one species over others in the area, particularly as it relates to the indicator species' ability to represent productive capacity of the local ecosystem as a whole. My response was therefore based almost entirely on the socio-economic parameters. That being said, I am not sure choosing a species on that basis is the best approach, especially to get at questions on ecosystem integrity.

- It was also a bit tricky to identify a species as an indicator as the first question, before having had the opportunity to see more detail (and provide input) on the parameters that would support that choice.]"
- The salmonids collectively as indicators of change because the juveniles rear in the estuary, the smelt because they (potentially) use high elevation sand beaches for spawning, and the lingcod because they utilize the reef habitat developed there (positive correlation). Lingcod are ecologically important because they feed on juvenile salmonids, and the others because they feed marine mammals and other aquatic and avian predators. Chinook are important food for Southern Resident Killer Whales. Salmonid juveniles are captured in Deltaport Third Berth monitoring. PREVIOUS RESPONSE: [The salmonids collectively are good change indicators. Lingcod require reef habitat (rare in Roberts Bank, an artifact of port development). Surf smelt require sand beaches for spawning (use of Roberts Bank appears uncertain, however). The salmonids feed marine mammals, the smelt are bait fish, and the lingcod feed on a variety of fish including juvenile salmonids. Out-migrating juvenile salmonids spend time in Roberts Bank. Chinook adults are food for Southern Resident Killer Whales, and Roberts Bank is SRKW critical habitat because chinook migration concentrates at the mouth of the Fraser River. Salmonid juveniles have been monitored for a number of years for Deltaport Third Berth.]
- Not sure whether surf smelt are still abundant in the area; they had potential spawning ground by terminal; hard to monitor their egg deposition; most species chosen are forage spp
- Species will "capture/represent" species with similar ecological requirements - this is a difficult question to answer given that each species has a defined niche in the estuarine ecosystem. Species at risk question: difficult to answer without checking recent legislation. Dolly Varden char was listed "blue" by BC CDB I believe. Note also possible migration/overlap between Dolly Varden char and bull trout in Puget Sound, where the latter is at risk. Species for which there are good historical data in the project area and other areas (and concurrent data in other areas), resulting in spatial and temporal controls - this is also a difficult question to answer without detailed knowledge on current activities in the region and adjacent areas such as Puget Sound. As far as I know however there are no studies or monitoring underway in BC for fish in estuaries. There are sporadic projects, but nothing consistent that could be called monitoring as far I know.

INVERTEBRATES

Comments on Focal Species Selection:

- Need to include biofilm and associated communities
- We have normally assessed juvenile and adult stages of Dungeness crab. Key to the selection of the most appropriate indicator is to understand the nature and extent of the potential pathways of effects for the various components of the project from building to utilization.
- Amphipods and polychaetes are too difficult to reliably identify and cover too many niches; cockles were declining; littleneck, if abundant, could be used in bioassays; two spp of isopods, easy to identify; don't know enough about *Pandalus* fishery; would focus on Dungeness juveniles rather than on adults; red rock crabs need boulders (riprap)

Comments on Criteria:

- Cockles are of cultural importance for Tsawwassen FN but may not be abundant enough
- This question is difficult to answer because there is no definition of what is meant by societal perspective. Also societal importance to First Nations can only be assessed by a FN person. Amphipods, burrowing shrimp (juveniles stages), calanoid copepods, and harpacticoid copepods are of economic importance because they are major food items in fish species of economic importance
- I include macrofauna that basically fall under the sensitive benthic areas policy within the sustainable fisheries framework i.e. corals and sponges
- No endemic sp to Roberts Bank hence ecological dependence could be moot; DFO was working on mgt objs for Nuttallia, not sure whether there are fishery objs yet
- Need to include biofilm communities in this assemblage
- See comments concerning response to fish Q, except that for Dungeness crab and *Pandalid* shrimp there is a monitoring program
- I am unfamiliar with the long-term sampling at the site so cannot offer an opinion on the last question.

MARINE VEGETATION

Comments on Focal Species Selection:

- *Bolboschoenus maritimus* (genus is spelled incorrectly above)
- Don't know much about salt marsh spp nor about biofilm
- presumably bacroalgae is macroalgae

Comments on Criteria:

- see previous comments re fish about the difficulty in answering this question These plants are at the basal level in the food web and therefore support higher trophic level organisms which have direct social, cultural and economic importance
- is the species dependent on RB or is RB prod cap dependent on the spp?
- *Nereocystis* bed may be severely impacted by project; don't know much about *Salicornia*
- see previous comments re fish about the difficulty in answering this question Except for monitoring/historical info on native eelgrass which does have a reasonably good spatial and temporal data base

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Appendix B - Present state-of-knowledge on the quantitative estimation of productive capacity (Draft Report)

DRAFT REPORT

Present state-of-knowledge on the quantitative estimation of productive capacity

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EXECUTIVE SUMMARY

This document provides a review of the rationale and methods used to estimate productive capacity in Canada and abroad. The literature was surveyed for methods and models used to estimate species and habitat productivity and productive capacity. Secondly, recent development projects that estimate habitat productive capacity were evaluated to determine their methodology. Finally, additional insights are outlined and expert resources for the estimation of productive capacity are recommended.

Overall, ten methods used to calculate productive capacity are described in this review. Of these models, nine have been successfully implemented in Canada, while one method - Biomass Size Distributions - has been primarily used in Europe. One especially well documented model, the Habitat Evaluation Procedure (HEP), was developed by the US Fish and Wildlife Service (1980), and has been adapted several times by Canadian researchers.

A total of 10 development projects, 7 Canadian and 3 US are described, with an emphasis on the nature of the project, its social and biological relevance, the method used to estimate productive capacity and the rationale provided to justify the estimate.

Recommendations for enhancing estimates of productive capacity are outlined, specifically, the importance of incorporating controls in the estimation of habitat productive capacity for habitat compensation, the importance of incorporating uncertainty into calculations of species productivity and habitat productive capacity, the need for cumulative effects monitoring and, finally, the disparity between marine and aquatic projects in their estimation of productive capacity in Canada. Additionally, six expert environmental and fisheries scientists are recommended as potential resources for the derivation of a definition of productive capacity for future development projects causing HADD within Canada.

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1.0 INTRODUCTION

The guiding principle of the Department of Fisheries and Ocean's policy for the management of fish habitat in Canada is *no net loss of productive capacity of fish habitats* (DFO 1986). This policy requires that any action that results in harmful alteration or disruptive destruction of fish habitat (HADD) be minimized and to the extent that it is unavoidable, mitigated or compensated (Canadian Fisheries Act Section 35). Productive Capacity, defined as the maximum natural capability of habitats to produce healthy fish, safe for human consumption, or to support or produce aquatic organisms on which fish depend, is an important component of the Canadian directive on fish habitat (DFO 2010). The term productive capacity implicitly assumes a quantity with which fish habitat can be measured and net loss, or gain can be calculated. Since the publication of the 1986 DFO directive, biologists have used multiple quantitative measurement of productive capacity with the goal of achieving no net loss of fish habitat in Canada (Minns 2009, Minns 2011).

Efforts to achieve no net loss exist worldwide and other countries have a similar motivation to accurately quantify habitat for management goals (BBOP 2009, Madsen et al 2010). For example, in the United States, the no net loss of wetlands is used as a regulatory policy instrument for section 404 of the Clean Water Act (1972), which regulates discharge of dredged or fill material into waters of the US (USFWS 2011). Although the term productive capacity is not specifically used in this context, there has been a similar motivation to quantify habitat productivity to achieve no net loss of habitat in the US and other regions (BBOP 2009). Furthermore, since the Canadian directive refers to any habitat directly or indirectly supporting fish stocks or populations that sustain commercial, recreational or FSC (food, social or ceremonial) fishing activities of benefit to Canadians, fish habitat can be defined in a broader sense, similarly to a wetland or other general habitat quality (e.g. see NMFS USA, EFH version 1.1 April 2004). This more broad definition of fish habitat implies that methods used quantify habitat in other jurisdictions may be of use in the Canadian framework.

Since the 1986 framework outlined a no net loss policy, there have been numerous efforts to create methods to quantify fish habitat productive capacity (e.g. see Smokorowski et al. 2008). Projects that result in HADD of fish habitats have used these methods to quantify fish habitats in order to achieve no net loss (Pearson et al. 2005, Packman et al. 2006). DFO provides guidelines on achieving no net loss via habitat compensation, including specifications for monitoring of HADD and in-kind (like for like) compensation (DFO 2010). However, the methods of inferring productive capacity are ultimately left to the discretion of the proponent. Therefore, no single standard metric or methodology exists for the quantification of productive capacity of fish habitat for the achievement of no net loss (Minns 1997).

The success and effectiveness of the implementation of various methods to infer productive capacity of fish habitat has been mixed. A review by Harper and Quigley (2005) showed that a net loss of fish habitat has often incurred in the course development projects, in spite of efforts to quantify the loss of productive

capacity to compensate for that loss. These authors suggest that methods to quantify habitat productive capacity are insufficient and may require more standardized and/or rigorous estimates (Quigley and Harper 2006). Similarly, critiques of no net loss policies have questioned the achievability of no net loss, given the level of development, and available habitat for compensation when a net loss is inevitable (Gibbons and Lindenmayer 2007; Sibbing 2011, Minns et al. 2011). Nevertheless, quantitative estimates of habitat for mitigation and compensation, with the ultimate goal of achieving no net loss, are numerous and efforts to quantify impacted habitats for banking and compensation worldwide increasing (Madsen et al. 2010).

The term Productive Capacity encompasses a diverse array of physiological and ecological components of fish habitats (see table 1 for definitions). Here we review the rationale and methods used to estimate productive capacity for habitat compensation in recent development projects in Canada and abroad.

2.0 CURRENT PRACTICES: QUANTIFYING PRODUCTIVITY AND PRODUCTIVE CAPACITY

2.1 INTRODUCTION

Estimating productive capacity for the evaluation of Net Loss involves first establishing quantifiable estimates of species use or productivity in an environment and then scaling this estimate up to reflect the habitat being monitored. In Canada, Minns et al. 1995 described three strategies for measuring population productivity. His description was directed toward fish habitat but it incorporates techniques commonly used in a diversity of net loss evaluations, habitat compensation and other ecological analyses that specifically estimate the productive capacity of habitats or productivity of populations (Robinson et al. 1998). His strategies include: (i) direct measures of productivity (individual based), (ii) indirect measures of productivity (population and community based) and (iii) habitat based methods that relate habitat variables to species productivity (Minns 2011). These methods are basis for incorporation of species specific values into a quantitative framework that can be used to evaluate the productive capacity of a habitat with relation to species of interest.

The first of the general techniques are direct or individual-based measures of productivity such as biomass or grams of carbon per square meter (Robinson et al. 1998, Irwin 2001, Minns 2011). These values provide a close approximation of the true natural productivity but they can be among the most difficult to derive and quantification can be time and labor intensive.

The second category includes measurements of population or community-based variables indirectly associated with species abundance and productivity in a particular habitat. Examples in fish include measures of biomass per unit effort (BPUE) catch per unit effort (CPUE), and commercial fisheries landing data (Minns 2011). Other examples of indirect methods include individual count data and presence/absence data, or other measures of abundance. While not as exhaustive as the direct

measures, these values are commonly utilized as they are more easily obtained from field and literature data; however, it should be noted that they rest on the assumption that indirect estimates of species productivity are directly related to species productive capacity (Table 1).

The third strategy includes measurements of both biotic and abiotic habitat based indices known to be associated with species abundance and productivity (also known as habitat-based methods (see Minns et al. 2011). These indices can incorporate measurements of indirect variables related to species abundance and productivity from the previous strategy into estimation. The metrics are based on the assumption that the habitat features being measured are directly related to the productivity of a species. In this example, a certain proportion of habitat would be equivalent to some metric of species productivity measured in the second strategy or inferred prior to the project.

Estimates of species-specific productivity serve as a basis for more complex models that link species productivity with habitat and the areal extent of the habitat being impacted (Minns 2001). The ultimate goal of these models is to quantify a value of habitat productive capacity that is representative of the link between species and the habitat being impacted. It is notable that the two levels of quantification (species level and habitat level) are not mutually exclusive, and it is often the case that a model that quantitatively estimates productive capacity will use a specific metric to estimate species level productivity.

In this section we describe methods, used in Canada and internationally, to evaluate productive capacity of species and to incorporate measures of species productive capacity into metrics that can be used calculate loss, change or modification of productivity in a specific location or habitat (see also Minns 2011)

2.2 METHODS AND MODELS FOR ESTIMATING PRODUCTIVITY AND PRODUCTIVE CAPACITY

This section reviews relevant methods and models used to estimate productive capacity. Many of these methods have been published in reports for projects related to the HADD of fish and fish habitat within Canada or for NNL policies in the US (de Kerckhove 2008, Smokorowski 2008). While not exhaustive, this section outlines the methods most commonly used in Canada and the US to evaluate habitat productive capacity. In addition, a short summary has been included on additional procedures being implemented or developed in the US, Australia and Europe, which could be viable alternatives to the techniques described here.

The following is a list of methods, which will be described in the subsequent section. Each method, a brief description and its associated references are outlined in Table 2.

- Habitat Suitability Index
- Habitat Productivity Index
- Habitat Utilization Index
- Biomass Size Distributions
- Index of Biotic Integrity
- Habitat Evaluation Procedure
- Defensible Methods
- Habitat Equivalency Analysis
- Bioenergetic Models
- Trophic Models

2.2.1 Habitat Suitability Index

The Habitat Suitability Index (HSI) involves quantifying the relationship between species productivity and habitat characteristics. It was initially described by the US Fish and Wildlife Service (1980) but has been the source of methods used by Canadian biologists in estimation of the productive capacity of fish habitat (Bradbury et al. 1999, Minns et al. 2001). It thus serves as a basis for many of the methods described in this section.

The HSI method was developed to quantify habitat requirements for a species of interest, allowing biologists to link particular species' with environmental variables within the impacted habitat being studied. The index has a minimum value of 0 indicating totally unsuitable habitat and a maximum value of 1, which represents optimum habitat where species may have maximum productivity. Most habitats fall on the suitability scale between 0 and 1 indicating that the combination of habitat variables present generates a particular level of suitability or productivity for that species. The basic methodology for calculating a discrete habitat suitability index (HSI) is outlined below.

A prerequisite for calculating HSI is to identify the species and habitats of interest. The degree to which habitat is broken down into measureable components is left up to the judgment of the proponent (USFWS 1980). A tree diagram can be used to separate habitat into less complex components each of which is related to a set of measureable variables (USFWS 1980). Habitat characteristics described in Bradbury et al. 1999 for aquatic species include: vegetation type, substrate, and bathymetry. Other suitable habitat characteristics include density of cover, chlorophyll a concentration, and temperature (Wakeley 1988). Data on suitability indices can be calculated independently for different life history stages within a species. Examples include young of the year, juvenile, adult, and spawning life history stages in fish. If species are numerous, it has been deemed acceptable to group them into guilds based on life history or habitat requirements. In this case HSI can be calculated for guilds of species rather than individual species (Bradbury 2001).

After identification of the species of interest, the HSI calculation can be described as a three step process including, 1) collection of data for species 2) derivation of the habitat suitability index, and 3) incorporation of indices into further studies (de Kerckhove et al. 2008).

A measure for species productivity associated with habitat variables of interest must be identified. This data can be obtained from previously collected empirical data from direct and indirect measures of species productivity associated with each habitat characteristic in the study location. Such measures include as biomass, count data, species abundance at different life history stages; in fish, Catch Per Unit Effort (CPUE), Biomass Per Unit Effort (BPUE), or fisheries landing (catch data) data. Tian et al. (2009) used fish Catch Per Unit Effort (CPUE) and fisheries effort data to estimate seasonal habitat suitability of a short-lived neon flying squid in the Pacific Ocean. Data on productivity can also be collected from previous literature on habitat preference based on direct or indirect measures, or qualitative estimates of habitat suitability inferred from the literature (de Kerckhove et al. 2008, Ahmadi-Nedushan 2006).

These estimates are then incorporated into suitability indices (SI) for each species and habitat variable. Bradbury 2001 outlined a method first described by the US Fish and Wildlife Service (1980) that uses qualitative data on fish habitat preference to derive a habitat suitability index between 0 and 1. In this example excellent, good, and average can be broken down into numerical values of 1.0 for excellent 0.67 for good and 0.33 for average habitat suitability for a particular species and habitat variable. In this case the degree to which suitability in a habitat is broken down is based on a subjective number of categories inferred from a study of habitat association.

Measures from empirical data on abundance, presence absence or CPUE can be quantitatively transformed into a suitability index for a particular habitat variable by calculating the percentage of individuals in a species occurring in association with a particular habitat variable.

$$\mathbf{SI} = \frac{\text{Counts of Individuals Associated with a habitat variable}}{\text{Total Counts}}$$

Species data from multiple habitat variables can be combined into a habitat suitability indices (HSI) by using either an additive or averaging approach (USFWS 1980). Additional details of habitat can be incorporated into HSI indices including interspersion among habitat variables (such as a suitability index for the distance between cover and vegetation).

The first method, termed the composite method, involves adding suitability indices of multiple habitat variables for a single species. These methods apply when a threshold level of habitat variables exist such that species can meet their maximum capacity with combinations of habitat variables.

Example: Eelgrass cover is given a predefined suitability index of 0.5 for species x or life history stage x, and this habitat sits at a depth of 2 meters, which has a suitability index of 0.35 for species x or life history x. The additive Habitat Suitability index would be 0.85 for a species in eelgrass habitat at 2m depth.

Additive methods become problematic when the sums of suitability indices are greater than one. In this case, the USFWS (1980) handbook recommends equating this value to a suitability index of 1.0.

The second method, termed the compensatory method, involves using an averaging approach for calculating habitat suitability indices. These methods are applicable when a low suitability variable can be offset by a high suitability variable within a habitat. It is appropriate to use either the geometric or arithmetic mean to calculate the habitat suitability index.

In the previous example the arithmetic mean habitat suitability index would be equal to (0.50 + 0.35) / 2 = 0.425, and the geometric mean habitat suitability would be (0.50 x 0.35)1/2 = 0.41. The geometric mean should be used when there is less confidence in the compensatory relationship between habitat variables. An additional benefit to the compensatory averaging approach is that habitat variables can be weighted according to some prior information on their importance to species productivity.

If the values of habitat suitability index are calculated for each life history stage within a species the mean of HSI values for each life history stage can be used to calculate the total species level habitat suitability index. If species have been assigned to guilds the species with the highest habitat suitability index within the guild should be chosen as a representative of that guild. Ultimately these composite or compensatory values of habitat suitability indices can be scaled up to the habitat size in question and used to compare habitat values that relate directly to the species or guild of interest.

The relationship between species productivity data and habitat variables can be analyzed using a linear modeling approach (Ahmadi-Nedushan 2006). The results may be used in a predictive framework to estimate suitability indices in habitats for which empirical data does not exist.

An assumption when using HSI models to estimate productive capacity of species or guild within a given habitat is that indirect estimates of species productivity or other subjective measures of suitability correlate with the actual population productivity. This method of estimating productive capacity further assumes a linear relationship between HSI and habitat capacity such that at an HSI of 1 indicates maximum productive capacity for a species. This method also relies on the assumption that habitat variables are not correlated. The correlation of habitat variables can lead to inflation of a Habitat Suitability Index because two habitat variables are in actuality a single component of a habitat. Finally, there is little opportunity to incorporate the effect that any degree of demographic change such as competition, availability of immigrants and ability to emigrate would have on the HSI.

2.2.2 Habitat Productivity Index

The Habitat Productivity Index (HPI) is a measure of habitat productive capacity that was described by Randall and Minns (2000). The HPI is similar to the Habitat Suitability Index described above, in that it quantifies a productivity value for species that corresponds to a particular habitat type. However, HPI indices describe quantities related to a suite of habitat variables that correspond to a unit area of impacted habitat. This measure is additionally unique in that its value can be quantified as the sum value of productivities of all species in a habitat. Additionally the HPI specifically uses production biomass ratios of species or guilds to estimate productive capacity.

The HPI quantity is based on a measurement of population productivity (P) for a given habitat, which is the product of instantaneous growth rate (G) and average biomass (B) of a species over a discrete time interval (Δt) (de Kerckhove et al. 2008). Therefore:

$P = G_{\Delta t}B$, thus $P/B = G_{\Delta t}$

Measurement of productivity as the product of growth rate and biomass over a given time interval can be costly, and thus Randall and Minns (2000) suggested that productivity could be calculated by measuring indirect biological indices of production.. The habitat productivity index for a particular species in a habitat of interest is defined as, HPI = B (P/B). This measure can be summed across species using the equation HPI = □ Bi (P/B)i, whe
the habitat. The units for HPI are expressed as the rate of weight per unit area per year (e.g. kg/ha/yr.).

In freshwater fish the relationship between production and biomass is linear and not significantly different from a slope of 1. Therefore, a productivity index can be measured based on the allometry with fish biomass (measured as size) (Randall 2005). Because of this allometric relationship Randall and Minns (2002) showed that the production biomass (P/B) ratio could be estimated using an equation for the weight at maturity of freshwater fish species (see Randall and Minns 2000). In their paper they found that the relationship between P/B ratio and fish size was P/B = 2.64w -0.35 where w is equal to the weight at maturity for a particular fish species. They point out that this relationship is specific to freshwater fish species. They suggest that a similar relationship may hold for taxa other than freshwater fish but the scale of the relationship between weight at maturity and P/B ratio would have to be examined specifically in these species.

If the allometric relationship between P/B ratio is known then the HPI can be calculated as the product of Biomass and the average weight of individuals captured, summed over each species in the habitat. This measure of HPI can then be scaled up to the areal extent of the habitat of interest.

De Kerckhove (2008) highlights the benefits and drawbacks of this method for estimating productive capacity. First this method assumes a specific allometry between biomass and productivity, which would

have to be tested before use on the species or taxon of interest. The model also assumes that fish biomass density is linked to the habitat capacity such that the data collected for biomass represents the maximum capacity for that habitat. Furthermore, de Kerckhove (2008) points out that, while HPI values are estimated as a rate, they are best used as indices because the estimates are not actual estimates of growth rates but rather a proxy of growth rate estimated from body size. By estimating productivity based on biomass the HPI fails to recognize the diversity of species in the habitat (Randall and Minns 2002). It has been suggested that HPI be used in addition to measure such as the Index of Biotic Integrity (IBI) that capture species diversity.

2.2.3 Habitat Utilization Index

The habitat utilization index (HUI) is a method developed by McCarthy et al. (2008) to estimate the productive capacity of fish species in a large watershed hydroelectric project. This method estimates catch based utilization indices (CUI), in a series of defined habitats throughout the watershed or habitat area. This method is similar to the previous HSI and HPI methods in that species productivity is estimated for a particular habitat, or set of habitat variables of interest. However, this method differs from the previous two approaches in that it specifically uses CPUE data to estimate species productivity. Furthermore this methodology recommends using CPUE data in the habitat that will be impacted so, unlike HSI indices that can be calculated form previous accounts of habitat preferences, HUI is specific to the habitat in question.

Habitats were defined by methods from previous literature Bradbury (2001) that delineated habitat based on physical biotic and abiotic features. To estimate species productivity catch per unit effort data was collected using standard fish collection procedures (Smokorowski 2008) that were suitable to each species and life stage in a particular habitat. Upon catch, each individual of a species was classified by life history stage.

A catch base utilization index (CUI) is then calculated from CPUE data for each life history stage for a species. The mean of these measures represented the species level Habitat Utilization Index. In this method, if a species had a critical life history stage that only occupied a single habitat type then the CUI for that life history stage was used as the HUI for that species in the specific habitat type.

In this study, Churchill et al (2008) separated species HUI values into guilds based on trophic level. The species with the highest HUI in each guild was used as the representative for a particular guild in a habitat. Finally the mean of the guild indices for a particular habitat type was used to calculate the HUI for all fish species in a habitat.

This method uses CPUE data to estimate the Habitat Utilization Index for species within an entire habitat of interest. This aspect is beneficial because it estimates values for the particular habitat of interest. If this

CUI for a species or life history stage is conducted throughout the habitat of interest then CUI data would not need to be scaled to represent the actual size of the habitat.

Smokorowski (2008) pointed out some pitfalls of this study. Notable assumptions include the idea that the estimation of HUI in one season represents that present throughout the year in a particular habitat and this method also assumes that CPUE sampling is conducted exhaustively. Similar to the HPI model this model does no incorporate information on species diversity within a habitat and this method does not have the ability to account for interactions with among species (such as predation pressures) or immigration emigration frequencies.

2.2.4 Biomass Size Distributions

DeLeeuw et al. (2003) described the calculation of Biomass Size Distributions as a method for characterizing freshwater fish communities in Europe. A biomass size distribution is a graphical representation of the relationship between the quantity of fish biomass in a habitat and the size of fish. See the diagram below:

This metric can reveal how the frequency of size classes within a population changes with habitat type. This method is similar to the methods described previously in that distributions of biomass size classes are associated with a particular habitat variable of interest. However, this method evaluates the relationship on a graphical basis rather than a numerical basis. It can be measured for a particular species or scaled up to a particular taxonomic or trophic group within a habitat. The biomass size distribution of a particular set of habitat variables would ultimately serve as a species or taxon specific proxy for the productive capacity of a habitat.

The method described by DeLeeuw et al. (2003) uses CPUE data to estimate biomass associated with each habitat of interest. In this study length was used as a proxy for size. The biomass size line would therefore represent the number of individuals caught (biomass) of a particular length (size). Size can be distributed on a log scale in order to better visualize small and large size classes. The authors quantified one habitat variable throughout their study area and compared the variation in biomass size distribution over the extent of that habitat variable.

In DeLeeuw et al. (2003) biomass size distributions were plotted on a species level. These distributions were then plotted for trophic level and taxonomic grouping to determine how habitat variables affected the distribution of biomass and size at these levels independently.

Measures of biomass size distributions were found to correlate strongly with quantitative results from regression analysis of habitat and productivity indicators (DeLeeuw 2003). This suggests that these measures can be used to qualify the relationship between habitat productive capacity and species of interest. One benefit to the biomass size distribution method to estimate habitat productive capacity is that it can be measured for groups of species on a similar trophic or taxonomic level. Alternatively, these methods are a snapshot in biological time and assume that growth-rate, mortality and immigration remain constant throughout the habitat variable in question.

2.2.5 The Index of Biotic Integrity

The Index of Biotic Integrity (IBI) was derived from the work of Karr et al. (1986) and Steedman (1988) to measure fish assemblages. This method was designed to describe habitat quality and can serve as a proxy for productive capacity (Smokorowski 2008). The IBI samples habitat parameters related to species diversity, abundance, ecological role (native/invasive, or tolerance), trophic structure, and biomass within either a portion of the habitat of interest, or within the entire habitat in order to estimate its ecological status. This method is unique to previous metrics described in this review in that it was developed to assess the quality of habitats in addition to more direct measures of productivity or count data. Randall and Minns (2000), suggest that the IBI captures aspects of habitat quality not assessed in other productive capacity estimates such as the habitat productivity index (HPI).

Karr et al (1986) set out to develop a biologically based model, interpretable across all trophic levels, that was sensitive to habitat or ecosystem status, responsive over a range of use, and reproducible and precise with low variability. Since its derivation, this method has been widely used to assess impacted habitats throughout North America, Europe, and Asia (Ganasan and Hughes 2002, Bowen 1996, Weigel and Dimick 2011).

The IBI involves first choosing the appropriate habitat indicators. Indicators can include, species richness, species composition, tolerance categories, trophic categories, health status of individuals and reproductive rates. Studies such as Minns et al (1994) use up to 12 metrics. These raw metrics can be expressed as either the sum of a subset of species or individuals or percentage of total species abundance or biomass. This subjective selection procedure allows metrics to be chosen on the basis of significance in a particular habitat. For example, if sedimentation tolerance was an indicator of habitat quality in a particular region, then this metric could be included in the analysis.

Sampling can be conducted within a habitat along an environmental gradient and/or among habitats with differing habitat features. For example, sampling by Minns et al. (1994) was conducted using transects within and among habitats, which can then be compared within a habitat or among habitats.

After habitat metrics are calculated the quantities are standardized. Minns (1994) and others described the quartile method, which expresses the standardized metric as a linear function of the raw metric. This method uses the 0/1/3/5 method where 1 = poor habitat quality, 3 = moderate quality and 5 = excellent quality. Expert knowledge is used to assess the directionality of the relationship between the metric and estimates of habitat quality. The sum of standardized habitat metrics is then calculated and multiplied by 10/Nm, where Nm is the total number of metrics. Minns et al. (1994) categorized the overall IBI into a range of values between 0 and 100 with 100 being excellent fish habitat and 0 being habitat with no fish species present.

If standardized IBI metrics conform to normality, the mean overall IBI score for each habitat can be compared among habitats using ANOVA. Redundancy between both raw metric data and IBI data can be tested using and PCA or Pearson Correlations. Tests for sensitivity of the overall IBI score to individual IBI metric data can be conducted to assess the influence of different metrics on the overall IBI calculation (Smokorowski 2008).

This method has been historically criticized for subjectivity in the choice of habitat indicators (de Kerckhove 2008, Smokorowski 2008). Similarly, because of differences in the number and qualities of the habitat metrics, as well as differences in measurement of these metrics, IBI values are specific to each study and it would be difficult to compare values among studies of different regions or ecosystems.

2.2.6 Habitat Evaluation Procedure

Bradburry (2001) and others have used the basic framework of the Habitat Evaluation Procedure (HEP) developed by the US Fish and Wildlife Service in 1980, to quantify net change in habitat productive capacity. This method has been used extensively in the US and throughout Canada to evaluate net loss.

The HEP methodology uses habitat suitability indices (HSI) and the areal extent of the habitat of interest to calculate habitat units (HU) (USFWS 1980). Habitat Units can be calculated for a single species HSI value or from HSI value that represents multiple species or a guild (see HSI section). The basic formula for calculating Habitat Units (HU) for the Habitat Evaluation Procedure is,

$HU = HSI^{u/m2} \bullet \text{Habitat Area } (m^2)$

This method builds on existing methods by incorporating the areal extent of impacted habitat. This technique results in units of productive capacity for a particular species or guild within a habitat that can

be used as a currency to compare productivity values of species within similar habitats in different locations.

The first step in calculating the net change in HU through an impacted habitat is to determine the baseline HU within the study area, the second step is to determine future habitat units, if habitat will be lost the next step is to develop a compensation plan. Once a compensation plan has been developed, its value can be compared with that of the baseline and loss HU to determine the net change in habitat units, which can be used as a proxy for the net change in habitat productive capacity. To calculate the areal extent of compensation needed, the ratio of HU for the proposed development to the HU from the proposed compensation multiplied by the areal extent of the study cite will give the areal extent of compensation needed for No Net Loss.

In using HEP analysis for habitat compensation calculations, the authors recommend that species used to calculate impacted HU be the same species used to calculate compensatory HU. Software for application of the HEP is available from the USGS website.

2.2.7 Defensible Methods

Minns (1997) established a framework specifically designed to estimate the productive capacity of a habitat for all fish species within a habitat. This method presents a baseline on which to estimate the areal extent of lost or modified productivity within an impacted habitat. This framework differs from previous models in that the estimate of productivity (p) for a given habitat is somewhat arbitrary. Its focus is instead, a model that combines species productivity into a single habitat productive capacity estimate that can be used to evaluate the net change of productive capacity with and without compensatory measures. Following the development of this quantitative framework to evaluate net change in productive capacity, Minns et al. (2001) described the Habitat Suitability Matrix method of calculating a value for species productivity within a specific habitat.

Minns (1997) defined species specific productivity as (p), habitat productivity as (P), and habitat area as (A), such that the productive capacity of an area (P) is equal to,

$P = p \times A$

Species productivity (p) can be scaled to represent the sum of all species productivity estimates within a habitat, where specifies specific productivities are expressed as a value between 0 and 1. The basic objective of the productivity area equation is to arrive at a quantity of productivity and area that result in no net loss of habitat productivity.

Minns (1997) defines the following area and productivity parameters:

p_{max} represents the maximum natural productivity in the habitat prior to human contact or alteration. When an area is lost the maximum possible productivity of that habitat is lost forever.

p_{now} represents the productivity of the current habitat and

p_{mod} represents the productivity of the modified habitat after development. Note that modification is different than loss.

A_{mod} is the areal extent of habitat modification is termed

A_{loss} the areal extent of lost habitat

P_{comp} the productivity in the compensatory habitat

A_{comp} the areal extent of the compensatory habitat

Net Change Equations

To account for destruction and loss of habitat this model sets the areal loss (A_{loss}) of habitat against the maximum possible productivity (p_{max}) of that habitat. To account for loss due to modified habitat the productivity pre-modification (p_{now}) is subtracted from the productivity of the modified habitat (pmod) to determine the loss of productivity due to modification. This quantity is quantified for the total area of modified habitat (A_{mod}). The quantity p_{mod} can change throughout the development project as mitigation strategies increase the productivity of the modified habitat to that of the productivity pre-modification. The following is the calculation of net change in productive capacity without compensatory measures.

$$\text{Net Change} = ((p_{mod} - p_{now}) \bullet A_{mod}) - (p_{max} \bullet A_{loss}) \quad \text{[Eqn 1]}$$

If some areal extent of habitat (A_{comp}) has been compensated by some unit area productivity (Pcomp) then the calculation of net change in productive capacity accounts for that compensation.

$$\text{Net Change comp} = ((p_{mod} - p_{now}) \bullet A_{mod}) + ((p_{comp} - p_{now}) \bullet A_{comp}) - (p_{max} \bullet A_{loss})$$

[Eqn 2]

If areas being considered contain several smaller areas with differing productivity then the net chance is the summation of those productive capacity estimates over differing habitats or habitat variables.

$$\text{Net Change} = \sum_{mod}((p_{mod} - p_{now}) \bullet A_{mod}) - (p_{max} \bullet A_{loss})$$

[Eqn 3]

The Net Change comp equation can also be manipulated to determine the compensation area needed to arrive at 'No Net Loss' of productive capacity.

Areal Compensation (A_{comp}) = $A_{mod} + A_{loss} \bullet p_{max} / (p_{comp} \bullet p_{now})$

[Eqn 4]

Finally, if C is the proportion of A_{now} that must be conserved in order to avoid further losses then $C \bullet A_{now}$ can be substituted for A_{mod} (with some rearrangement) to set a conservation target for achieving 'No Net Loss' (Smokorowski 2008).

Conservation Target (C) = $p_{max} / (p_{max} + p_{mod} - p_{now})$

[Eqn 5]

Minns et al. (2001) built on this initial framework by introducing the Habitat Suitability Matrix (HSM). This is a quantitative method for calculating habitat suitability values (p) for a species in a particular habitat. This value is similar to the HSI and HPI methods described previously but the expert identification of suitable habitat workshop model was replaced by an extensive literature review of habitat suitability. In this method the habitat suitability for a particular species (similar to the SI above) within a particular habitat is divided by the combine suitability for that species summed over all permutations of habitat variable categories.

The entire suite of 'Defensible Methods' to quantify habitat suitability and productive capacity of habitats was made available as an online computational resource for consultants and regulators to use when estimating net change in productive capacity (Minns et al. 2001).

Smokorowski (2008) and de Kerckhove et al. (2008) outlined specific benefits and drawbacks associated with this method. The major strength of this method is that it outlines a quantitative model, from which habitat managers and regulators can base their calculations of net loss of productive capacity.

Drawbacks of this framework include, the assumption that the productivity after development will be lessened relative to the current productivity or the compensatory productivity estimates. Currently, there is no parameter in this model to account for an increase in productivity that is the result of habitat modification. Furthermore, there is uncertainty involved in each estimate of productivity and in the net change equation, Minns et al. (2003) describes a method for including a method of statistical uncertainty in the habitat suitability and net change equations. The productivity of endangered or rare species may be more important in the calculation of net change. Productivity values associated with these species warrant extra consideration. Additionally, this model does not incorporate a quantity for the time necessary to equate compensatory habitat with lost habitat and the loss of productivity that results.

Minns (2003) similarly points to the need to incorporate temporal compensation into his Defensible Methods framework.

2.2.8 Habitat Equivalency Analysis

Habitat Equivalency analysis is a tool developed by NOAA (US National Oceanographic and Atmospheric Administration) to evaluate natural resource damage and to assess possible compensatory options (NOAA 1995). This method focused on scaling habitat for in-kind compensation of lost or damaged habitat. The HEA method incorporates concepts from discounting theory, which is based on paying back principle habitat and adding interest, corresponding to the length of time taken to complete total payback (NOAA 1999). This method is similar to the previous method in that it incorporates the areal extent of habitat but differs with respect to the inclusion of an element of payback associated with compensation procedures.

In the HEA, one or more ecosystem services, most applicable to the species(s) of interest is chosen, and evidence from literature of expert information is used to choose a metric to represent the service (Allen et al. 2005).

The habitat equivalency analysis can be broken down into the following seven steps; 1) determine the area of the impacted habitat, 2) Select an appropriate service to replace and a metric to represent the service, 3) Estimate the loss in service of the impacted habitat, 4) Determine the shape of the recovery curve, 5) Estimate losses occurring while recovery proceeds, 6) Estimate total losses, 7) Calculate the amount of restored habitat necessary to offset total losses. Once the service has been selected and measured and the quantity of habitat loss has been calculated, the shape of the habitat recovery curve and the estimates of total losses including recovery can be calculate as follows. The following equation is taken directly from G. Ray (EMRRP 2010).

$$\text{Total Losses}\,(L) = V_L * \sum_{t=i}^{B} A_L * (1+d)^{(T-i)}$$

where

V_L = value per unit area of injured habitat
A_L = area of injured habitat
B = year in which services are finally recouped
i = year of impact
t = number of years between impact and start of restoration
T = base year
d = discount rate (usually 3 percent)

Gains of a service that are the product of habitat compensation or habitat banking can be calculated as follows. The following equation is taken directly from G. Ray (EMRRP 2010).

$$\text{Total Gains}\,(G) = V_G * \sum_{t=j}^{M} S_t * (1+d)^{(T-i)}$$

where

V_G = value per unit area of restored
S_t = additional area of restored habitat constructed in year t
j = year when gains begin
M = year in which services are finally recouped
T = base year
d = discount rate (usually 3 percent)

Once these gain and loss values are quantified, estimates of how much habitat to restore on a 1:1 scale can be calculated by making total losses (L) equal total gains (G).

Allen et al 2005 pointed out that habitat Equivalency analysis would be difficult to use if there was an added benefit to habitat due the initial habitat alteration.

2.2.9 Trophic Models and Bioenergetic Models of Productivity

In addition to a selection of the methods and models reviewed in this section de Kerckhove suggests two additional models that could be of used in calculate productive capacity of fish habitats.

The Bioenergetic model uses the metabolic and physiological relationships between species and environment to estimate productivity. The implementation of this method involves quantifying biotic and abiotic variables within an environment and quantifying their functional significance to the physiology of the species of interest. The Net Energy, when scaled to the habitat of interest can be useful in measuring the productive capacity of habitats. This model relies on a sound understanding of the ecological connections among species and the physiological conditions of the species of interest within its environment.

Another method suggested by de Kerckhove (2008) applies Trophic Models to examine habitat productive capacity. This method emphasizes the interaction among species within an ecosystem.

A species trophic position can be calculated as the proportion of energy that comes from various components of a habitat such as its prey species. These models can be incorporated into larger models that evaluate the role of the community and abiotic components in the trophic position of the species of interest; the idea being that as the community changes the trophic composition of the species of interest will change. The software ECOSIM, a popular trophic modeling program uses an equation that explores the flow of energy between two groups of organisms over a specific time period (Walters et al. 1999). This model incorporates interactions among groups as well as elements of mortality, growth and emigration to determine the net production of a given trophic position for a unit time. Three programs, namely Ecopath, Ecosim and Ecospace are available for trophic modeling and are specifically designed for examining changes in within and among group trophic structure through space and time (Christensen and Pauly 1992).

2.3 ADDITIONAL METHODS FOR ESTIMATING PRODUCTIVITY OF SPECIES AND/OR HABITATS

Several international organizations are involved in implementing 'No Net Loss' policies and in developing methods for conducting estimates of species productivity and habitat capacity for compensation and habitat banking (BBOP 2009). The following is a list of additional methods and models that might be reviewed in the future as viable estimates of productive capacity.

Natural Capital Project: inVEst software (http://www.naturalcapitalproject.org/).

Marine Biotic Index (Borja et al. 2000)

Europe REMEDE program (REMEDE 2009)

Biotope valuation (Darbi and Tausch 2007)

3.0 PRODUCTIVE CAPACITY IN RECENT DEVELOPMENT PROJECTS

3.1 INTRODUCTION

Here we review a subset of development projects throughout Canada and internationally that implement estimates of productive capacity for 'No Net Loss'. For each project, we provide a short description of the nature of the project; its social and biological relevance, the method used to estimate productive capacity, and the rational provided to justify the estimate. A summary of details on each project's implementation and methods can be found in Table 3.

3.1.1 Mt. Milligan Gold and Copper Project

Mt Milligan Gold and Copper Project is an open pit copper-gold mining operation in Northern British Columbia. This project followed the general approach outlined by DFO for Management of fish habitat (1986). The procedural steps that this project followed in the derivation of net loss and a habitat

compensation plan are as follows; Aquatic Resources Baseline Data compilation, Summary of Predicted Project Effects, HADD habitat Quantification, Regional Objectives Identification, Compensation Option Compilation, Compensation Option Evaluation and Analysis, Public and First Nations Input, and Identification and Analysis of Candidate Compensation Sites.

This project arrived at a net loss of 15.98 hectares of aquatic habitat. The loss of this habitat impacted several fish species including Rainbow Trout, Slimy Sculpin, Bull Trout, Arctic Greyling and Mountain Whitefish. Rainbow Trout was chosen as the representative fish species for quantitative loss of productive capacity because viable habitat for this species is also suitable for other impacted species. The Habitat Evaluation Procedure (HEP) was used to quantify habitat (USFWS 1980, Bradbury 1999). Habitat type was broken into nine categories and only those habitat types with a substantial fish population were further evaluated for compensation. A habitat suitability index for each type of habitat was calculated from literature sources on Rainbow Trout. Habitat units for each habitat type were calculated as the HSI multiplied by the areal extent of impacted habitat (AMEC 2008).

This project was approved in 2009. Construction is underway and the mine is scheduled to open in 2013.

3.1.2 Melford International Terminal

The Melford International Terminal Project is a shipping terminal expansion project that was predicted to cause a loss of 25.5 ha marine habitat via terminal expansion and additional loss of 7.56 ha of aquatic fish habitat from development of a terrestrial logistics area adjacent to the terminal.

Marine Habitat was surveyed using transects. Five major marine faunal zones were inferred including, Intertidal, Algal Cover, Eelgrass Bed, Transition Zone, and Barrens. The productivity of these faunal zones was predicted but rational for prediction of productivity was not given in the compensation plan. A suggested factor for compensation, which corresponded to the productivity of each faunal zone was provided. This factor was multiplied by the total area of each faunal zone to arrive at compensation area for each faunal zone. A similar methodology was followed for aquatic fish habitat. Major faunal zones were inferred and scored based on productivity. Each zone was then given a corresponding compensation factor, which was multiplied by the areal extent of each of its corresponding faunal zones to arrive at a compensation area for each faunal zone (Thaumas Ltd 2008).

Although this project does not directly follow any of the protocols outlined in the previous section, methods from this project are of a similar format and suggest yet another alternative to the methods describe previously. This compensation plan, in association with the EIA, was approved by the Ministry of the Environment in 2008.

3.1.3 Churchill River Power Project

The Churchill River Power Project is a hydroelectric project that will inundate a large quantity of terrestrial and aquatic watershed habitat surrounding the Churchill River in Labrador. The total development outlined by McCarthy et al. (2006) has the potential to alter approximately 18,000 ha of aquatic and terrestrial habitat (AMEC 2009).

Hydroelectric projects are unique in that much of the HADD of fish habitat is altered in such a way as to create additional habitat for alternate life history stages of fish species identified. As such, their direct application to development projects of a differing variety is small. However, the project scale and method of quantification of fish habitat productive capacity make it relevant to this review.

For the quantification of aquatic habitat, freshwater fish species and habitat potentially impacted by the project were identified. Catch Based Utilization indices (CUI) based on long term monitoring studies and Literature Based Utilization Indices (LUI) were quantified to determine the extent of fish species utilization of each habitat type. Calculations were conducted for each life cycle stage, fish species guild and habitat type to determine the habitat utilization index for each habitat. Habitat utilization indices post-construction were estimated through the use of baseline data, modeling and past experience on reservoirs in northern Quebec and Labrador (AMEC 2009). Pre and post-construction estimates were evaluated to determine the extent of habitat loss.

3.1.4 Romaine River Hydroelectric

The Romaine River Hydroelectric project is a hydroelectric project that proposed flooding terrestrial and aquatic watershed area along the Romaine River in Quebec. Productive capacity of fish habitat was estimated using productivity data for the literature, which utilized indirect methods such as catch per unit effort and biomass per unit effort. Changes in productive capacity of fish habitats were estimated with specific emphasis on alteration of abiotic components of the watershed associated with flooding.

Catch Per Unit Effort and Biomass per Unit Effort data were used to calculate weighted productivity indices (WPI) for each habitat (Randall and Minns 1995). This method is similar to the HPI of Randall and Minns (2000) however, biomass and productivity information inferred from CPUE and BPUE data are assessed in relation to abiotic habitat variables associated with flooding such as water temperature, depth and flow for each species. These estimates were incorporated into a Weighted Productivity Index (WPI) that compared species productivity among affected abiotic habitat variables. Environmental variables such as flow rate change and sediment changes as well as existing biomass data for fish species in the region was used to model WPI for species post inundation.

3.1.5 Voisey's Bay

The Voisey's Bay Nickel Company proposed the construction of a nickel-copper-cobalt mine/mill at Voisey's bay in Northern Labrador. This project resulted in both marine and aquatic HADD due to the construction of port facilities for transport of mill products and the terrestrial footprint of the mine/mill. A total HADD of 2.2 ha of marine habitat and 5.0 ha of aquatic habitat was inferred (DFO 2008).

Quantification of marine habitat was conducted by examining areal loss of habitat associated with the port facilities. Little information or rational was available with regard to reasons for inferring the marine HADD as a simple areal measurement (DFO 2008).

Aquatic Fish habitat was measured using the Habitat Evaluation Procedure (HEP) (USFWS 1980). Fish species were identified and Habitat suitability matrices were constructed for each species over multiple habitat variables. From these HSM values productive capacity was estimated in the form habitat units.

3.1.6 Keltic Petrochemicals

Keltic Petrochemicals proposed the construction of a liquefied natural gas facility and marine terminal. This project will result in the HADD 25 ha of marine fish habitat.

Indirect estimates of marine habitat were quantified via fisheries landing data and the areal extent of fish habitat was used to evaluate the Net Loss of productive capacity. Landing and observational data of marine habitat suggested that several commercially important fish and invertebrate species occurred within the development region although this habitat was not thought to be critical for these species (Keltic Petrochemicals Inc. 2007).

3.1.7 Diavik

The Diavik development is a diamond-mining project in the Northwest Territories. The total areal of the mine site is 9 km squared, with a fraction of that quantity resulting in HADD of fish habitat (Diavik 2002). The altered fish habitat will be due to the construction of a series of dykes along Lac de Gras and disturbance of surrounding tributaries. The fish species affected by the project include Arctic grayling, Lake Trout, Round Whitefish, Cisco, Lake Whitefish, Lake Chub, Longnose Sucker, Northern Pike, Butbot and Slimy Sculpin.

Estimates of loss of habitat productive capacity were conducted using a modified habitat evaluation procedure (HEP). For this project HSI values were determined from the literature (Packman 2006). HSI values for some species had to be tested for applicability to arctic environments and other models such as that for Lake Trout was deemed unsuitable for the Lac de Gras environment (Diavik 1998). For each species for which published models were inadequate or unavailable, simple HSI models were developed

to fit conditions specific to Lac de Gras. Confidence in the HSI models varied among fish species. In order to compensate for this lack of confidence conservative HSI values were used (Packman 2006).

The HSI values of each species and life history stage were multiplied by the area for each type of habitat in the affected aquatic environment. This generated Habitat Unit (HU) values, which were available for each habitat, species and life history stage during each phase of the project (Packman 2006, Diavik 1998). The number of HU pre-Diavik was compared to the number of HU predicted to be available throughout the life of the mine (less mitigative measures) to determine the net loss of productive capacity (Packman 2006).

3.1.8 Lower Bois D'Arc Reservoir

Bois D'Arc creek reservoir will inundate approximately 2200 hectares of wetland habitat. This habitat was historically used for farming and grazing but the loss of wetland habitat put the development under the jurisdiction of the US clean water act (North Texas Municipal Water District 2008).

This project used the HEP procedure to predict the loss of habitat due to reservoir inundation. The justification for use of HEP was that HEP was recommended by the USFWS and because similar projects within Texas had used the HEP method. The study area was defined, and habitat (based on Cover type) was determined and delineated. Species were selected for evaluation by a panel of experts based on their ecological significance and availability of HSI models. The areal extent of habitat loss for each habitat type was calculated by multiplying the composite habitat suitability indices by the areal extent of habitat lost to yield habitat units (HU).

3.1.9 Miami Harbor

The Miami Harbor revaluation report and EIA addresses plans to widen and deepen channels in Miami Harbor, resulting in impacts to hard-bottom Reefs (USACE. Jacksonville 2002). Two types of habitats that will require mitigation and or compensation will be lost during development, namely, seagrass habitat, and limestone reef habitat. While no formal information was available for seagrass habitat the US Army Corps of Engineers (USACE) (2008) describes the formal HEA for limestone reef habitat. Of the total reef habitat loss, 0.5 ha of low-relief reef habitat, and 1.09 ha of high-relief reef habitat will be impacted.

The metric to represent loss of ecosystem service was determined. The total time interval between impact and compensation, the relative loss of services and the rate and form of the recovery curve was calculated using the HEA model. Habitat loss was calculated as number of acres but a factor that accounts for the time interval between impact and compensation was incorporated into the estimate.

3.1.10 Craney Island

Craney Island is a 1011 hectare confined dredged material disposal and port facility located near Norfolk VA USA (Virginia Port Authority 2010). This project proposed to expand the existing facility to impact an additional 234 hectares estuarine habitat. These habitats were thought to be important in supporting the estuarine food chain, providing a valuable resource for fish species.

In order to compensate for the loss of habitat an HEA analysis was employed. The compensation HEA model was similar to that mentioned in the previous example except that the resulting habitat compensation was conducted using out-of-kind replacement. The impacted habitat was relatively barren compared to other habitats in this region. Salt marsh and oyster bed habitats were considered the most appropriate proxies to replace the barren area, and had experienced considerable declines in the recent past. Despite the differences among these habitats the measured habitat service metric used in the HEA had to be common among all three habitats. The service metric used for the analysis of the benthic habitat was an invertebrate herbivore habitat productivity index (HPI), which was calculated using standing crop biomass (ash-free dry weight). Similarly, the estimate of service loss from the water-column was conducted by calculating HPI using microzooplankton biomass. In this case, construction of compensatory habitat occurred prior to the Craney expansion and thus it was not necessary to apply a discount rate to the quantity of habitat impacted.

3.2 ADDITIONAL PROJECTS FOR FUTURE CONSIDERATION

Jonah Infill Drilling Project Wyoming

US Port Expansion Projects (Port Everglades, Savanna, Jacksonville, New York, Charleston)

Doris North Northwest Territories Canada.

Hibernia Oil Field

4.0 FUTURE CONSIDERATIONS

4.1 INTRODUCTION

The estimation of productive capacity and of habitats for measures that result in no net loss has a rich history in the literature from its initiation in 1986 to the present. Thus, in order to determine the appropriate measure of species productivity and model of habitat productive capacity new techniques and expert recommendation must be carefully considered by the proponent. Here we provide information on future considerations for habitat quantification for ‘no net loss’ as well as potential expert resources that could provide useful guidance on arriving at a suitable measure of productive capacity for a habitat or location of interest.

4.1.1 Future Considerations

Several authors suggest the usefulness of a specified control reference site habitat, within which the habitat will remain at the current level of productive capacity throughout the life of the project. The control habitat would be of similar composition to the impacted and compensatory habitat, if in-kind replacement were the goal. This habitat can serve as a reference with which impacted and compensatory habitat can be compared. One criticism of the US policy of no net loss of wetlands is the lack of true in-kind replacement such that wetlands diversity is becoming more homogenous as diverse wetland habitats are lost and replaced by habitat banking and compensation (Sibbing 2011, National Wildlife Federation). A control site that was representative of the impacted habitat and that remained constant over the course of a project would mitigate the effects of uncertainty in in-kind replacement, as this reference location would always be available for comparison with the compensatory site.

Minns and Moore (2003) highlight sources and levels of uncertainty in quantitative estimation of habitat productive capacity. The authors specifically emphasize uncertainty generated through the estimation of habitat suitability indices of species from non-empirical sources, or sources not specific to the habitat of interest. They used interval analyses to document variance around estimates of habitat suitability modeling, assigning a 95% credibility interval to HSI estimates. The authors specifically emphasize the need for careful selection of habitat criteria and the urgency for uniformity of measurements of species productivity indices and habitat variables within an analysis of net loss.

Minns and Moore (2003) further highlight the need for modeling of uncertainty of consistency of abiotic habitat components. For example, water levels, salinity and other abiotic components can change over the course of a project. The authors suggest that models should be further expanded to include the variation in these components in the calculation of habitat productive capacity.

Similarly, Canter and Atkinson (2011) outline methods for incorporating cumulative effects assessment into quantitative measurements of habitats. Cumulative effects assessment is a method of predicting cumulative consequences to species or habitats from multiple sources. For example, a species or habitat likely to be influenced by a development project is also likely to be influenced by impacts of climate change, as well as other natural and anthropogenic induced factors (such as fishing pressure). These authors suggest incorporating multiple factors into an estimate of species productivity or habitat capacity in order to better approximate the net or cumulative influence of a particular factor (such as a development project) on the species or habitat of interest.

Finally, there is a notable difference between marine and freshwater studies, with regard to the method of quantification of habitat. While this review was not exhaustive, there was a large disparity between quantification of productive capacity in aquatic habitats (see Mt Milligan) and those in marine habitats (see Melford Terminal). Estimates of productive capacity in aquatic habitats in Canada were

quantitatively estimated through an objective approach such as HEP, or some other quantitative estimate outline in part 1 of this document. The opposite was true for marine studies in Canada, in which habitat productive capacity was often estimated as the value of the areal extent of a qualitative habitat type (such as eelgrass habitat). Several explanations may exist for this disparity, however none were found in the literature. To speculate, one possibility is that because many of the protocols for quantitatively estimating productive capacity were developed in aquatic systems in Canada, there is a bias, toward aquatic researchers, in exposure to the techniques in the literature. The second possibility is that because marine systems are much less finite relative to aquatic habitats, there is a general sentiment that quantitative models developed in aquatic systems cannot be used in marine system. That said, this pattern did not hold in the United States, where marine studies documented in this review utilized quantitative analyses of habitat. Nevertheless, the roll of quantitative estimates of productive capacity in marine systems in Canada is uncertain and warrants further evaluation.

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5.0 CONCLUSION

This document provides a review of the rational and methods used to estimate productive capacity for habitat compensation. It explores recent development projects in Canada as well as in the US that utilize these methods and models for quantifying habitats.

The Habitat Evaluation Procedure developed by the USFWS (1980) was the most commonly used model. The straightforward implementation and longevity are likely explanations for the relative success of this model. This model been adapted several times in the Canadian literature and thus has served as a template for many of the newer models that incorporate uncertainty, habitat modification and other cumulative effects.

This review illuminates the disparity between aquatic and marine projects. There are noticeably fewer marine projects in Canada that quantitatively estimate productive capacity relative to aquatic projects. Although, no explanation for this disparity was found in the literature, we predict that because the development of these methods was largely aquatic, their usage is skewed toward aquatic studies. More importantly, the use of more qualitative methods in marine projects did not noticeably adversely affect the federal approval rate of these projects, suggesting that the existing methods for estimating productive capacity in marine systems in Canada may be sufficient. Alternatively, the quantitative rigor used in marine projects in the US suggests that a quantitative approach could be used in Canada. Further research on the extent of application of quantitative methods for estimating marine productive capacity in Canada may be required to more accurately describe this observation.

The DFO framework has historically fostered a subjective and accommodative approach to the estimation of productive capacity (Minns 2003). Although efforts to obtain a more objective and standardized method for estimating productive capacity are increasing, there is no single standardized method for the quantitative estimation of productive capacity of fish habitats in Canada. Future practical efforts to develop the appropriate definition of productive capacity can utilize methods and models like those described in this review as a template.

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TABLES

Table 1 Useful Definitions

Term	Definition
Productive Capacity	Maximum natural capability of habitats to produce healthy fish, safe for human consumption, or to support or produce aquatic organisms on which fish depend
Habitat (fish)	Spawning grounds and nursery, rearing, food supply, migration areas on which fish depend directly or indirectly in order to carry out their life processes.
Productivity	Maximum survival rate of a species at low population densities.
Habitat Capacity	Total density of a species that can be supported by the resources found within a habitat.
Population	A group of individuals in one species that live in a particular geographic area.
Biomass	Weight of organic matter comprising a group of organisms in a particular habitat.
Habitat Compensation	The replacement of natural habitat, increase in the productivity of existing habitat or maintenance of production by artificial means in circumstances dictated by social and economic conditions after development.
Habitat Banking	The replacement of natural habitat, or maintenance of production by artificial means in circumstances dictated by social and economic conditions in anticipation of expected adverse impacts.
HADD	Habitat Alteration Disruptive Destruction

Note: The sources for definitions were as follows (DFO Policy on the Management of Fish Habitat 2010; Biology 5th edition, Campbell Reece and Mitchell)

Table 2 Methods and Models for Estimating Productive Capacity

Method/Model	Reference
Habitat Suitability Index	USFWS 1980, Minns et al. 2001, Bradbury et al. 1999
Habitat Productivity Index	Randall and Minns 2000
Habitat Utilization Index	McCarthy et al. 2008
Biomass Size Distribution	DeLeeuw et al. 2003
Index of Biotic Integrity	Karr et. al 1986
Habitat Evaluation Procedure	USFWS 1980, Bradbury 2001
Defensible Methods	Minns 1997, Minns et al. 2001
Habitat Equivalency Analysis	NOAA 1995, NOAA 1999
Bioenergetic Models	de Kerckhove 2008
Trophic Models	de Kerckhove 2008

Table 3 Recent Development Projects

Project	Year	Nature of Project	Country	HADD or Habitat Area	Habitat	Impact	Productivity Measurement	Habitat Quantification Model	Project Status
Mt. Milligan Copper-Gold Project	2009	Mining: Copper	Canada	15.982ha aquatic	Aquatic Rainbow Trout	-Fish Habitat: Rainbow Trout, Slimy Sculpin, Bull Trout, Arctic Grayling	Literature Based HSI	-Habitat Evaluation Procedure (HEP) -Habitat Suitability Index (HSI) Habitat Units (HU)	Yes
Melford International Terminal Inc.	2008	Infrastructure: Shipping Terminal Expansion	Canada	28.557ha marine 7.576ha aquatic	Marine intertidal Subtidal/ Aquatic	-Fish Habitat: , American Lobster Aquatic Stream	Fisheries Landing Data Lobster	-m^2 /kilometers -Scaled by inferred productivity of habitat type by suggested factor.	Yes

Churchill River Power Project	2008	Infrastructure: Hydroelectric	Canada	~18,000 ha terrestrial/ aquatic	Aquatic	-Fish Habitat: Multiple Species	Catch Per Unit Effort (CPUE) Catch Based Utilization Index (CUI) Literature Based Utilization Index (LIU)	Guild Based Habitat Utilization Indices (HUI) Habitat Units (HU) Based On Habitat Evaluation Procedure (HEP)	IP
Romaine River Hydroelectric	2006	Infrastructure: Hydroelectric	Canada	27,300 ha terrestrial/ aquatic	River	-Fish Habitat	Catch Per Unit Effort (CPUE) Biomass Per Unit Effort (BPUE)	Weighted Production Index (WPI) Defensible Methods Corrected for changes in temperature	?
Voisey Bay	2005	Mining and Infrastructure	Canada	2.2 ha marine 5 ha Aquatic	Marine, Aquatic	-Fish Habitat	Marine = m^2 Aquatic = Habitat Suitability Index (HSI)	Habitat Evaluation Procedure	Yes

Keltic Petrochemicals Inc.	2005-2007	Liquefied Natural Gas Facility, Marine Terminal	Canada	21 ha Marine	Marine	-Fish Habitat	Fisheries Landing Data for impacted habitat (kg)	Area	Yes
Diavik	1999	Diamond Mine	Canada	Mine Footprint 900 ha	Aquatic: Lake	-Fish Habitat	Literature Based HSI	Habitat Evaluation Procedure (HEP)	Yes
Lower Bois D'Arc Reservoir Texas USA	2008	Reservoir Construction	United States	6907 ha total forest, grassland	Forrest, Riparian, River	Removal of habitat for birds, mammals, reptiles and tree species via flooding	Species Counts Per Unit Habitat Sampling Site	-Habitat Evaluation Procedure (HEP) -Habitat Suitability Index (HSI) -Habitat utilization index (HU)	Yes
Miami Harbor	2010	Port Development	United States	3.7 ha Marine	Limestone Reef	Removal of Marine Habitat	?	Habitat Equivalency Analysis	Yes

Craney Island	2010	Infilling	United States	234 ha Marine	Barren	Removal of Marine Habitat	Biomass (g dry weight). Productivity Count. Invertebrate Microzooplankton Habitat Productivity Index (HPI)	Habitat Equivalency Analysis (HEA)	Yes

Note: This table describes recent development projects in Canada and the US that quantify habitat or estimate habitat productive capacity specifically. In the project status column, yes = project has been approved and is finished or ongoing, IP = project approval is in progress, No = project has not been approved and ? = no information available on the status of the project.

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Appendix C - Direct and indirect estimates of the productive capacity of fish habitat under Canada's Policy for the Management of Fish Habitat: where have we been, where are we now, and where are we going?

PERSPECTIVE / PERSPECTIVE

Direct and indirect estimates of the productive capacity of fish habitat under Canada's Policy for the Management of Fish Habitat: where have we been, where are we now, and where are we going?

Charles K. Minns, Robert G. Randall, Karen E. Smokorowski, Keith D. Clarke, Antonio Vélez-Espino, Robert S. Gregory, Simon Courtenay, and Patrice LeBlanc

Abstract: No net loss of productive capacity (PC) of fish habitat has been the central concept guiding Canadian fish habitat management policy since 1986. The purpose of this paper is to describe the concept of PC, to review the history and application of the fish habitat management policy in Canada, and to provide a critical review of the range of potential approaches to estimating PC. The approaches were grouped by their central focus: habitat, individual, population, and community–ecosystem. A set of case studies is used to illustrate the use of some approaches drawn from freshwater and marine contexts. Ten components to assessing no net loss of PC were developed and used in the review of approaches for evaluating potential limitations. The review also highlighted the likely future direction of method development, with increasing emphasis on dynamic models integrating population responses to habitat supply characteristics. More work needs to be done to turn research-based metrics of PC into practical operational management assessment tools and to better quantify the link between habitat structure and function and fisheries productivity. The evolving approaches to measure PC reinforce the ties that fish habitat management has to the emerging practices in ecosystem-based management.

Résumé : La prévention de la perte nette de la capacité de production de l'habitat des poissons constitue le concept central qui régit la politique canadienne de gestion des habitats de poissons depuis 1986. L'objectif de notre travail est de décrire le concept de la capacité de production, de récapituler l'histoire et l'application de la gestion des habitats de poissons au Canada et présenter une revue critique de la gamme des approches potentielles pour estimer la capacité de production. Ces approches ont été regroupées en fonction de leur cible principale, soit l'habitat, l'individu, la population et la communauté et l'écosystème. Nous présentons une série d'études de cas pour illustrer l'utilisation de quelques approches tirées des contextes marins et d'eau douce. Nous mettons au point dix composantes pour évaluer la prévention de la perte nette de la capacité de production et les utilisons dans notre revue des approches pour évaluer les limitations potentielles. Notre revue souligne aussi la direction future vraisemblable de la mise au point de méthodes, avec une emphase croissance sur les modè-

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les dynamiques qui intègrent les réactions des populations aux caractéristiques des apports des habitats. Il est nécessaire de faire plus de travail pour traduire les métriques de la capacité de production basées sur la recherche en outils d'exécution pratiques d'évaluation de la gestion et pour mieux mesurer le lien entre la structure et le fonctionnement des habitats et la productivité des pêches. Les approches en cours pour mesurer la capacité de production renforcent les liens qui existent entre la gestion des habitats des poissons et les pratiques émergentes dans la gestion basée sur les écosystèmes.

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Introduction

Canada's freshwater and marine fish species and fish habitats have a vital role in the economic prosperity of Canada, the biological diversity of Canada, and the lives of Canadians. They provide an important source of food and enjoyment, contributing many jobs and ~$12 billion to the economy (www.dfo-mpo.gc.ca/stats/FastFacts_09-eng.pdf). They provide food and a living for aboriginal peoples and are a critical part of their culture. They play an important role in the economy, life, and well-being of rural, coastal, and northern communities. They are a primary feature of the biological diversity, integrity, health, and productivity of aquatic ecosystems and represent a powerful symbol and strong indicator of the quality of Canada's natural environment. However, they are under significant pressure from unprecedented increases in the diversity and intensity of uses (Chu et al. 2003), while public concerns and scrutiny are escalating in parallel (Schindler 2001). Thus, how fragmentation and losses of fish habitat are managed in Canada and, in particular, how science-based evidence and methods are used to guide development decisions affecting fish habitat are important questions.

The purpose here is to provide a review of potential approaches to the measurement of productive capacity (PC), which is a central concept in fish habitat management in Canada. For context, we begin with an overview of fish habitat management in Canada and of definitions of PC and related concepts. Next, we present an extensive review of potential measures of PC, recognizing that in most habitat management contexts, direct measurement of PC is not feasible and that surrogate indicators, both partial and complete, will have a central role. Then we use some case studies to expose some of the challenges faced when trying to apply these approaches.

Fish habitat management in Canada

Under Canada's *Constitution Act* (1982), the federal government is assigned legislative responsibilities for "sea-coast and inland fisheries," whereby Canada's Parliament establishes laws for the conservation and protection of its fisheries resources, inclusive of fish habitats. Fisheries and Oceans Canada (DFO) is responsible for the administration of the *Fisheries Act* (FA), the *Oceans Act* (OA), and the aquatic species part of the *Species at Risk Act* (SARA). Canada's *Fisheries Act* of 1868 established the legal framework governing sea coast and inland fisheries. The FA also includes authorities for regulating a variety of impacts to fishes and fish habitat known as the "habitat protection and pollution prevention" provisions. Environment Canada (EC) has the delegated responsibility for the administration of Section 36 of the FA for regulating water pollution through a 1985 Memorandum of Understanding (MOU). Provinces, through delegation of inland fisheries and constitutional responsibilities for the management of natural resources, deliver a range of programs related to the management of freshwaters complementing those of the federal government for the management of fish habitat. The key habitat protection and pollution prevention provisions in the FA are Section 32, which prohibits destruction of fish by other means than fishing, Section 35, which prohibits harmful alteration, disruption, or destruction (HADD) of fish habitat, and Section 36, which prohibits the deposit of deleterious substances in water frequented by fishes (for more details, see www.dfo-mpo.gc.ca/habitat). DFO conducts environmental assessments (EAs) under the *Canadian Environmental Assessment Act* (CEAA) or other EA processes in the North, meets requirements under the SARA and duty for Aboriginal consultations prior to making regulatory decisions under the FA, and coordinates with EC on delivery of the pollution prevention provisions of the FA. As a result, many consider the FA to be one of the strongest environmental laws in Canada.

In 1986, DFO introduced the Policy for the Management of Fish Habitat (Fisheries and Oceans Canada (DFO) 1986) as a comprehensive framework for the administration of the habitat protection and pollution prevention provisions of the FA. The policy includes (*i*) an objective, net gain of PC of fish habitat, (*ii*) three goals, conservation, restoration, and development of fish habitat, and (*iii*) a guiding principle, no net loss (NNL) of PC of fish habitat, to support the conservation goal. The policy also includes (*i*) procedures for applying the NNL principle, (*ii*) a framework on integrated planning for habitat management, and (*iii*) eight implementation strategies.

DFO's Habitat Management Program (HMP) administers the habitat protection provisions using policy tools, including the risk management framework, habitat compensation (replacement of natural habitat) guidelines, operational statements, and procedural protocols (Goodchild 2004). In practice, HMP reviews development proposals referred (referrals) to DFO to determine if they will result in adverse impacts to fishes and fish habitat, negotiates to avoid any adverse impacts, or considers authorizations under the FA. Where an authorization is issued, it negotiates a compensation plan designed to offset the loss of fish habitat and to monitor its implementation. Reviewing referrals, habitat management staff apply a risk management framework (RMF) with three components: (*i*) aquatic effects assessment to identify the potential effects to fishes and fish habitat using pathways of effects (PoE) diagrams (www.dfo-mpo.gc.ca/habitat/what-quoi/2-evalh-eng.htm); (*ii*) risk assessment to determine the level of risk posed by residual effects; and (*iii*) risk management in which risk level (low, medium, high) is characterized and guides practitioners to tools that can be used to best manage the risk.

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DFO receives and reviews numerous FA referrals and CEAA environmental screenings each year. All these fish habitat management activities must be supported by science-based concepts and techniques that address the measurement of PC and how it responds to habitat changes.

Productive capacity and related concepts in fisheries science

The concept of PC is central to DFO's fish habitat management activities and is defined as "the maximum natural capability of habitats to produce healthy fish, safe for human consumption, or to support or produce aquatic organisms upon which fish depend" (DFO 1986). PC is part of a growing lexicon of concepts that are the currency of modern attempts at ecosystem-based management, including habitats, physical and chemical processes, biodiversity, and productivity of the species and communities (Gavaris 2009). Fish production is usually defined as the product of average biomass and specific growth rate ($kg \cdot ha^{-1} \cdot year^{-1}$) (Randall and Minns 2000; Randall 2003), and for a defined area of habitat, PC is "the sum of all production accrued by all stock during the time they spend any part of their life history in that area" (Minns 1997, p. 2464).

In fisheries science, PC is tied to the concept of maximum sustained yield (MSY) as the yield taken at the maximum rate of production (Rosenberg et al. 1993; Randall 2003), although various risk factors have largely rendered MSY unsuitable for regulating exploitation of fisheries resources (Larkin 1996). A related natural resource management term, carrying capacity (CC), defined as the equilibrium maximum abundance of a population in the absence of exploitation, has also been greatly criticised (Sayre 2008). For fisheries scientists, these key terms (PC, CC, and MSY) are more familiarly linked via the terms in simple population growth and stock biomass models long used in fisheries (e.g., Kashiwai 1995; Williams 1999; Quinn and Collie 2005). In the simplest models, MSY is a function of maximum instantaneous growth rate and the equilibrium unexploited biomass, or CC. Thus PC, which is tied to the quality and quantity of suitable habitats, fits easily within the main body of fisheries science (Randall 2003). The scientific foundations of PC are sound, making it suitable as a basis for assessing potential fisheries value of habitats.

Since the introduction of the Policy for the Management of Fish Habitat in Canada (DFO 1986), considerable scientific research effort has been devoted to rendering the concept of PC in quantitative tools and methodologies to apply the principle of NNL of PC. By definition, net change of PC should be assessed in units of production (mass per area per time). However, the knowledge gained in ecosystem science in recent decades has made it clear that PC must also take account of the many structural (e.g., biodiversity and habitat) and functional (e.g., energy and material flows) ecosystem features essential for sustained natural productivity. Many surrogate and partial measures of PC fall short of the ideal but nonetheless have contributed to the evolution of a scientific framework for the implementation of DFO's Policy for the Management of Fish Habitat (DFO 1986). Indeed, most fish habitat management in Canada is based on the use of PC purely as an abstract implicit concept and not a concrete measurable quantity.

Our purpose here is to review and evaluate progress in fish habitat science as indicated by the development of pieces of science that are gradually advancing the potential to shift the role of PC from the abstract to the concrete. Approaches for measuring PC and for assessing net change of PC are examined in a series of categories beginning with those relying almost entirely on measurements of habitat characteristics, through those linking habitat features with individual, population, and community–ecosystem fish characteristics. Case studies are presented to illustrate the main features of several approaches. Trends, degree of progress, and emerging directions of the science are appraised and suggestions for future priorities are identified. The potential for using PC and NNL as central features in ecosystem-based management of fish habitats is examined.

To provide context and a point of reference for this review, 10 key components for assessing NNL of PC were identified (Table 1). Components 1–3 establish the frames of reference for an assessment, along with the relative values assigned to various fish components and the areas of habitats by type. Components 4–6 are where measurements and units are specified and applied to estimate productivity capacity, albeit in a surrogate form in many approaches. Components 7–8 are where alternate development configurations are considered to minimize or avoid a loss, with attention to uncertainties, risks, and timing (Minns and Moore 2003; Minns 2006). Components 9–10 allow for the potential incompleteness of the net change assessment with regard to additional habitat and biotic cofactors beyond the physical aspects of fish habitats. For example, the abundant presence of a non-fish invasive species or persistent organic contamination of bottom substrates and the food web may preclude attainment of a preferred level of fish productivity.

Approaches

Measures of PC have been developed using a broad array of approaches. These approaches were classified into four groups: habitat, individual, population, and community–ecosystem. Within these groups, both assessment methods and models were examined. The potential role of methods involving lower trophic levels was not considered, although many methodologies do use non-fish biota as a basis for evaluating the status of aquatic habitat with composition and abundance data (Barbour et al. 1995; Niemi and McDonald 2004; Bonada et al. 2006) or with production data (Downing et al. 1990; Benke 1994; Grubaugh et al. 1997). The four groups of approaches were reviewed by addressing the following five key questions. (1) What was the method designed to do? (2) What are the assumptions and limitations? (3) What measurements are required? (4) How has the method been used in a habitat context? (5) Does the method produce an estimate of PC, or an acceptable surrogate thereof, or does it require additional data and calculations to complete the quantification? Much of the information was summarized in tables but discussion of key aspects, particularly assumptions and limitations, was provided in the text. This review of approaches focuses on components 4–6 of the assessment framework (Table 1).

Given the prior definitions of PC and the framework outlined, the four groups of approaches represent an upward pro-

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Table 1. Components of an assessment of no net loss of productive capacity (PC) of fish habitats.

Component	Description	Commentary
1. Frames of reference (fish and ecosystem)	Identification of the ecosystem, the habitats, and the fishes that will be assessed.	All native species present, or that might be expected to be present, in the ecosystem are to be the default reference point for an assessment. Non-native species can be included as appropriate.
2. Assignment of weights	Relative weights are assigned to all fish and life stages identified. The relative weights represent efforts by management agencies to balance among social, economic, and ecological factors. Specification of weights is a management responsibility.	Socioeconomic factors may include fishery preferences, species-at-risk, or exotic or invasive species, etc. Ecological factors may include rarity, relative contribution to productivity or biomass, trophic level, dietary contribution in prey, etc. For example, weights might be used to distinguish between native and non-native species, with the former being given higher weights.
3. Habitat mapping	Designation of identifiable habitat types and quantitative assessment of their extent by habitat type. Area is the usual basis for spatial assessment, although length or volume might be relevant in some instances.	Habitat types should be specified with regard to the requirements of all fishes, though schemes that lead to very large numbers of types can be difficult to assess.
4. PC metrics	PC metrics for habitat are specified on a relative scale (usually 0 to 1) for all fish elements with respect to all habitat types.	Suitabilities are the most commonly used metrics. The specification of suitability may be based on assessments of selection for, preference for, relative performance or fitness, or similar for fish elements.
5. PC units	The absolute PC units provide a means of scaling from relative productivities expressed in suitability values to some absolute measure of productivity (mass per area per unit time).	Production rate per unit area is the ideal choice but often cannot be estimated when some required PC metrics (growth rate, CPUE, presence or absence) are not available.
6. Computing PC supply	The sum over all fish elements and habitat types of the product of spatial extents (component 3) and PC metrics (component 4) and possibly with the absolute scalar (5) leads to a total PC supply with the weights applied (component 2).	Within an ecosystem, relative metrics (see component 4) will suffice. Absolute units (see component 5) may be needed to balance the consideration of all issues in a societal context. However, it should be noted that socioeconomic valuations of productivity must be based on the cost of developing and sustaining habitats that can supply the production and not the mere cost of stocking equivalent amounts of fish.
7. Net change assessments	Explicit comparison among alternate habitat configurations, one of which is a predevelopment baseline or reference scenario. Differences are estimates of net change.	Various scenarios can be examined as part of a design process leading to a preferred option that prevents a net loss or minimizes losses when unavoidable.
8. Uncertainty, risk, and timing	Explicit consideration of methodological incompleteness and the uncertainties and timing issues surrounding assessment of net change	Methodological completeness is balanced with the precautionary principle. Uncertainties (measurement error, spatial and temporal variability, specification errors, etc.) can affect the potential for discerning net change or the differences among alternate options (Minns 2006). Risks of success or failure vary. Timing issues such as when losses precede gains in a development affect net change, as does the temporal discount rate (Minns and Moore 2003)
9. Habitat cofactors	Habitat factors that were not captured in the basic mapping of physical habitat features.	Cofactors might include the hydrological and thermal regimes, climate variability and change, or levels of beneficial (nutrients) and detrimental (toxicants or contaminants) chemical attributes of habitat features. The spatial configuration and connectivity of habitat patches also needs to be considered.
10. Biotic cofactors	The lists of fish elements that make up the focus of an assessment may not fully take account of thresholds, interactions, and feedbacks operating among biota in the ecosystems.	Factors such as depensatory population growth thresholds, predator–prey or host–parasite interactions, indirect effects of fisheries harvests, etc., may shape responses to habitat changes beyond the immediate habitat impacts. Invasives species may constrain productivity

gression in which the level of attainment of the measurement of PC (question 5 above) depends on completeness and the extent of calibration and validation. The habitat- and individual-based methods can only represent components 4–6 in a relative manner, and then their use may only be based on broad inference unless specific calibration evidence is presented. The population- and community–ecosystem-based methods may also provide only a relative scaling of PC unless full production calculations are involved.

Habitat-based methods

Included in this group are methods that exclusively measure physical habitat properties of ecosystems and, less frequently, those that directly measure physical habitat features

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but then make assumptions or inferences about the biological use of those features to make quantitative assessments of the habitat change. Hence, these methods do not actually measure PC, although they are widely used as surrogates to guide fish habitat managers. Habitat-based methods can be classified into four subcategories: (*i*) hydrological methods; (*ii*) hydraulic rating curves; (*iii*) habitat simulation models; and (*iv*) defensible methods. Each category addresses different purposes, requires specific data, makes certain assumptions, and comes with its own limitations (Table 2).

Historically, all of these habitat-based methods have been used to some degree to assess impacts of human development on fish habitat in Canada. Measuring physical properties of systems is often easier and less expensive than quantifying attributes of fishes or a biological surrogate, particularly if the ultimate goal is to measure fish production. Hydrological and hydraulic rating methods are most frequently applied to calculate minimum flows (instream flow needs) for fluvial environments in the context of water abstractions or establishing minimum flows below dams or diversions. They are suitable for application when risk to fish habitat is considered low and a quick, but quantitative, desktop or minimal data requirement method is desired. Although hydrological (40%) and hydraulic rating (5%) methods collectively comprise 45% of environmental flow methods used in Canada, habitat simulation is also extensively used, making up an additional 45% of methodologies (Tharme 2003). Strictly speaking, hydrological and hydraulic rating methods are not suitable for assessing NNL as they involve no measure of biological change and, therefore, technically do not represent PC.

Habitat simulation models predict change in habitat availability resulting from incremental changes in flow, which are then linked to a composite habitat suitability index (HSI), based on habitat preferences for fish species of interest, to ultimately arrive at weighted useable areas (Ahmadi-Nedushan et al. 2006; de Kerckhove et al. 2008). Although habitat suitability models could be used to calculate NNL, their data-intensive nature means that they are more often applied in situations in which multistakeholder interests are considered and objectives are broader than simply achieving NNL (e.g., Katopodis 2003). Criticisms of HSI models focus on assumptions, specifically the assumed linear relationship between habitat area and population biomass, and that HSI curves are independent of flow conditions, both of which have been demonstrated to be false (Holm et al. 2001; Vilizzi et al. 2004). HSI transferability between locations has been questioned (Guay et al. 2003; Nykänen and Huusko 2004) but has also been shown to be regionally supported (e.g., Mäki-Petäys et al. 2002). Transferability is not an issue when HSIs are developed for the fishes in the system in question via direct measurement. Regardless, habitat simulation models continue to be used and improved for use in environmental flow assessments. Attempts at improvement include increasing the scale of habitat measurements to make them more relevant to management decisions (i.e., MesoHABitat SIMulation or MesoHABSIM; Parasiewicz 2001, 2007*a*, 2007*b*) and integrating dynamic ecological feedbacks (such as competition and food supply) into models (e.g., Anderson et al. 2006).

Defensible methods (Minns and Nairn 1999) is the only method in this category that was specifically created to provide a scientifically robust approach to the application of DFO's Policy for the Management of Fish Habitat (DFO 1986) and that is suitable for application to lacustrine environments. This approach assumes that there is a direct relationship between amounts of suitable habitat and PC. The conceptual approach of defensible methods is similar to habitat simulation models in that it assigns relative suitabilities to habitat and calculates useable areas as a basis for assessing change, but it is significantly different in that all fish species and life stages affected are taken into account and only parts of lake ecosystems can be assessed in isolation of the whole (Minns and Nairn 1999). The initial implementation of the approach was designed for application to Great Lakes nearshore habitat. To facilitate its use by the HMP, a literature-based database of fish species by life stage habitat requirements was compiled (Lane et al. 1996*a*, 1996*b*, 1996*c*), and computer software was developed. Validation of field predictions is an important next step to increase confidence in the approach (Minns and Nairn 1999). Nonetheless, the correct application of defensible methods allows for the calculation of compensation habitat required to achieve NNL and for objective discussions with the proponent around a quantitative and consistent assessment of the impact of the proposed development. When the scale of the project warranted its application (e.g., Diavik diamond mine in the Northwest Territories), defensible methods has been successfully used by the HMP and, had it been applied more frequently, would have resulted in better achievement of NNL than traditional, less quantitative file reviews (MacNeil et al. 2008). Current efforts are underway to develop an application suitable for southern Ontario streams (realignments, crossing) and to compile a report documenting all the features of the software package that go beyond its current practical use and the regional habitat requirements databases available for regional application of the tool.

Individual metrics and vital rates

Individual fish measurements of habitat quality, including body size, individual growth, condition, fitness, health, and behaviour (Minns et al. 1996*a*; Pearson et al. 2005) (Table 3), provide a key part of the information needed to calculate PC and might be used as surrogate indicators. Fitness combines two metrics as it is a function of both growth potential and mortality risk (Rosenfeld and Boss 2001; Railsback et al. 2003; Rosenfeld and Taylor 2009). The vital rates of population growth, survival, and reproduction are also discussed in this section as individual measures of habitat quality, to provide a transition from individual to population approaches, and also to emphasize the constraints and limitations of interpreting individual measures by themselves as scalars of habitat quality and quantity. Constraints and limitations are discussed in the context of (*i*) interdependence and interaction among measures, (*ii*) methods, and (*iii*) future application as defensible measures of habitat quality.

Individual metrics are sometimes overlooked as measures of PC because managers often focus on population or community metrics (Pearson et al. 2005). Individual metrics were included in a review of methods for measuring PC in Canada, but usually as subcomponents of habitat- or population-based models (Smokorowski and Derbowka 2008). Metrics of fish health (parasites, tumours, disease, morphology, physiology)

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Table 2. Habitat-based methods of assessing productive capacity (PC).

Method (examples)	Purpose	Data Needs	Assumptions and (or) limitations	References
Hydrological method (e.g., Tennant, median monthly flow — Q50, 7Q10)	• Based on flow data only • Designed to be a simple desktop exercise without the need for rigorous field data collections	• Uses some percentage of historical flows (or predictions of MAF based on catchment characteristics) or rules from flow duration curves	• Relies on assumptions between flow and habitat and usually is not calibrated to the watershed in question	Tennant 1976; Caissie and El-Jabi 1995
Hydraulic rating curves (e.g., wetted perimeter, transect method)	• Correlation between hydraulic parameters and physical habitat features at specific transects across a river	• Vary but can include wetted perimeter, water surface width, velocity, depth, cross-sectional area, and substrate size	• Direct measurement of systems avoids many assumptions • Simple data to collect but lacks the link to biological attributes and results in a single recommended flow value	O'Shea 1995; Reinfelds et al. 2004; Kilgour et al. 2005
Habitat simulation models (e.g., IFIM, PHABSIM, River 2D, MesoHABSIM)	• Specific habitat features are the focus (e.g., depth, substrate, velocity, cover) and are simulated at different flows to give WUA for species of interest	• Similar to hydraulic rating but at more transects to cover a broader area of river • MesoHABSIM uses larger scale habitat features (riffle, run pool, etc.) under multiple flow conditions • All require a component of biological knowledge of habitat use by animals preferably calibrated to the watershed in question	• Biggest criticism is the weakness of habitat suitability curves relating standing crop to habitat features and the transferability of habitat suitability curves across systems	Stalnaker et al. 1995; Parasiewicz 2001, 2007*a*, 2007*b*; Katopodis 2003; Parasiewicz and Walker 2007
Defensible methods (e.g., HAAT)	• To develop an equation that can calculate the net change in PC of habitat affected by human developments	• Area affected by development (pre- and post-development, including any compensation habitat) • PC of the habitat before and after development • Potential maximum PC of the lost habitat	• Estimates of habitat value often dependent on expert panels or habitat surrogates • Assumes a fixed value of habitat for each species and life stage and does not take adaptability into account • Requires a large amount of information to validate	Minns 1997; Minns and Nairn 1999; Minns et al. 2001

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Table 3. Individual-based metrics for estimating or inferring productive capacity.

Metric	Purpose	Data needs	Assumptions and (or) limitations	References
Body size	• Use of fish body size as an indicator of habitat type	• Habitat-dependent body size	• Link between body size and population vital rates	Schlosser 1990; Harvey and Stewart 1991; Crozier et al. 2010
Condition	• Use of condition factor as an indicator of habitat quality	• Estimates of condition and accepted reference	• Usually used as a measure of fish nutrition status • Assumes link between condition and population vital rates • Highly variability	Copeland et al. 2008; also see references for the health metric
Health	• Use of fish health as an indicator of environmental quality	• Indicators and quantification of fish health	• Used as a tool for measuring water or environmental quality rather than habitat quality	Munkittrick and Dixon 1989; Adams et al. 1993
Behaviour or movement	• Use of localized fish movement as an indicator of habitat quality	• Movement observations by habitat type also should have individual growth and (or) survival observations	• Assumes movement benefits vital rates • Tools and methods are often species- or habitat-dependent and expensive	Bélanger and Rodríquez 2002; McMahon and Matter 2006; Dolinsek et al. 2007
Growth	• Use of fish growth rate as an indicator of habitat quality	• Direct growth observations by habitat type and (or) bioenergetic model	• Assumes direct link between habitat quality and growth, but interacting factors may be confounding	Jones and Tonn 2004; Gilliers et al. 2006; Amara et al. 2009; Rosenfeld and Taylor 2009; Crozier et al. 2010
Survival	• Use of habitat-dependent survival rate as an indicator of habitat quality	• Direct survival estimates by habitat type	• Must distinguish between emigration and mortality	Gorman et al. 2009; Laurel et al. 2003
Fitness	• See survival and growth purposes	• Growth and survival estimates by habitat type	• Statistical method to combine the above estimates to measure fitness	Railsback et al. 2003; Rosenfeld 2003; Harvey et al. 2005
Reproduction	• Recruitment success as an index of habitat quality	• Direct recruitment estimates by habitat type	• Recruitment is a limiting factor to population production • Long-term and spatially extensive data are needed	Knapp et al. 1998; Baglinière et al. 2005; Johnson 2007

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and condition factor, in conjunction with population indicators, have been used to assess water quality and other environmental factors or stressors (e.g., mine waste, pulp mill effluents, reservoir management) (e.g., Munkittrick and Dixon 1989; Goede and Barton 1990; Adams et al. 1993) rather than to assess habitat quality per se. Fish body size has important fitness consequences (Crozier et al. 2010) and has been related to habitats at both landscape (Schlosser 1990) and site scales (Harvey and Stewart 1991; Heggenes et al. 2002) but is most effective as a measure of habitat condition if used together with other individual and population indicators (Crozier et al. 2010). Pearson et al. (2005) recommended the use of individual-based biotic variables in habitat assessments for two reasons: (*i*) differences in body size, condition, and behaviour are very sensitive indicators of environmental change and provide insight into mechanistic links between habitat and fishes; and (*ii*) individual metrics have high statistical power compared with population measures (Osenberg et al. 1994).

Directed fish movements are a behavioural response of individual fish to gradients in habitat quality to seek cover (survival), efficient foraging (growth), or successful reproduction (Lomnicki 1988; Sutherland 1996; McMahon and Matter 2006). Because of these functional links to habitat, localized movements have been proposed as a preferred measure of habitat quality over traditional density–quality relationships for stream salmonids (Bélanger and Rodríquez 2002). Hayes et al. (2009, p. 296) using five case studies from the Great Lakes concluded that there is a "paucity of field-based data directly relating birth, death, and movement rates to habitat conditions experienced by individual fish". Historically, studies of fish movement in the field were time consuming and species- and habitat-dependent, limiting their application as a tool for habitat management, but recent technological advances (e.g., telemetry, video, acoustics) have increased the range of techniques available, allowing biologists to better track spatial behaviour and to determine habitat preference more broadly (Lucas and Baras 2000; Spedicato et al. 2005).

Growth, survival, and recruitment are the key components of population production, and each of these vital rates varies with habitat heterogeneity and quality. Examples of research on habitat-dependent vital rates include growth (Jones and Tonn 2004; Rosenfeld and Taylor 2009; Crozier et al. 2010), survival (Laurel et al. 2003; Gorman et al. 2009), fitness (Railsback et al. 2003; Rosenfeld 2003), and reproductive success (Knapp et al. 1998; Pihl et al. 2005; Johnson 2007) (Table 3). A common constraint with using these metrics individually in a PC context is that they are not independent. To be defensible indices of habitat quality, it is necessary to investigate the vital rates collectively, to better understand interactions, and to link the individual metrics to net effects on populations (Railsback et al. 2003; Harvey et al. 2005; McMahon and Matter 2006). Vital rates are best explored collectively using process-oriented habitat–population models (Hayes et al. 2009), as discussed under the model section.

Individual metrics are included, explicitly or implicitly, in PoE diagrams (noted earlier) that link in-water activities to habitat change and subsequently to population effects. An example is potential impacts to movements, recruitment, and growth of migratory trout caused by stream crossings (Jones et al. 1996). The PoE diagrams are used by habitat managers and proponents to assist in identifying mitigation actions needed to avoid the negative impacts to individual metrics. Validation of the flow management pathway included the science review of many of the individual metrics discussed in this section (Table 3), as well as the interactions among metrics (Clarke et al. 2008).

For the PoE process, the default but reasonable assumption is that potential negative effects on individual metrics are undesirable. Limitations and uncertainty associated with using individual metrics for measuring PC could be overcome by developing peer-reviewed guidelines and by undertaking meta-analysis of the science literature (e.g., see Smokorowski and Pratt (2007) and Jensen et al. (2009)). Synthesis of information on relationships between individual metrics and fish habitat to obtain general science-based rules can be used as surrogates for component 4 (assigning suitabilities) within the NNL assessment framework (Table 1) as done using growth potential by Jones et al. (2003).

Population-based approaches

Population-based methods traditionally have been used to measure fish responses to habitat changes. Population-based methods vary from simple to complex: relative or absolute abundance (catch per unit effort, density, biomass); population structure; production rate; stock–recruitment relationships; and more recently, habitat–population models (Table 4). The extent to which population approaches fulfil the conditions laid out for complete NNL assessments (Table 1) depends on whether abundance measures like catch-per-unit-effect are used alone or in combination with vital rates to estimate production rates. Abundance methods mainly represent partial or surrogate indicators, whereas rate-adjusted methods are likely to be more complete, although production calculations may not be an explicit output of the method.

Historically, in Canada and elsewhere, population responses to habitat manipulations were often not assessed (Smokorowski et al. 1998; Quigley and Harper 2006). If assessments were done, the frequency of use of the different methods decreased with complexity: abundance (biomass) was measured often (Quigley and Harper 2006), and production rarely (Smokorowski et al. 1998). Population–habitat models were introduced relatively recently, and their use is increasing, particularly for quantifying habitat needs for recovery of species at risk (e.g., DFO 2007*b*). This brief critique of the application of population methods in Canada (i.e., assessing NNL) indicates that the assumptions (and uncertainty) decrease, but the data and knowledge needs increase with method complexity.

For quantifying habitat quality for species at risk, if ecological gradients of habitat use and habitat features are known through surveys, generalized linear models (GLMs) or generalized additive models (GAMs) can be used to fit data on species abundance to habitat features (DFO 2007*b*). GLMs assume the habitat–abundance relationships are linear (or are transformable to linear) over a range of habitat features and are statistically slightly more powerful than GAMs. Detecting discernible ecological gradients of habitat use from empirical data assumes that there are gradients in PC.

Measuring response of fish abundance to habitat alteration to assess NNL assumes a direct link between abundance and habitat quality (fitness), an assumption that is often not tested

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Table 4. Population-based assessment methods and models for measuring productive capacity.

Methods	Purpose	Data needs	Assumptions and (or) limitations	References
Abundance (CPUE, density, biomass); GLMs; GAMs	• Traditional measure of population response	• Relative (CPUE) or absolute abundance (density) by habitat category	• Link between abundance and population production is inferred • Abundance is habitat-limited • Abundance is related to habitat quality and function: food supply, refugia, reproduction, movement • High variance in abundance data limits statistical precision	Smokorowski et al. 1998; Minns et al. 1996*a*; Clarke and Scruton 2002; Quigley and Harper 2006; DFO 2007*b*
Population structure (age, body size, growth, production/biomass (*P*/*B*))	• Biological indices or surrogates of production as an intermediate measure between abundance and production	• Seasonal mean biomass and *P*/*B* • Body size, age structure, and seasonal growth	• Site data reflect population structure • Population structure is habitat-dependent • Production can be compartmentized by habitat type • Static data are used to make inferences regarding dynamic process	Minns et al. 1996*b*; Randall and Minns 2000; Jones et al. 2003; Pratt 2004; Cote 2007
Production ($g \cdot m^{-2} \cdot year^{-1}$)	• Fish production is the measure of habitat capacity implied by habitat policy • Measure link between habitat and productivity	• Recruitment, seasonal abundance and survival, biomass, and growth by life stage	• Survey areas are representative of habitat and ecosystem • Requires large field effort • Used for stock assessment but rarely for habitat assessment	Hunt 1974; Smokorowski et al. 1998
Stock–recruitment (*S*–*R*) models, including stage-structured models	• Identify population carrying capacity • Evaluation of habitat effects on population status	• Long-term data sets (>10 years) • Spawning stock size and recruitment abundance • Habitat-associated survival	• Recruitment is determined by numbers of spawners and habitat supply • Requires long-term monitoring of fish response to habitat restoration to validate models	Sharma and Hilborn 2001; Gibson 2006; Lobón-Cerviá 2007; Moussalli and Hilborn 1986; Scheuerell et al. 2006; Honea et al. 2009
Stage-structured, habitat supply models	• Quantify habitat needs for recovery of species and habitat management	• Quantitative links between habitat and vital rates for life stages	• Do not deal with habitat quantity and quality simultaneously	Minns et al. 1996*b*, 1999*a*; Minns 2003; Vélez-Espino and Koops 2009a
Statistical models	• Link population characteristics to multiple habitat features	• Statistical links are established using complex techniques such as MLR and ANN	• Often difficult to determine which inputs are most influential	Fausch et al. 1988; Laë et al. 1999; Lek et al. 1996
Individual-based models	• Model population response to habitat conditions	• Vital rates linked to environmental conditions, fish transport, and movement behaviour	• Paucity of field-based data relating birth, death, and movement rates to habitat conditions at fine temporal and spatial scales • Large data needs	Tyler and Rose 1994; Rose 2000; Hayes et al. 2009

Note: Data needs and complexity increase from top to bottom.

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or is shown to be invalid if tested (Van Horne 1983; Rose 2000; Railsback et al. 2003). In their review, for example, Clarke and Scruton (2002) cited studies showing an increase in salmonid density or biomass in habitats in which compensation efforts were applied to offset losses elsewhere but were uncertain if this reflected increased production or fish redistribution. Uncertainty of a direct link between fish abundance and habitat quality is a major weakness. Aside from precision issues (high variance; Minns et al. 1996*a*; Quigley and Harper 2006), there are several reasons why fish abundance and habitat quality may not be correlated (Rose 2000; Railsback et al. 2003). Three factors are mentioned here to demonstrate that the confounding factors are both directly or indirectly related to habitat: (*i*) nonlinear and nonproportional responses to complex spatial heterogeneity in habitat (Rose 2000; DFO 2004); (*ii*) population responses are affected by fish community interactions (Rose 2000; Railsback et al. 2003); and (*iii*) cumulative effects of multiple stressors, both habitat and nonhabitat related, can mask direct links between habitat quality and fish abundance (Rose 2000; Harvey and Railsback 2007).

Measuring abundance responses to habitat alteration requires knowledge of the production mechanisms that determine the key fitness elements of habitat — reproduction, growth, and survival. For an artificial stream in the Canadian Arctic, PC was assessed by comparing growth, biomass, and movements of Arctic grayling (*Thymallus arcticus*) at an artificial and reference stream (Jones et al. 2003). For example, adult grayling successfully moved through the artificial channel, spawned, and produced fry, but growth rate and biomass of fry in the artificial stream were lower than those found in the reference stream because nursery habitat was deficient (reduced habitat complexity, food supply, temperature). This mechanistic approach to assessment revealed both positive and negative population effects and was instructive for planning and advancing future compensation measures.

More complex population methods utilize size structure information of fishes to make inferences about production to biomass ratios (*P*/*B*) and productivity (Randall and Minns 2002; Pratt 2004; Cote 2007). Assumptions related to abundance apply to these biological indices of production as well. Because of the cost and data requirements, estimates of production rate continue to be used more often for fisheries than habitat management.

Stock–recruitment (*S–R*) relationships quantify area-based survival, and with sufficient time series of data, population productivity can be estimated, providing information to habitat managers on regional and site-specific factors affecting carrying capacity (Sharma and Hilborn 2001; see Gibson (2006) and Parken et al. (2006) for Canadian examples). *S–R* data usually involve large spatial-scale analysis (ecosystems). A multistage *S–R* model (Moussalli and Hilborn 1986) was used to measure habitat effects on the status of *Oncorhynchus* spp. (Sharma and Hilborn 2001; Scheuerell et al. 2006; Honea et al. 2009) by explicitly linking survivorship between different life stages to location and specific habitat parameters (e.g., fine sediment, temperature, habitat structure, pools, gradient). Using a different approach, Lobón-Cerviá (2007) used *S–R* data at a site rather than a river scale to show the importance of site depth and discharge on the survivorship of brown trout (*Salmo trutta)*. Significantly, *S–R* models traditionally used for fisheries assessment at an ecosystem scale are now being used to quantify habitat–population linkages at regional and site scales. *S–R* data and production estimates have rarely been used for habitat management in Canada, but their use will likely increase in the future (Randall 2003).

Population-based methods for assessing PC are useful in ecosystems dominated by one or a few species (e.g., salmonids), but community-based approaches are more often used in species-rich areas of Canada such as the Laurentian Great Lakes basin (Randall and Minns 2002). More sophisticated habitat–population models, recently used for the management of endangered species, are discussed in the section on habitat–population and ecosystem models.

Habitat–population models linking population traits to habitat

The strength of mechanistic habitat–population models is that they consider causal relationships between changes in habitat and gain or loss in fish production (de Kerckhove et al. 2008). Two categories of models merge habitat-explicit information and population dynamics at different levels of information: (*i*) unstructured population models focusing on a specific life stage or aggregating individuals from all stages regardless of their habitat preferences; and (*ii*) structured population models explicitly dividing the life cycle into life stages (Table 4).

Examples of the first category are the habitat suitability index and *S–R* models, both described briefly in previous sections. Also included are multiple linear regression (MLR) models (Fausch et al. 1988) and artificial neural networks (ANN) (Laë et al. 1999) used to predict fish production (Table 4). The advantage of ANN over MLR models is the ability of ANN to assess nonlinear relationships. Multiple linear regression and ANN have been combined to develop stochastic models of fish production using habitat features on a microhabitat scale (Lek et al. 1996).

The second category of models requires accommodating ontogenetic shifts in vital rates (e.g., growth, survival, fecundity) and habitat requirements. Spatial distribution and connectivity among habitats used by different life stages can represent important modelling features (Schindler and Scheuerell 2002). Two modelling approaches fall within this category (Table 4): (*i*) stage-structured matrix models that consider all individuals within a stage identical; and (*ii*) individual-based models that explicitly incorporate individual differences in behaviour and response to habitat conditions (e.g., Humston et al. 2004). Some advantages attributed to individual-based models such as the ability to explicitly incorporate spatial distribution and heterogeneity can be achieved at the population level with multisite matrix models (Caswell 2001; Morris and Doak 2002) through the incorporation of spatially explicit dynamics and (or) vital rate variation within life stages (Vélez-Espino and Koops 2009*a*).

Structured habitat–population models have been used to develop management strategies for recovery of endangered species. The most common limitation of structured population models is that they focus on a particular vital rate or life stage (Brandt and Kirsch 1993; Mason et al. 1995) and cope with changes in either habitat quality or quantity. Merging the combined effects of changes in quantity and quality of habitat on PC should be considered. Habitat–population mod-

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els require both habitat preferences of all life stages and functional relationships between habitat variables and vital rates (Cowan et al. 2000; Hayes et al. 2009). Important improvements could be achieved by focusing on those functional relationships with the greatest contributions to population performance (Vélez-Espino and Koops 2009*b*). It is important to distinguish between evaluations of "essential fish habitat", based on the analysis of population responses to changes in vital rates, assuming no habitat constraints (e.g., Levin and Stunz 2005), and "limiting habitat," which is the stage-specific habitat most sensitive to management interventions and the demographic sensitivities of the vital rates of life stages using that habitat (Vélez-Espino and Koops 2009*b*).

Habitat supply models (Minns et al. 1996*b*, 1999*a*; Minns 2003), which are based on the assumption that stage-specific survival decreases in proportion to the ratio between habitat supply and habitat requirements below a threshold, identified as the critical area, have been used to measure the effect of habitat loss on population growth (Vélez-Espino and Koops 2009*b*). Although individual-based models appear to be the best approach to model population responses to habitat conditions (Hayes et al. 2009), the paucity of information at fine scales for important habitat variables (Hayes et al. 2009) favours the use of methods explicitly separating life stages but demanding less information. Nonetheless, any type of habitat–population model still requires a known or assumed functional relationship between some habitat component (biotic or abiotic) and population attributes (e.g., Hayes et al. 1996; Rodwell et al. 2003; Eby et al. 2005).

Future application of habitat–population models to estimate no net loss

Balancing the efficacy with the feasibility of measuring PC may require a combination of approaches to guide habitat management under the NNL principle. Given the trade-off between the level of assessment of PC, quality of data, and number of assumptions of habitat–population models, it may be appropriate to follow a holistic approach in which insights gained from an aggregated model encompassing the entire community or fish assemblage (discussed in next section) can be corroborated or complemented with a structured model (category 2 above) of an indicator species. Indicators can be represented by strongly interactive species, which at low abundances can trigger ecological cascades of degradation and species loss (Soulé et al. 2005), which would also be highly relevant from a diversity standpoint. For those cases with access to rich biological and ecological information, including knowledge of spatial and temporal variation, an individual-based model should be favoured. Otherwise, a single-site or multisite matrix model could be used to assess PC at the population level.

For habitat–population models, it is a challenge to determine the true nature of the relationships (linear or nonlinear) between habitat quantity or quality and population vital and movement rates, which could strongly influence predictions of PC (e.g., Rodwell et al. 2003). In addition, because area–abundance curves change with habitat carrying capacity, the integration of habitat quality and quantity in a single analysis must address density-dependent processes (e.g., Englert et al. 2000). One effective way of incorporating habitat suitability information into density-dependent models is through the use of software programs (e.g., RAMAS GIS/Metapop, RAMAS Ecological Software, Setauket, New York) linking map overlays with metapopulation dynamics (e.g., Root 1998). Moreover, cumulative effects of multiple stressors of habitat quality could be incorporated for projections of PC. This is important because synergistic effects can be missed by short-term studies focusing on individual habitat variables (Rose 2000) and because aquatic habitats are subject to cumulative impacts from diffuse activities (Schlosser 1991). Finally, source–sink dynamics and connectivity should be understood and assessed to guide the placement and creation of new habitat or the protection of specific areas (Crowder et al. 2000) within the framework of NNL.

Community- and ecosystem-based approaches

By definition, PC is a habitat characteristic that is measured, directly or by surrogate, as fish production. Early attempts to provide an operational definition emphasized that the concept of PC implicitly included biodiversity (Jones et al. 1996). Fish community changes resulting from habitat alteration are likely a more sensitive indicator (Minns et al. 1996*a*) than changes in fish biomass and production. Minns et al. (1996*a*) listed five fish community measures that have been used to detect response to habitat changes: species richness; community biomass and productivity; composition (species, size, trophic); and interspecies distribution. Multimetric measures have also been used (Table 5). As with population approaches, the degree of compliance with the assessment requirements (Table 1) depends on the extent to which vital rates and abundance measures are used to estimate production rates. Nonproduction methods will provide surrogate indicators. Community- and ecosystem-based methods provide a greater potential to account for overall changes in PC.

For assessing the effectiveness of habitat compensation, Quigley and Harper (2006) measured both fish diversity and biomass as proxies of PC. Quigley and Harper (2006) and others (Minns et al. 1996*a*; Rose 2000) have emphasized that because of inherent ecosystem variability, differences in community measures between sites must be large to detect responses. Another constraint is that the efficacy of fishing gear is often habitat-dependent (Portt et al. 2006), and multiple gear types are needed to measure fish diversity in different habitats (Jackson and Harvey 1997).

To effectively measure PC, community-based approaches often go beyond measures of diversity. Minns et al. (1994) developed an index of biotic integrity (IBI) for littoral habitats, which utilizes data on fish trophic composition and abundance, as well as species diversity. IBI was originally developed and successfully applied to rivers (Karr 1991; Wang et al. 1997), and fish metrics have proven useful for measuring perturbations in other habitats such as estuaries (Deegan et al. 1997; Meng et al. 2002). Metrics for application of the IBI in both lakes and rivers are sometimes redundant (Minns et al. 1994; de Kerckhove et al. 2008) and may need site-specific modifications (Long and Walker 2005).

Randall and Minns (2000) developed a habitat productivity index (HPI), calculated as the sum of the average seasonal biomass times P/B for all species in a particular habitat. The HPI assumes that community production is positively correlated with community biomass and that community biomass

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Table 5. Community-based assessment methods and models for measuring productive capacity (PC).

Methods	Purpose	Data needs	Assumptions and (or) limitations	References
Biodiversity	• Measure habitat conservation	• Species richness and relative abundance	• Inherent ecosystem and habitat variability in community diversity • Multigear types needed for different habitats	Quigley and Harper 2006
IBI	• Measures ecosystem health based on four factors: habitat supply, water quality, exotic species, and piscivore abundance	• Fish assemblage measures of species richness and trophic composition	• Selection of metrics may be subjective • Not as useful in species-poor areas	Minns et al. 1994 Long and Walker 2005
Habitat productivity index (HPI)	• Designed as a field measure of PC	• Seasonal biomass and production/biomass (*P*/*B*), all species	• Assumes biomass summed for all species measures PC • Difficult to obtain quantitative data in all habitats • Factors other than habitat (e.g., exploitation) may affect biomass	Randall and Minns 2000, 2002
Multimetric ecosystem approach	• Measures ecosystem productivity	• Fishes, invertebrates, habitat	• High variability	Roth et al. 2007 Jones et al. 2008 Gavaris 2009
Fish assemblage models	• Usually used to assess marine protected areas	• Fish biomass (community) in protected area and at fishing grounds • Habitat quality in protected area • Habitat quality – mortality relationship	• Assumed habitat quality – mortality relationship • Uncertainty of habitat and density-dependent fish movement	Rodwell et al. 2003
MEI	• Estimate fish yield	• Lake morphology, TDS	• Limited to lentic systems	Ryder 1982
Mass–balance (EcoSpace)	• Compare management scenarios	• Biomass of functional groups, *P*/*B*, diet, spatial dynamics	• Uncertainty of seasonal changes and directed migration • Large data needs?	Walters et al. 1999
Multiple trophic level models	• Integrated production	• Biomass, *P*/*B*, diet	• Applied to coastal wetlands	French McCay and Rowe 2003

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is a function (and thus a measure) of habitat productivity. Both assumptions require further research for validation. For species-rich nearshore areas of the Great Lakes, Randall and Minns (2002) recommended a two-axis approach, using IBI and HPI simultaneously to measure the diversity and productivity components of PC, respectively. In addition to fish measurements, Quigley and Harper (2006) measured periphyton and invertebrate biomass and the density of riparian vegetation, using a multimetric ecosystem approach, for measuring PC. Jones et al. (2008) also used a multitrophic approach to measure compensation habitat in Canada's arctic. Roth et al. (2007) assessed the role of woody habitat, impacted by residential development, on fishes and food supply. Although effective, these multimetric approaches have rarely been used in Canada because of their high cost.

Multimetric, community approaches for measuring habitat capacity are consistent with the recent focus on the ecosystem in conservation ecology, both in Canada and internationally. Together with maintaining productivity and preserving biodiversity, protecting the habitat needed to sustain aquatic resources is one of the three key conservation principles used to manage in-water and land-based human activities that impact aquatic resources (Gavaris 2009). Although challenging, managing fish habitat as an ecosystem component is a critical priority in both freshwater and marine areas.

Community and ecosystem models

Ecosystem science has become the foundation for the integrated management of diverse human activities that are regularly undertaken in a common area (DFO 2007*a*). The use of ecosystem-based management (EBM) in Canada (e.g., Gavaris 2009) is consistent with global approaches (e.g., International Council for the Exploration of the Sea, European Commission) for managing habitat, fisheries, and endangered species. Ecosystem models used to assess changes in the PC of habitat have ranged from simple applications of the morphoedaphic index (Ryder 1982), through aggregate community models, to complex computer simulations of trophic flows among the functional groups of an ecosystem (e.g., Ecopath: www.ecopath.org) (Table 5).

The morphoedaphic index (MEI, total dissolved solids ($mg \cdot L^{-1}$) divided by mean depth (in metres)) has been used globally as a pragmatic estimator of fishing yield on the basis of constraints in productivity being determined by lake-basin morphometry and nutrient and energy availability (Ryder 1982; Jenkins and Oglesby1982). The MEI applies only to lentic systems and, in principle, can be applied to any set of freshwater (Ryder 1982) or saltwater (Khalil 1997) lakes or reservoirs within a region with relatively homogeneous climatic conditions. However, it has been demonstrated that MEI is more effective in natural lakes than in reservoirs given greater index variability in reservoirs during the first decades of impoundment (Jenkins and Oglesby 1982). Species interactions affect the efficiency of the MEI to assess productivity changes at the population level (Hubert and Guenther 1992), and therefore, MEI seems more appropriate as a productivity surrogate at the community level. Also, there are statistical problems with MEI as it employs ratios (Jackson et al. 1990). Other limnological indices used to assess aquatic productivity in lakes include shoreline development, primary production, and nutrient input (Downing et al. 1990; Khalil 1997; Hayes et al. 2009).

Aggregate community models usually rely on difference and steady-state equations and have been used to determine the importance of habitat quality and quantity for protected areas and marine reserves (Mangel 2000; Rodwell et al. 2003). As the definition of PC is the sum of the production rates for all cohabiting fish species within a defined area (Minns 1997), these aggregated models are relevant for measuring PC but were originally designed to explore different management scenarios (e.g., Rodwell et al. 2003). Data requirements of these aggregate models are difficult to meet. Assumed parameters, or borrowing data from other species, may lead to substantial model uncertainty (Hayes et al. 2009).

The use of dynamic simulation models of biomass fluxes' responses to ecosystem modifications (e.g., fishing, eutrophication) as tools to evaluate management scenarios has increased since the development of the model suite ECOPATH, ECOSIM, and ECOSPACE (Walters et al. 1999; Pitcher et al. 2002). ECOPATH is a mass-balanced model of an ecosystem's trophic flows that can be used to structure dynamic simulations using ECOSIM. Ecosystem attributes such as dispersal rates, foraging, and predator avoidance can be incorporated for a defined range of habitats through the use of ECOSPACE, which has been used to evaluate the interactions between policy scenarios, catch returns, and shifts in species compositions in marine protected areas (Pitcher et al. 2002). Although ecosystem projections using ECOSPACE have rarely been corroborated with actual data, comparisons among management scenarios could still be comprehensive enough to screen different policies (Walters et al. 1999). In addition, ecological uncertainty can be incorporated through Monte Carlo simulations of trophic biomass flows using another tool of the ECOPATH software called ECORANGER (Christensen and Pauly 1992).

Another ecosystem approach, involving multiple trophic level models, is the habitat equivalency analysis (HEA; Julius 1999) that converts losses of production of multiple species to an energetically equivalent single trophic level. HEA has been used to estimate the scale of habitat restoration required to compensate for losses of organisms at multiple trophic levels resulting from habitat degradation or destruction (French McCay and Rowe 2003). Thus, it is not difficult to see that this approach explicitly addresses concerns associated with NNL. The use of food-chain transfers to assess changes in PC dates back to the 1960s, building upon food chain energetics (Slobodkin 1960; Odum 1971), and frequently relies on energy transfer efficiency at lower trophic levels to infer productivity changes at higher trophic levels following trophic cascades (Hashimoto et al. 1997; Yee et al. 2007). Studies of lower trophic dynamics have also been used to determine relationships between species richness and productivity (Yee et al. 2007) and have been coupled with water quality models (Saito et al. 2001) and water circulation models (Polovina et al. 2008) to assess ecosystem effects of changes in habitat quality.

Case studies

River and streams

Habitat science has a long history within flowing waters

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(see Table 2). Hydrological methods, hydraulic rating curves, and habitat simulation models were derived from flowing systems and logically place an emphasis on the physical drivers of PC as rivers are defined by the physical aspects of their watersheds (Leopold et al. 1964; Hynes 1975; Vannote et al. 1980). Recently, in Canada, the impacts of proposed projects on fishes and fish habitat in a number of large rivers have been assessed under the FA. Three current examples give an overview of how PC is being assessed in these diverse situations: the Athabasca River, Churchill River, and Romaine River. We selected examples from large rivers (mean annual flow of about 300, 600, and 1700 $m^3 \cdot s^{-1}$ for Romaine, Athabasca, and Lower Churchill rivers, respectively) to demonstrate the challenges associated with large-scale assessments.

The Athabasca River in northern Alberta has recently been the subject of an extensive review related to water withdrawals associated with the oil and gas sector (Ohlson et al. 2010). Within this review, fish habitat considerations were analyzed by the instream flow incremental methodology (IFIM) process (Paul and Locke 2009). Local habitat use data for fishes was lacking, so habitat suitability curves were developed by expert opinion (see Paul and Locke 2009), augmented by local radiotelemetry investigations for a few species (Golder Associates Ltd. 2009). The IFIM process led to the evaluation of expected habitat loss for the species tested under various water withdrawal scenarios and identified two important areas for future research: (*i*) quantification of habitat–population links; and (*ii*) within Canada, the need for habitat research in the winter is paramount. Although these topics should be the subject of directed research, the Athabasca example provides an ideal scenario for an adaptive monitoring program to test predictions. However, in the context of the assessment of NNL of PC (Table 1), this process would score low on compliance given the focus on physical habitat change and assumed production–habitat relationships.

The lower section of the Churchill River in Labrador is currently under review in relation to a proposed project that would harness its remaining hydroelectric potential (Nalcor 2009). This project used a modification of the habitat evaluation procedure (U.S. Fish and Wildlife Service 1980, 1981) and an extensive fish capture database collected locally over an extended period of time (Ryan 1980; McCarthy et al. 2008) to generate life-stage-specific catch-based utilization indices (CUIs) (McCarthy et al. 2008). The resulting large number of CUIs, some of which still relied heavily on literature-derived information, were reduced to a manageable number by a guilding approach (McCarthy et al. 2008). These grouped CUIs could then be used to quantify the habitat proposed to be altered or destroyed by the project but could not make predictions in relation to future conditions as many of the locally derived habitat classifications would be changed after the project. Although using locally collected data reduced a number of uncertainties, many assumptions still had to be made, including uncertainties related to gear selectivity, habitat characterization, and temporal considerations, as all fish captures occurred under ice-free conditions.

A new hydro development (1550 MW capacity) is proposed for the Romaine River located on the north shore of the St. Lawrence River, Quebec. The proposal involves the construction of four dams that will transform two-thirds of the 300 km river into reservoirs. Anadromous Atlantic salmon utilize the lower 52 km of river, below an impassable natural waterfall. The PC of the river and proposed reservoir habitat were assessed using a biological (community-based) rather than a habitat-based approach (Bérubé et al. 2005; Smokorowski and Derbowka 2008), although the methods used to generate data did depend on habitat type: the main river, tributaries, lakes, and reservoirs (Smokorowski and Derbowka 2008). For all habitat types, fish production per unit area for each species was estimated using biomass density and body size as predictors and was scaled up as the product of unit area production and total surface area. Future PC of reservoirs was extrapolated from the current estimates of lake production, together with data from an existing Quebec reservoir, and scaling factors for projected reservoir surface areas. Methods for estimating fish density and production were based on a number of assumptions related to fish catches from different habitats (gear bias, catch efficiency, and others), and significantly, the estimates assumed a change in the fish community because of reservoir development (Smokorowski and Derbowka 2008).

Proposed approaches for assessing PC in the Romaine River are currently being reviewed. From a science perspective, the Romaine River case study is timely and important for two reasons: (*i*) as a test of the efficacy, limitations, and constraints of using a biological-based (production-based) approach; and (*ii*) the need for accepted science-based fish community targets to provide guidelines and context for predicting and modeling changes in fish production. Defining acceptable limits to changes in fish composition caused by large-scale changes in habitat (river to reservoir) is a key policy issue that applies not only to the Romaine, but also to many other watersheds undergoing development in Canada.

Lakes

Lake ecosystems provide a set of case studies to demonstrate the utility of habitat-based methods to measure PC. All of these examples would score relatively low on compliance as they rely heavily on literature-derived HSI and not any measure or index of biological production rate (Table 1). Results and application of habitat-based methods are initially discussed in the context of coastal areas of the Great Lakes and are then extended to inland lakes to contrast spatial scales.

MacNeil et al. (2008) analysed waterfront stabilization projects that altered fish habitat in the Great Lakes from 1997 to 2001. During this period, 53 projects that involved infilling (direct loss of habitat area ranging from 0 to 6000 m^2) were authorized under the FA (Section 35) (MacNeil et al. 2008). MacNeil et al. (2008) used the operational application of defensible methods, the habitat alteration assessment tool (HAAT), in retrospect to assess NNL of fish habitat for a subset of 18 infilling projects. The effect of infilling on fish habitat was represented by changes to suitable habitat supply for all fish species known to have access to the site, categorized by their thermal preference, feeding group, and life stage. By design, HAAT is based on seven components within the assessment framework outlined in Table 1. Significantly, the case study analyses showed that despite compensation and attempts to offset losses through enhancement of modified areas, most projects resulted in a net loss

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of habitat PC. The analysis of infilling in the Great Lakes demonstrated the importance of using quantitative habitat inventories, suitability indices, and a science-based model (e.g., HAAT) to assess PC, to guide future mitigation, and to determine the quantity and quality of habitat needed for compensation. Although impacts were inferred from literature-derived HSI curves, scoring low on our compliance framework, this example demonstrates the importance of using an objective, quantitative approach to achieve even assumed NNL and improve application of the precautionary principle in light of uncertainty.

Fish habitat classification models were developed for Severn Sound (Georgian Bay) and Bay of Quinte (Lake Ontario) to help guide the management of fish habitat in these degraded areas (Minns et al. 1999*b*, 2006). Habitat inventories were assembled in a geographic information system (GIS) database, and suitability values for all habitats were developed, providing a relative measure of PC. The resulting habitat classification maps aided in identifying and protecting high suitability habitat and targeted restoration at low suitability areas, thereby, demonstrating the efficacy of fish habitat management plans (DFO 1986) as a tool for managing habitat at a regional scale.

For inland lakes, HAAT was used to predict the effects of habitat alteration on fish populations (Frezza and Minns 2002). Littoral habitat diversity was decreased (experiment manipulation) in three small (<25 ha) Canadian Shield lakes by removing coarse woody material (CWM) from 50% of the nearshore area (Kelso et al. 2001; Smokorowski et al. 2006). Additionally, in one of the lakes, a portion of the substrate was covered with geotextile. The HAAT analysis indicated that despite the experimental alterations, only minor changes in habitat supply (weighted suitable area) were expected to occur. However, there were limitations in applying the HAAT model to small shield lakes (CWM was considered to be poorly represented in the assessment framework; Frezza and Minns 2002). Also, the magnitude of the response depended on the spatial scale; the physical habitat manipulations were spatially limited at both the whole lake and littoral zone scale. Preliminary BACI (before–after control–impact) analysis of field studies of potential impacts to fishes or their food supply failed to show significant responses (Smokorowski et al. 2004, 2006).

Coastal marine areas

Construction activities in marine coastal areas (e.g., wharves, breakwaters, and similar facilities) are undertaken to improve access to nearby marine resources and sea lanes and to protect industrial and personal property onshore. Habitat quality of coastal fishes is altered both during and following construction of coastal structures (e.g., Sanger et al. 2004*a*, 2004*b*). Despite the need for scientifically defensible approaches, empirical studies of the ecological impacts of wharfs and breakwaters have been few and limited in scope. Here we review three ongoing studies on the east and west coasts of Canada, focusing on three topics: (*i*) succession of biota on introduced rocky structures; (*ii*) scientifically defensible decisions; and (*iii*) effect of footprint size.

In 2008, DFO and academic scientists were asked to provide advice on the productivity of breakwaters relative to natural rocky coasts in the southern Gulf of St. Lawrence. Well-established breakwaters (>15 years old) of similar construction (large boulders) to natural rocky shores are being compared with those younger in age. It is anticipated that biota found on breakwaters will be a function of the characteristics of the structure (e.g., material, size, shape, aspect with respect to shore) and how long the structure had been in place.

Estimating scientifically defensible gains and losses due to construction despite high background variability is a challenge. Vertical structures with associated rugosity are often productive and are considered desirable features of the coastal environment (e.g., Gregory and Anderson 1997) due to introduced edge effects (e.g., Sargent et al. 2006). However, the extent to which wharves and breakwaters self-compensate is rarely quantified. Scientists in Newfoundland are addressing this knowledge deficiency via a 10-year study (2007–2016) of a total of 18 sites (12 wharf–breakwater and six control locations) to quantify the habitat and fish productivity. Using a randomized intervention analysis (RIA) technique, this study will empirically quantify changes in habitat, fishes, and epibenthic macroinvertebrates associated with the wharves and breakwaters, providing proponents with analytical tools necessary to evaluate potential effects of other such developments and assisting habitat managers by guiding their mitigation and compensation decisions.

The scale of potential impact of wharves and breakwaters is broad, ranging from a few square metres to many kilometres, introducing a significant question: Are large developments merely linearly scaled versions of smaller ones or do they require a qualitatively different approach to compensation and mitigation? In British Columbia, responses to wharf and breakwater alterations are being measured through estimates of biotic community composition (taxa counts), ecological structure (functional grouping and biomass), species diversity, and physical and chemical alterations to address this question. The marine studies briefly described in this section represent three of the first quantitative evaluations testing and challenging the assumption that introduced rocky substrate and other wharf and breakwater developments have negative impacts compared with the unaltered habitats, status quo, and should be minimized. All approaches being used are measuring aspects of biological productivity and, if applied correctly, should be able to assess NNL following all required assessment components (Table 1).

Discussion

The broad question raised in the title of this paper is addressed by discussing a series of subquestions.

What role has productive capacity had in past fish habitat management decision-making?

Although much improvement in methods for assessing PC has occurred since 1986, application of these methods remains limited in the HMP (Minns 2001; Harper and Quigley 2005; Quigley and Harper 2006). DFO makes limited use of science-based quantitative assessment methods (Cudmore-Vokey et al. 2000; Lange et al. 2000). This outcome is due, in part, to the lack of generalization of results and simplification of data needs to facilitate applications (Cudmore-Vokey et al. 2000). Most of the methodologies reviewed here were not specifically framed as estimates or surrogates of PC and

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very few directly address the assessment of NNL of PC. Most operational applications have used relative suitability methods. HMP decision-making with regard to NNL is often nonquantitative. Such decision-making is not reproducible, transparent, or amenable to consistency when delivered across the country. Furthermore, many of the streamlining improvements in program delivery (PoE, integrated risk assessment) have neglected to address the likelihood that cumulative net loss is still facilitated by the many referrals judged to have low or no risk.

What progress has been made with productive capacity methodologies?

This review demonstrated considerable progress in the development of scientific methods of estimating PC since the Canadian policy for fish habitat management was put in place (DFO 1986). Science has progressed from simplistic to ecologically sophisticated concepts, from static to dynamic evaluation, and from partial to complete surrogates of PC but has yet to bring forward a common basis for estimating PC in all habitat management contexts. The progress demonstrated that as with fisheries management and species-at-risk assessments, the use of mathematical models is inescapable in fish habitat management; though it may be feasible given adequate time and resources to estimate PC at a proposed development site, a model still has to be used to predict change after development by which net change can be assessed. Given the limited time and resource available for assessment typical of development activities driven by socioeconomic pressures, the baseline evaluation of sites is often incomplete.

The progression of methods reviewed represents a continuum of completeness with respect to estimating PC. Complete estimation of ecosystem productivity and how it responds to dynamic change comes closest to providing an assessment of the maximum productive potential, whereas commonly used approaches such as individual performance metrics (e.g., growth) or catch-per-unit-effort represent partial methods of estimating PC. Given the necessary socioeconomic constraints on predevelopment assessment for all but the largest development projects, fish habitat management decision-making must rely on simple approaches that keep the assessment costs at acceptable levels relative to the value assigned to the development's purpose. This situation requires (*i*) that the simple surrogate models of PC be well supported by scientific evidence, and (*ii*) that the precautionary principle (Hornbaker and Cullen 2003) be firmly applied in inverse proportion to the completeness of the methods and, hence, directly in proportion to the uncertainty associated with incompleteness. When proposing particular approaches to assessing net change, practitioners need to clearly state the incompleteness and uncertainties of the approach: the greater the limitations, the greater the need for caution, hence the need for compensation ratios greater than 1:1 when using the simplest methods to assess net change of PC.

Despite this flourishing of possible approaches to assessing PC, there is relatively little evidence of their widespread application in habitat management decision-making. The simpler approaches such as instream flow analysis and variants of the defensible methods model based on the U.S. Fish and Wildlife Service HSI suitability models are the most used and, frequently, only for larger projects. In-house documentation of these applications is limited, and relatively little evidence of their application is presented in the primary literature. Suitability assessment models are popular with proponents of developments and their consultants (C.K. Minns, personal observation), but often their applications are flawed. The methods reviewed above are often not framed specifically as practical tools for fish habitat management, making it difficult for front-line management staff to adopt or recommend them. A key conclusion is that scientists need to make greater efforts to render the results of their studies in the form of operational models and practitioners need to be encouraged to make greater use of these models.

What do the case studies reveal about fish habitat management?

Most of the case studies reviewed were large scale with respect to either the size of ecosystem or the number of sites being considered together. Most were also the subject of research efforts, either large-scale comparative studies or whole-system experiments. The large scale is characteristic of the application of scientific methodology requiring time, many replicate sites (both control and impacted), and the active involvement of researchers. These are features beyond consideration for practitioners looking at single-development projects. Many of the case studies are ongoing and the results have yet to appear in the primary literature. Small-scale single-site studies rarely appear in the primary literature, although the published literature on cumulative meta-analytic studies of various aspects of habitat modification based, in part, on such small-scale studies is increasing.

Most case studies involve the extensive application of simpler surrogate measures of PC. As a result, little evidence is being accumulated about the complex dynamic ecosystem processes occurring when habitats are changed. Such ecosystem studies, however, often provide the strongest evidence of how the whole ecosystem responds to habitat changes (cf. Minns et al. 1996*a*) and not just the user-preferred fish stocks.

The best opportunity to conduct case studies are real-world development projects, although there can be many challenges with regard to study design: insufficient sample numbers, predevelopment time, adequate controls, etc. Monitoring programs are often specified in HADD authorizations under the FA, but the monitoring designs are typically insufficient to detect significant effects (Bradford et al. 2005). New ways should be sought to gather useful evidence from the many developments that go ahead every year (i.e., effectiveness monitoring).

What is productive capacity?

The review of methodologies and case studies reveals the incompleteness of most of the attempts to measure PC, raising again the question perennially asked since the release of Canada's fish habitat policy, "What is productive capacity?" That this question is still asked may explain the slow uptake of PC methodologies by practitioners.

The conventional scientific history of the term recounted above does not show the complete story. Adding on the diverse views expressed by habitat management practitioners, proponents of development projects and their consultants, environmental protection advocates, fishers of all kinds, and the

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general public, a spectrum of four definitions of PC emerge: (*i*) the sustainable harvest of preferred fishery species that can be practically achieved from the fish habitat; (*ii*) the sustainable total production of all fish species that can be practically realized from the fish habitat; (*iii*) the sustainable maximum production of all fish species that might be realized, without fetter or constraint, from the supporting habitat (ecosystem); and (*iv*) the sustainable maximum natural production of all biota that might be channelled into fish production, without fetter or constraint, from the supporting habitat (ecosystem).

The original Policy for the Management of Fish Habitat (DFO 1986) definition did not include any quantitative operationally defined terms, and hence, the meaning has remained somewhat dependent on the value systems of the beholders. Hence, the spectrum of opinions matches that of the wider philosophical debates about the protection, use, and domination of nature. However, the original definition clearly excludes the first two definitions, given that maximum potential productivity is the target based in the character of the habitat and not the fishes themselves. These definitions are all incomplete with respect to consideration of species or biodiversity questions and (or) the completeness and resilience of ecosystem structures and processes tied to ecological goods and services potentially produced by the ecosystems as a result of the presence of fishes. Hence, in the current language of ecosystem science, the fourth definition might be considered the closest fit to the intentions of those who framed the habitat policy as it makes habitat central but may be harder to define operationally. Most fishery scientists will likely prefer the third definition as it centres on the fishes and closely matches conventional operational definitions of production such as quoted earlier here from Minns (1997). Most likely, the third most closely approximates the fourth.

Recognizing the broader meaning of PC imposes a need for more research to be directed to showing the relationship between the structure and function of aquatic ecosystems and their potential fisheries productivity. It also reinforces the idea that fish habitat management has to become ecosystem-based management.

What is the connection between productive capacity and ecosystem-based management?

As approaches for assessing the PC of fish habitats have been evolving, so have the approaches to fisheries management. The need to consider the whole ecosystem, not just component parts, has gained greater recognition in recent decades. Although still strongly influenced by a long history of independent single-species assessment, fisheries are increasingly being managed with ecosystem-based approaches. Similar changes are beginning to be considered in fish habitat management and habitat science. For example, the availability of methods using lower trophic metrics is particularly evident in ongoing research, including coastal marine cases. In addition, the cumulative effects of multiple stressors (including, but beyond, habitat perturbations) are included in ecosystem assessment frameworks (Gavaris 2009). Of course, using ecosystem-based approaches will not be immediately feasible in many situations; therefore, the limitations of simpler, less complete methodologies need to be acknowledged when making decisions. A hierarchy of limitations is needed. For example, simple habitat-only methods cannot account for the biological feedbacks, interactions, and thresholds that are encountered in habitat–population or ecosystem methods and so assumptions should err in favour of avoiding net loss of PC.

Another consideration with ecosystem-based fish habitat management is the type of ecosystem approach being used. Like sustainable development, the phrase "ecosystem approach" has been co-opted for a wide range of methodologies, which may or may not involve science-based components. Unlike fisheries-focused approaches (Gavaris 2009), broad-based approaches often lack operationally defined metrics (Fitzsimmons 1996; Link 2002) and any bounding based on the biophysical constraints inherent in the ecosystem, e.g., maximum natural primary production rate and the portion that can be trophically transferred into fishable biomass (see, for example, Pauly and Christensen 1995).

Habitat management based on a broad scientific definition of PC should have a central role in ecosystem-based management, as the productive potential inherent in many habitat features are prerequisite for sustainable human use of aquatic resources, including fisheries. Although the science of fisheries management is highly evolved compared with those of habitat and ecosystem-based management, habitat science is still far ahead of ecosystem science as it is strongly embedded in fisheries science. The narrow focus on physical changes to habitats has undoubtedly restricted the growth of habitat science. Stressors such as climate change and lake acidification are considered beyond the scope of the habitat policy, although changes in habitat conditions due to such stressors can profoundly affect PC. Rather than replacing habitat management with loosely defined ecosystem-based management concepts, the various PC metrics reviewed here should be more widely applied to assessing NNL of PC in support of DFO's Policy for the Management of Fish Habitat (DFO 1986).

What are the essential elements for fish habitat management decision-making?

The comparative review of potential metrics and case studies indirectly helped highlight the features of a complete assessment of net change of PC. Complete assessments have an essential set of components (Table 1). The focus of habitat assessment of physical aspects of PC means that the fishes, their physical habitat requirements, and the availability of habitat constitute the primary essential components (1–6). The net change aspects of assessment are addressed in the comparison of scenarios and consideration of uncertainty and timing (7–8). Then, there are many abiotic and biotic factors (9–10) that may also influence or determine the outcome of physical habitat changes.

Many of the methodologies reviewed above contain some, but not all, of these essential features, although some components are often only implied. The limited attention given to the net change aspects of the Policy were reflected in the lack of effort applied to rendering research results as operational tools for practitioners. Simple methods usually lack features that are likely to further limit the amount of habitat that can be lost or modified before significant loss of PC occurs. The review of assessment approaches did indicate a

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progression towards explicit consideration of more of the essential features presented here. Eventually, methods should be developed that take full account of all identified essentials. In the meantime, there is a need to appreciate the risks associated with methods that include few essentials: the fewer features used in a particular method, the greater the need to apply the precautionary principle (Hornbaker and Cullen 2003).

What are the conclusions?

Six key conclusions of this review are as follows: (*i*) the scope of potential surrogate metrics of PC has been expanded in recent years; (*ii*) application of the surrogate PC metrics needs to be conditioned by their degree of completeness and their inversely related levels of uncertainty; (*iii*) research-based PC metrics need to be incorporated into practical operational management assessment tools; (*iv*) as a component of the assessment tools, effort is needed to better quantify and communicate the link between habitat suitability and absolute units of fish production; (*v*) testing the links between surrogate metrics and true PC needs to be thoroughly evaluated as it is the surrogates that will be used routinely; and (*vi*) larger-scale studies beyond the scope of individual development projects are needed to fully calibrate tools for operational use, possibly via regulator–industry partnerships.

What is the way forward?

The growth of methods for measuring PC has not been confined to the fish habitat management arena. Production (growth and reproduction rates to match or exceed mortality rates) is a defining feature of biological systems. PC and the role of habitat is a central consideration for understanding and managing species-at-risk, invasive species, conservation of biodiversity, fisheries, and ecosystems. The knowledge needed to advance tools for measuring PC for habitat management will benefit from the expanding but complementary science needed to address these current and emerging management issues. This perspective emphasizes that the way forward includes three key components: (*i*) strong communication between managers and scientists to better facilitate the application and validation of measures of PC; (*ii*) targeted work to continue to build on and address the six conclusions listed previously, with increasing emphasis on dynamic models that integrate population responses to habitat supply characteristics; and (*iii*) incorporation of knowledge and techniques relevant to habitat science from other emerging issues that affect the productivity and biodiversity of aquatic habitat and ecosystems. Recently, DFO has moved towards addressing these components by creating two centers of expertise relevant to habitat science and management: (*i*) the Center of Expertise for Aquatic Habitat Research (CAHR); and (*ii*) the Center of Expertise on Hydropower Impacts on Fish and Fish Habitat (CHIF). Both of these virtual centers include a network of scientists, academics, and sector partners (i.e., industry) to promote fish habitat science efforts across Canada, ultimately to understand PC linkages and facilitate the efficient and sustainable use of Canada's natural resources within regulatory frameworks. DFO has further expanded its ability to achieve research objectives by partnering with the Natural Sciences and Engineering Research Council of Canada's HydroNet, a national research network to promote sustainable hydropower and healthy aquatic ecosystems. The network goals are to develop new knowledge and new tools to assess, minimize, and mitigate the effects of hydropower on fishes and their habitats, improve the decision-making process associated with hydropower operations, and reduce conflict among stakeholders. Together, these initiatives should continue to advance fish habitat science and its functional application in the decision-making process.

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Appendix D - Summary of PC Methods Selection Exercise

The selection of appropriate methodologies for assessing PC at Roberts Bank involved a structured selection process utilizing a set of nine selection criteria developed by PC TAG members. This document provides a summary of the structured assessment methodology results, which included a review of the short-listed methodologies, HSI, IBI, and EwE, and a scoring exercise to select the most appropriate method.

Review of HSI approach:

Laura White of Hemmera presented the application of HSI to Dungeness crab; the TAG discussed strengths and weaknesses with respect to the selection criteria defined in TAG meetings #2 and #3. Key points of discussion:

- The HSI approach provides an understandable summary of what happens to a species or guild, by presenting summary information in understandable units (hectares) and by presenting the results spatially;
- TAG members noted that some regulators (i.e. DFO) may be familiar with the HSI approach and are for the most part comfortable with its use;
- Provides good information about species specific changes, and trade-offs among species;
- Provides no real summary of "net" effects on productive capacity (aggregated across species); some TAG members questioned the importance or relevance of a statement about "net" effect and suggested what matters to regulators is understanding key trade-offs – who are the winners and losers;
- With respect to uncertainty, TAG members suggest that sensitivity/scenario analyses are more valuable than statistical analyses (geometric mean etc.); they also suggest that an important consideration is the extent to which predicted results can be validated post implementation; HSI can be validated.

Review of ecosystem approach: Ecopath with Ecoism

Villy Christensen presented an overview of the Ecopath with Ecosim (EwE) model and its application to RBT2 project. The TAG discussed strengths and weaknesses with respect to the selection criteria. Key points of discussion:

- TAG members generally like the ecosystem approach;
- They clarified the treatment of migratory species (i.e. that are transient, move in/out of the Roberts Bank system); there may be advantages to EwE relative to HSI for the treatment of migratory species;
- They clarified the use of the model at other sites similar to Roberts Bank;
- They discussed the use of EwE for assessing the benefits of off-site offset areas (e.g., an offset located in Howe Sound);
- They noted the similarity of data requirements for HSI and EwE; since data collection is more expensive than analysis, and the data requirements are very similar for both, they noted the possibility of using both HSI and EwE to assess Productive Capacity and compare the results from the two methods;

- TAG members noted that EwE is readily understandable to scientists, but is complex and may be more difficult for regulators to understand. However, regulators often consult with outside expertise in such situations and this expertise is available locally.

Review of IBI approach:

Carson Keever presented an application of IBI to the Roberts Bank Terminal 2 project. The TAG discussed strengths and weaknesses with respect to the selection criteria. Key points of discussion:

- TAG members liked the approach conceptually as it provides an integrative approach and addresses community structure;
- TAG members noted that while IBI is commonly used in estuarine environments, it is typically used to compare sites; it is not typically used in predictive applications (e.g., EA) and the project team found no precedence for its use in assessing productive capacity in impact assessment;
- Parameter selection is subjective and open to criticism;
- Regulators are familiar with IBI, but it is not clear whether they will support its use in this application given lack of precedence.

Methods Evaluation:

TAG members participated in an exercise to score the shortlisted methods against nine selection criteria (using a 5-point scale), and rank the methods in terms of preference for use for assessing PC at Roberts Bank. The selection criteria are summarized as follows:

Table 1. Criteria for the selection of a Productive Capacity Assessment methodology

CRITERIA	DESCRIPTION
Applicable to Roberts Bank system	Is the method applicable to the Roberts Bank system (marine, estuarine), and is it able to address the species/habitats of concern?
Scientifically defensible	Is the method scientifically defensible and peer reviewed?
Practical	Is the method practical in terms of input data requirements (e.g. timelines, cost and technical feasibility)?
Understandable	Can the method produce summary statements that are understandable for the regulatory review process?
Describes net changes	Can the method describe expected net changes in PC? In other words, can it aggregate across species groups to produce a summary statement about overall change in net productivity?
Describes key trade-offs	Can the method describe key trade-offs among individual components of PC? In other words, can it ensure that gains and losses across species or species groups are transparent?
Incorporate uncertainty	Can the method estimate or characterize uncertainty and the range of possible outcomes given uncertainty?
Applicable to mitigation and offsetting	Can the method produce results that inform the evaluation of mitigation, compensation and banking options?
Robust to regulatory changes	Is the method robust to changes in the regulatory review process?

The questionnaire completed by participants, including instructions for scoring the alternatives, can be found at the end of this document. The exercise was designed for iterative implementation; Part A (Scoring and Initial Direct Ranking) was completed. Part B (Criteria Weighting and Final Direct Ranking), intended for use only if initial deliberations did not lead to a consensus opinion, was not needed.

Results of the scoring exercise are listed below. Figures 1, 2, and 3 show the scores assigned by the participants for each method (HSI, IBI, and EwE) on each criterion. These results provided a basis for discussion whereby differences in experts' scores for each criterion could be compared. TAG members discussed their initial scores, focusing in particular on reasons for outlier scores. TAG members were offered an opportunity to modify their scores after discussion. The only changes made were for one TAG member who accidentally entered scores for IBI in the EwE column, and vice-versa. Otherwise the TAG members were comfortable with their scores.

Group average scores for each of the three methods were then calculated, and are shown in Figure 4. The group agreed that the average scores are a good representation of the relative performance of the three methods. Table 1 shows the same results from Figure 4 but in tabular form with color coding, facilitating the comparison of averages between methods for each of the scoring criteria. Average scores in BLUE represent the method used as the basis for comparison (EwE), WHITE scores are not significantly different from the basis (< 10% difference), while scores in GREEN represent better performance than the basis method for the given criteria, and scores in RED represent lower performance than the basis method. The results show that EwE outperforms HSI on all criteria except "understandability" and "practicality", both of which were discussed in detail with key points of discussion noted in the sections above. Insights from discussion included clarification of definition/interpretation of some of the criterion, and sharing of perceptions and judgments about the performance of each method, which led to learning and deeper understanding of the trade-offs between the methods.

While considering overall performance for the three assessment methods, TAG members also ranked each method from first to third, in order of preference. Table 2 (Direct Ranking) shows that EwE is the highest ranking method, with HSI second, and IBI in third for all five participants.

Final consensus conclusion of the TAG:

EwE is the preferred method and is endorsed as a conceptually sound approach to assessing changes in PC at Roberts Bank as a result of the implementation of RBT2.

HSI is considered acceptable. If detailed evaluation of EwE proves it to be impractical with respect to timelines or budgets, HSI could be accepted.

IBI is viewed as less applicable method for this application. The lack of a precedent (has not been used in this manner) suggests that it would be questionable with respect to defensibility.

One key disadvantage of HSI is that it would be difficult to assess "net" effects on productive capacity (aggregated across species), whereas EwE enables assessment both of net effects and trade-offs between effects on different species

Figure 1. HSI Scores

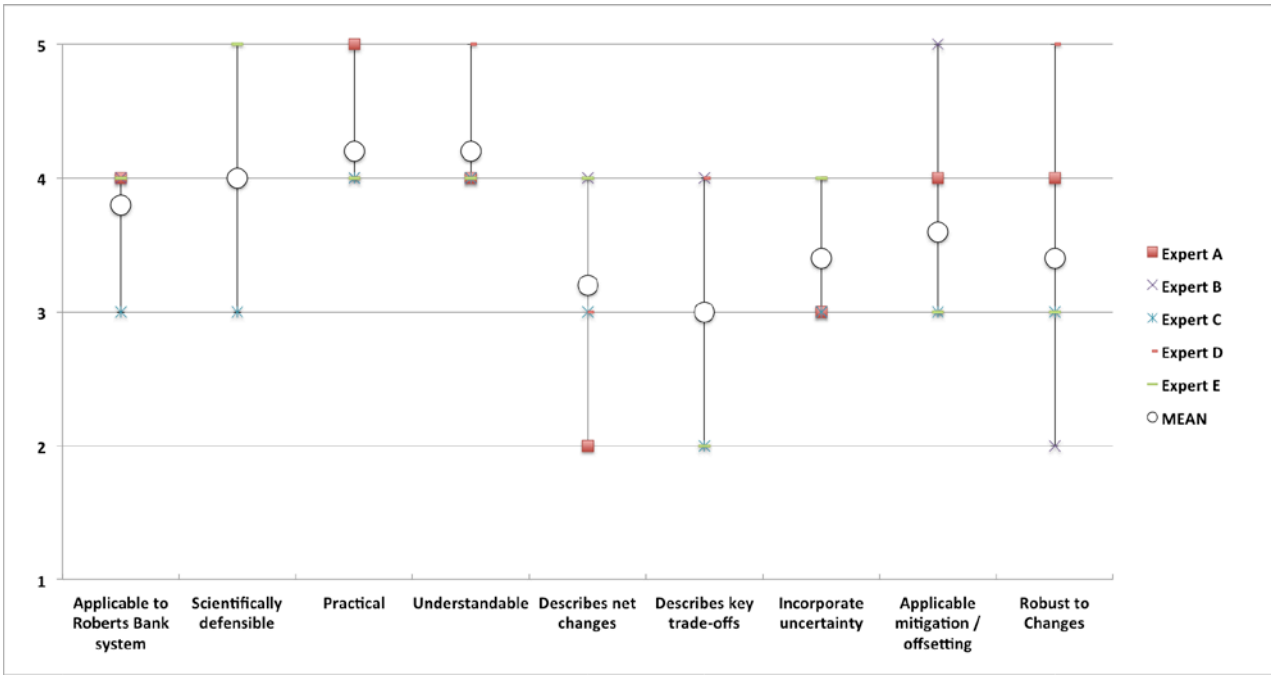

Figure 2. IBI Scores

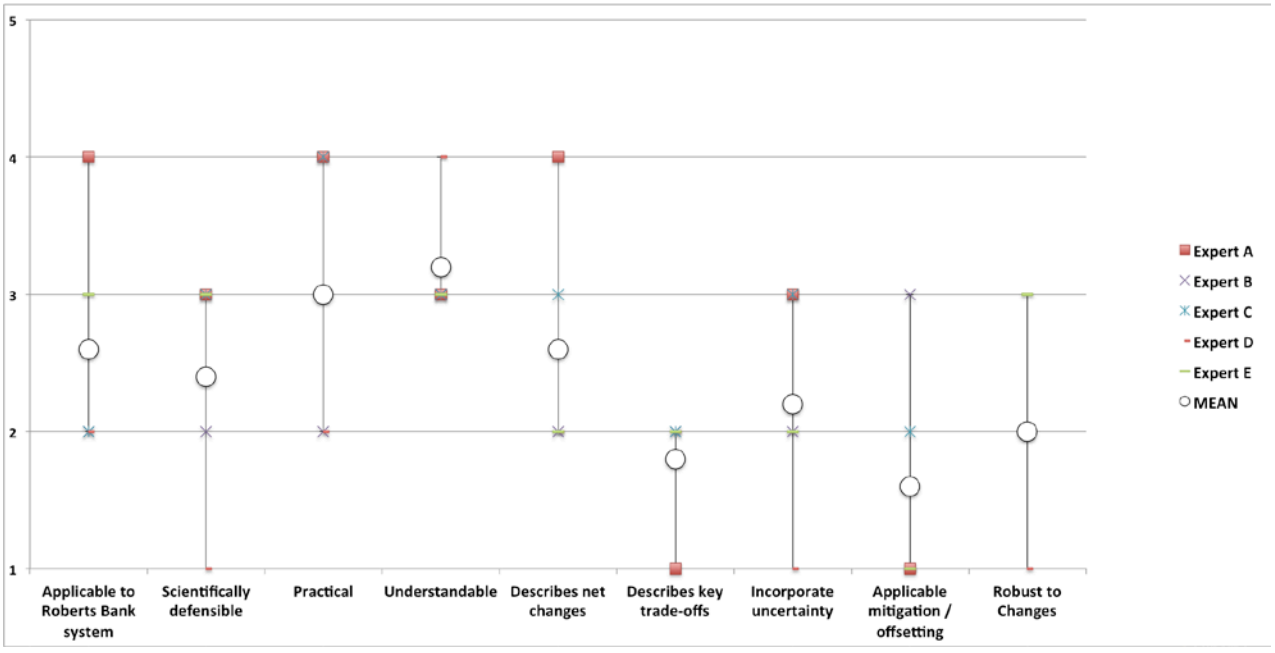

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Figure 3. EwE Scores

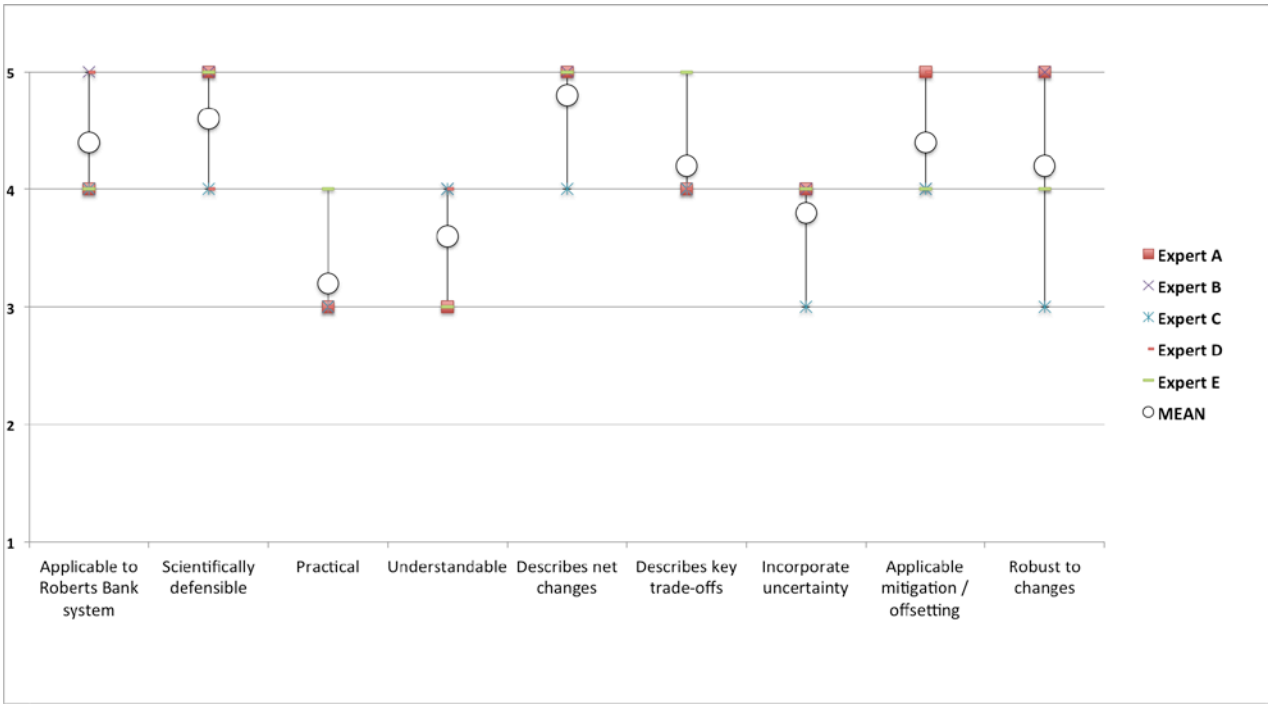

Figure 4. Average scores for all three methods

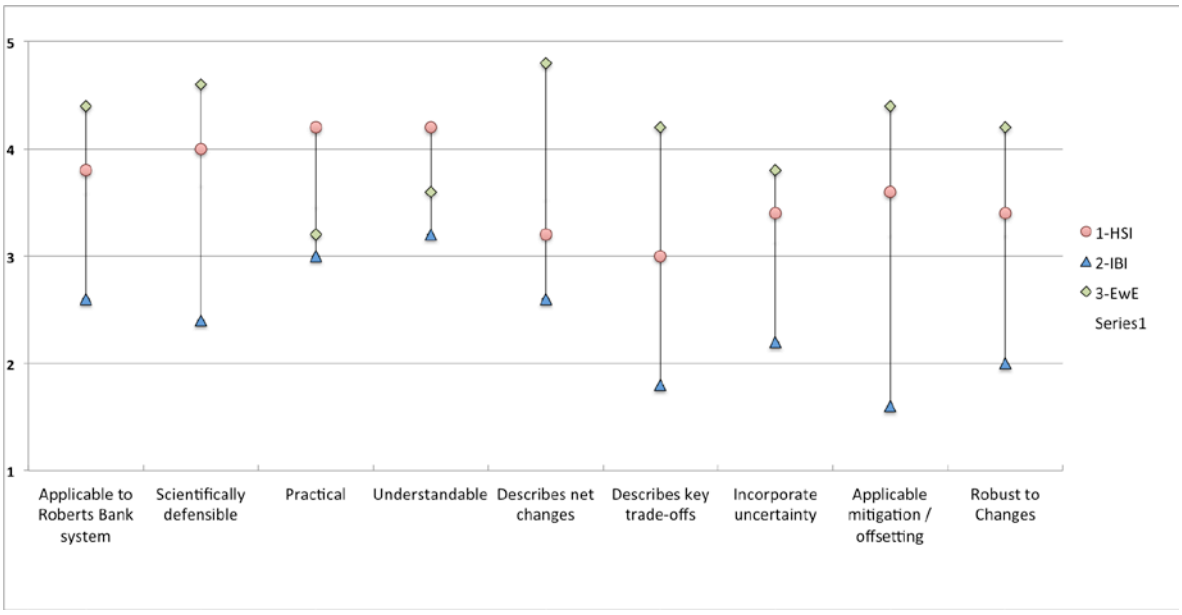

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Table 1. Consequence Table

Obj.	Sub Objective	Criteria / Units	Dir	HSI	IBI	EwE
CRITERIA						
	Applicable to Roberts Bank system	#	H	3.8	2.6	4.4
	Scientifically defensible	#	H	4.0	2.4	4.6
	Practical	#	H	4.2	3.0	3.2
	Understandable	#	H	4.2	3.2	3.6
	Describes net changes	#	H	3.2	2.6	4.8
	Describes key trade-offs	#	H	3.0	1.8	4.2
	Incorporates Uncertainty	#	H	3.4	2.2	3.8
	Applicable mitigation / offsetting	#	H	3.6	1.6	4.4
	Robust to changes	#	H	3.4	2.0	4.2

Legend
Better than selected
Worse than selected
Selected

Table 2. Direct Ranking

	HSI	IBI	EwE
Expert A	33%	22%	44%
Expert B	38%	21%	42%
Expert C	36%	18%	45%
Expert D	38%	21%	42%
Expert E	40%	10%	50%

Note: Scores are normalized, with percentages summing to 100% for each TAG member

One PC TAG member, who participated in the morning session but was unable to stay for the scoring and ranking, completed the exercise after the meeting (without the benefit of discussing scoring and ranking with other PC TAG members). This member also ranked IBI third, but ranked HSI first and EwE second, because of HSI's advantages with respect to practicality and understandability. However, this member noted that his judgment may have changed had he participated in the discussion and asked that the report reflect the judgments of the group.

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PC Methods Selection Questionnaire

REFERENCE SHEET

Please refer to the following three tables during the scoring exercise.

Table 1: Selection Criteria

CRITERIA	DESCRIPTION
Applicable to Roberts Bank system	Is the method **applicable to the Roberts Bank system** (marine, estuarine) and able to address the species/habitats of concern?
Scientifically defensible	Is the method **scientifically defensible**, and peer reviewed?
Practical	Is the method **practical** in terms of input data requirements (e.g. timelines, cost and technical feasibility)
Understandable	Can the method produce **summary statements that are understandable** for the regulatory review process
Describes net changes	Can the method describe expected **net changes in productive capacity**?
Describes key trade-offs	Can the method describe **key trade-offs** among individual components of productive capacity?
Incorporate uncertainty	Can the method **estimate/characterize uncertainty** and the range of possible outcomes given uncertainty?
Applicable mitigation / offsetting	Can the method produce results that **inform the evaluation of mitigation, compensation, and banking** options?
Robust to Changes	Is the method **robust to changes** in the regulatory review process?

Table 2: Scoring Scale

SCORE	DESCRIPTION
1	Does not meet this criterion
2	Minimally meets this criterion
3	Somewhat meets this criterion
4	Strongly meets this criterion
5	Fully meets this criterion

Table 3: Description of alternatives

METHOD	DESCRIPTION
HSI	The HSI method was developed to quantify available and usable habitat for a species or functional group of interest, allowing biologists to link taxa with specific environmental variables within the habitat being studied. The index ranges from 0 to 1, where 0 indicates totally unsuitable habitat and 1 represents optimal habitat where species have maximum productivity.
IBI	The IBI method is unique in that it was developed to assess the quality or integrity of an area based on the species occupying the area (Karr et al. 1986). The IBI samples information from species or communities such as diversity, abundance, ecological role (native/invasive, or tolerance), trophic structure, and biomass, within the area or scale of interest, to estimate the area's ecological status.
Ecopath with Ecosim (EwE)	Ecosystem modeling using Ecopath with Ecosim (EwE) is a trophic model that follows energy transfer through the food web. This method is unique relative to the HSI and IBI in that it incorporates multiple species variables into a single model for the ecosystem of interest. While the model itself uses information from all trophic levels, the outputs of the model can be species or taxon specific, so that impacts on specific species of interest can be tracked.

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SCORING EXERCISE

Name:_____

Background: This exercise involves the evaluation of three alternative methods for assessing productive capacity: HSI, IBI, and EwE. Task #1 will ask you to first score each of these methods (using a 5-point scale) on eight different criteria. Tasks #2 and #3 will ask you to consider each of the three assessment methods as a whole and evaluate which one you would rank as your first choice, second choice, and third choice. Task #4 will ask you to consider how important you think each of the eight criteria are for evaluating each PC assessment methodology. By ranking these criteria and assigning each a number of points (from 0 to 100) to each, it will be possible to devise a 'weight' for each criterion. These criteria weights will later be applied to the matrix in Task #1 to calculate an overall score for each of the three PC assessment methodologies. The TAG will then review the results from both the 'weighted' assessment of alternatives, and the 'direct ranking' of alternatives to determine which assessment method is most appropriate for assessing productive capacity.

TASK #1: Scoring Alternative Methods

Instructions: In the table below, please score each of the three assessment methods (HSI, IBI, EwE) on each of the eight criteria using the **five point scoring scale** from Table 2 on the REFERENCE SHEET.

CRITERIA	HSI	IBI	EwE
Applicable to Roberts Bank system			
Scientifically defensible			
Practical			
Understandable			
Describes net changes			
Describes key trade-offs			
Incorporate uncertainty			
Applicable mitigation / offsetting			
Robust to Changes			

TASK #2: Direct Ranking

Instructions: In the table below, please:

- Step 1: Rank each of the three assessment methods from 1 to 3 (first place to third place) considering the overall suitability or appropriateness of each method for assessing productive capacity.
- Step 2: Assign up to 100 points to each of the three assessment methods to the overall suitability or appropriateness of each method for assessing productive capacity.

METHODS	RANK	POINTS
HSI		
IBI		
Ecopath with Ecosim (EwE)		

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TASK #3: Direct Ranking

Instructions: In the table below, please:

- Step 1: Rank each of the three assessment methods from 1 to 3 (first place to third place) considering the overall suitability or appropriateness of each method for assessing productive capacity.
- Step 2: Assign up to 100 points to each of the three assessment methods to the overall suitability or appropriateness of each method for assessing productive capacity.

METHODS	RANK	POINTS
HSI		
IBI		
Ecopath with Ecosim (EwE)		

TASK #4: Relative Importance of the Criteria

Instructions: In the table below, please:

- Step 1: Rank each of the eight criteria in order from 1st to 8th according to their importance for evaluating a PC assessment methodology.
- Step 2: Assign up to 100 points to each of the eight criteria to express how important that criteria is for evaluating a PC assessment methodology.

CRITERIA	RANK	POINTS
Applicable to Roberts Bank system		
Scientifically defensible		
Practical		
Understandable		
Describes net changes		
Describes key trade-offs		
Incorporate uncertainty		
Applicable mitigation / offsetting		
Robust to Changes		

Comments:

IR3-01 EIS Modelling

Information Source(s)

EIS Volume 2: Section 9.0

EIS Volume 3: Sections 10 to 17

Context

The EIS relies upon a number of linked models to predict the effects from changes in physical conditions on marine valued components and their subsequent changes in the productivity of functional groups.

The coastal geomorphology model included TELEMAC, TOMAWAC and SISPHYE sub-models to predict changes to currents, salinity and sediment transport. Together with other biotic parameters, such as habitat, diet, trophic interactions, biomass and vital rates, these outputs were then modeled using the Ecopath, Ecosim and Ecospace models to predict changes in productivity for 58 functional groups, with and without the Project.

Other models were applied to functional groups and/or valued components including the Habitat Capacity Model; the Underwater Noise Model for marine mammals; the Population Consequence of Disturbance Model for Southern Resident Killer Whales; the Habitat Suitability Model for sand lance, Dungeness crabs and orange sea pens; and the Shorebird Foraging Opportunity Models for coastal shorebirds.

The various model results were then used to inform the Proponent's predictions of existing conditions, effects of the proposed Project and the development of mitigation measures including offsetting plans.

Information is needed to clarify the linkages between the various models utilized in the EIS in relation to the model input and output parameters.

Information Request

Provide a flow chart-type diagram that identifies the linkages between the various models used in the Roberts Bank Terminal 2 Project environmental assessment, their input and output parameters and the sequencing of model outputs for deriving conclusions about potential Project effects on functional groups, intermediate components and valued components.

VFPA Response

The requested flow charts identifying linkages between the various models used in the environmental assessment are provided in **Appendix IR3-01-A**.

Appendices

Appendix IR3-01-A Linkages between RBT2 Models (Flow Charts)

APPENDIX IR3-01-A
LINKAGES BETWEEN RBT2 MODELS (FLOW CHARTS)

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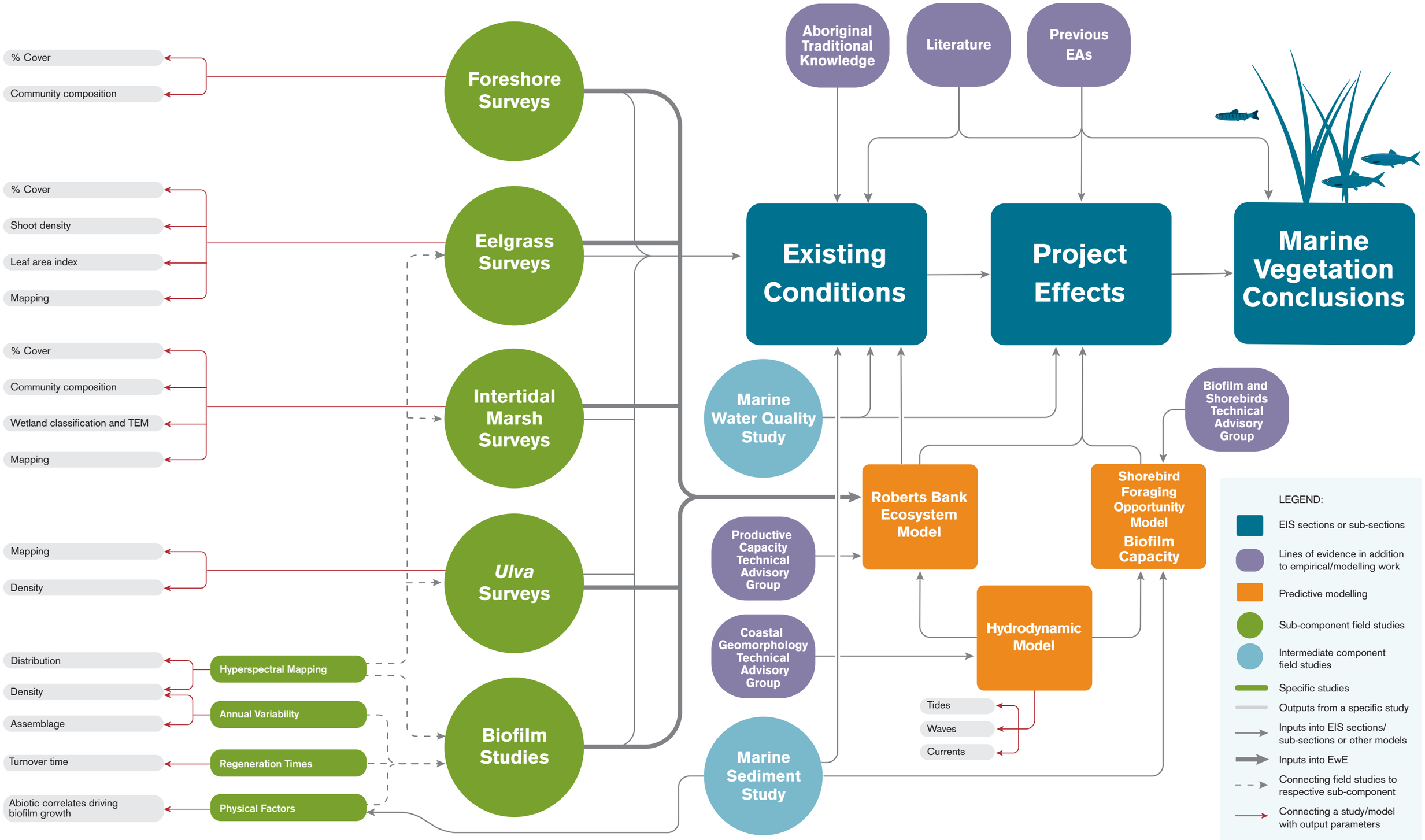
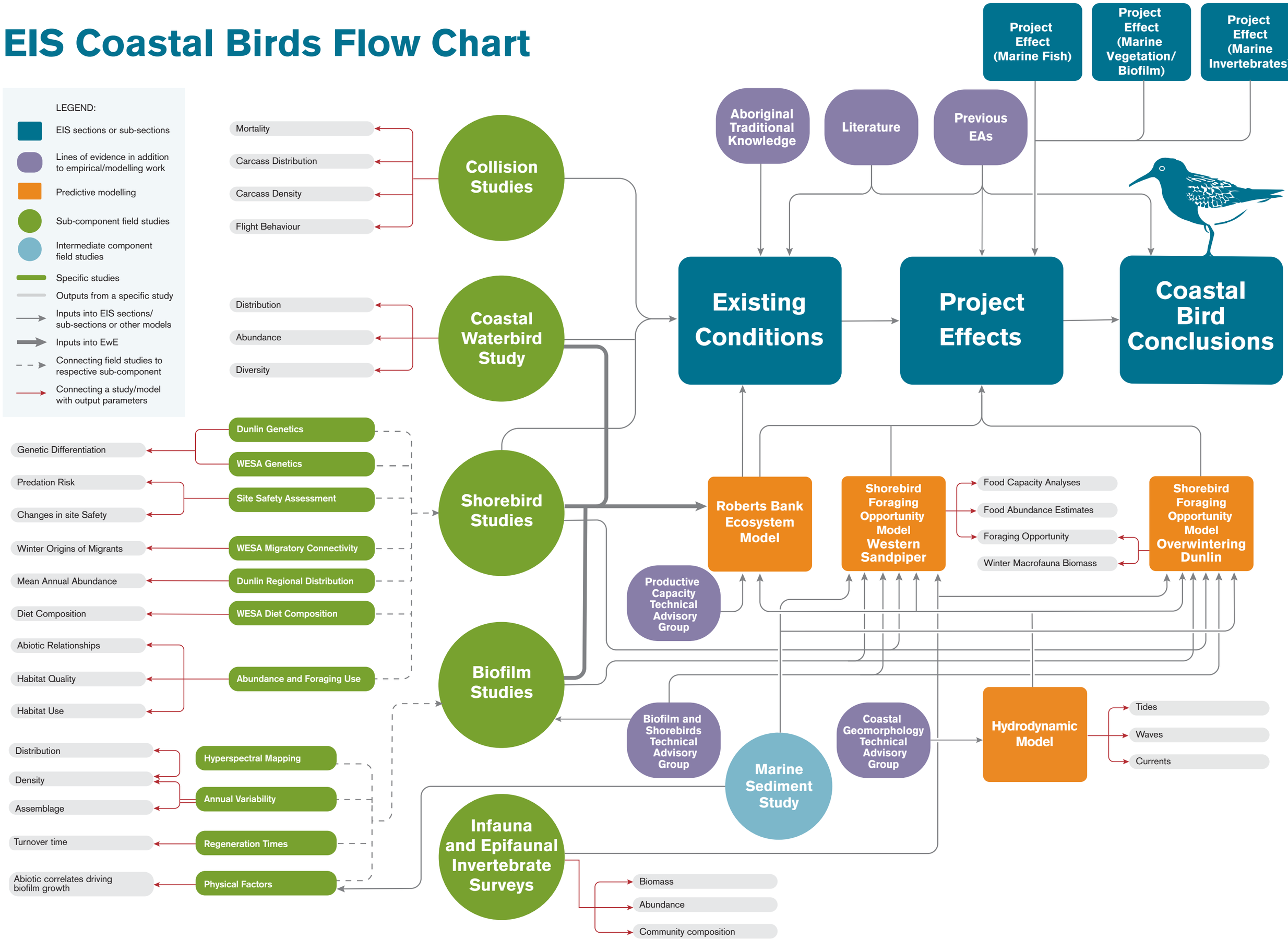
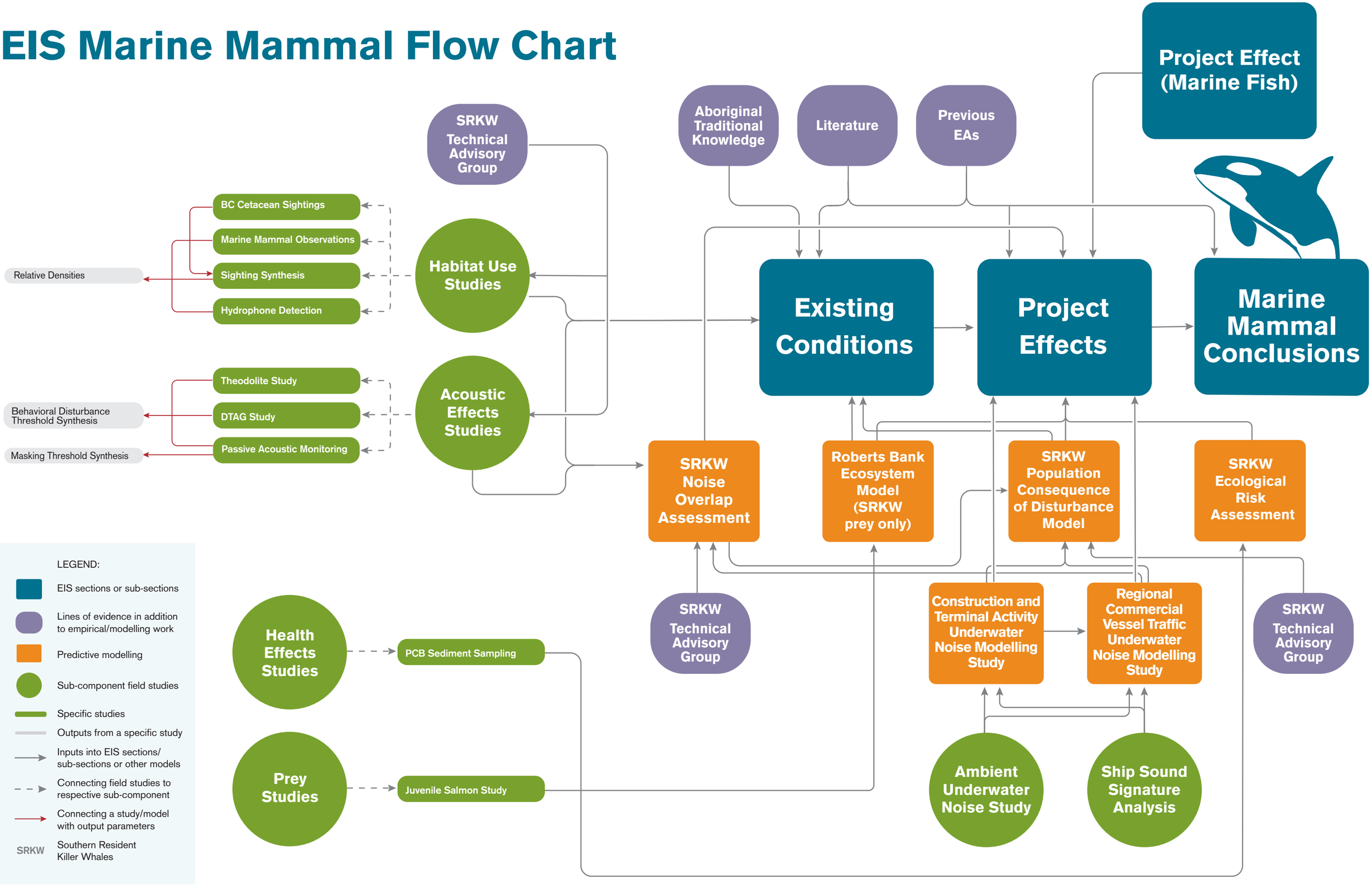
EIS Marine Vegetation Flow Chart



EIS Coastal Birds Flow Chart



EIS Marine Mammal Flow Chart



EIS Marine Invertebrate Flow Chart

LEGEND:

- EIS sections or sub-sections
- Lines of evidence in addition to empirical/modelling work
- Predictive modelling
- Sub-component field studies
- Intermediate component field studies
- Specific studies
- Outputs from a specific study
- Inputs into EIS sections/ sub-sections or other models
- Inputs into EwE
- Connecting field studies to respective sub-component
- Connecting a study/model with output parameters

Biofilm and Shorebirds Technical Advisory Group

Aboriginal Traditional Knowledge

Literature

Previous EAs

Project Effect (Marine Vegetation/ Biofilm)

Biomass

Abundance

Community composition

Infauna and Epifaunal Invertebrate Surveys

Existing Conditions

Project Effects

Marine Invertebrate Conclusions

Density

Bivalve Shellfish Studies

Productive Capacity Technical Advisory Group

Roberts Bank Ecosystem Model

Hydrodynamic Model

Shorebird Foraging Opportunity Model Infaunal Capacity

Marine Sediment Study

Mapping

Density

Community associations

Underwater Video Surveys

SCUBA Surveys

Orange Sea Pen Studies

Species Distribution Model

Tides

Waves

Currents

Probability of Occurrence

Coastal Geomorphology Technical Advisory Group

Marine Water Quality Study

Section 27 Human Health

Contamination Studies

Contaminant Concentrations

Bayesian Population Dynamics Model

Biomass

Production

Recruitment

Biofilm and Shorebirds Technical Advisory Group

Density

Habitat Preferences

Juvenile Crab Surveys

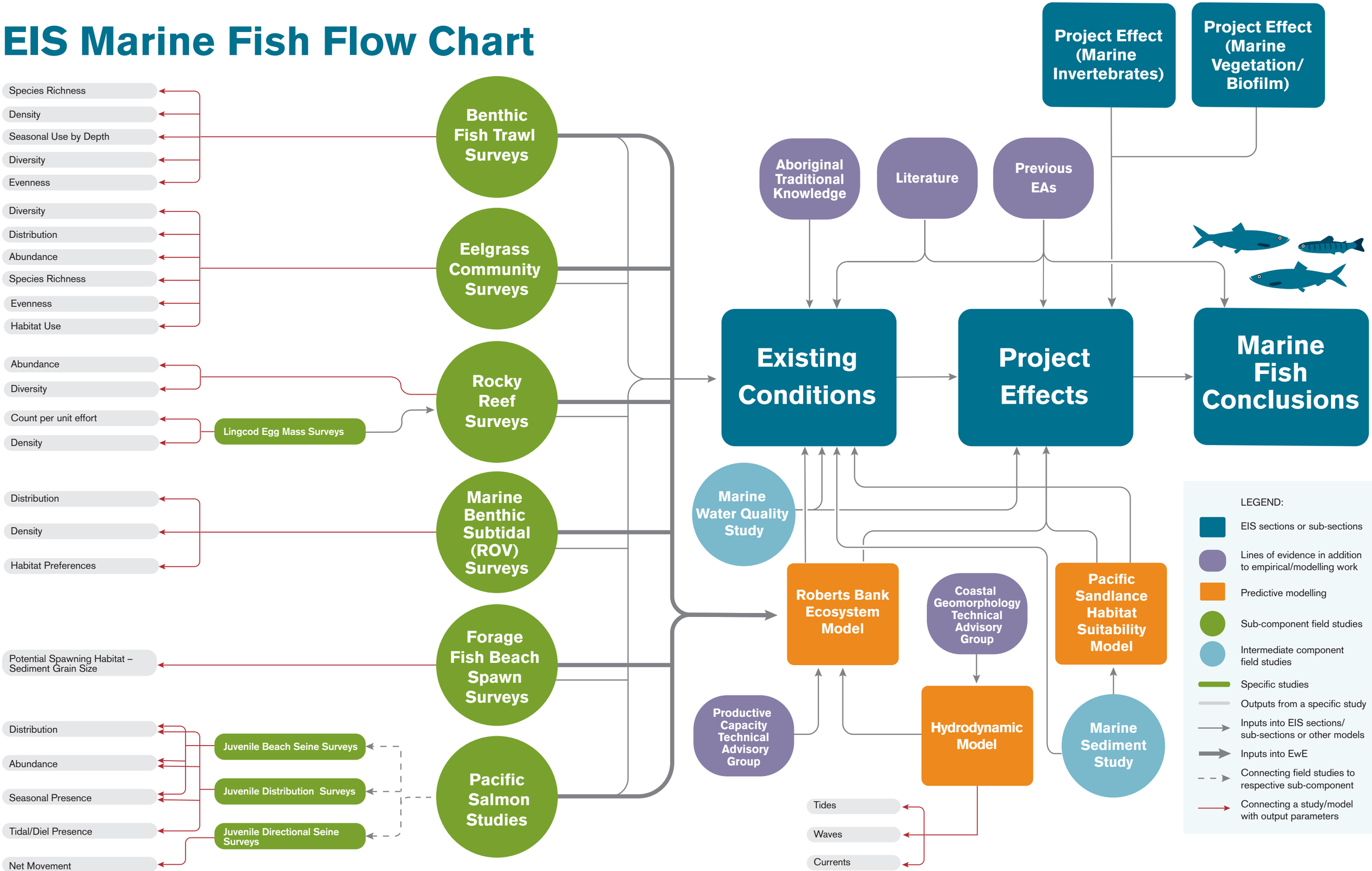
Gravid female SCUBA surveys

Dungeness Crab Studies

Habitat Suitability Model

Area of Suitable Habitat

EIS Marine Fish Flow Chart



IR3-02 Roberts Bank Ecosystem Model – Geomorphic Changes

Information Source(s)

EIS Volume 2: Appendix 9.5-A

EIS Volume 3: Appendix 10-B, Appendix 10-C, Appendix 10-D

Context

In the EIS, the Proponent reported that the coastal geomorphology model predicted that eight hydrodynamic processes would be affected by the proposed Project:

- scour around the NW corner of terminal pad (5.8 ha affected)
- deposition along the west side of terminal pad (20 ha affected)
- accelerated tidal channel development (50 ha affected)
- deposition off the NE corner of terminal pad (40 ha affected)
- reduction in wave in the lee of the structure (70 ha affected)
- limited wave scour at the east of the terminal (1 ha affected)
- decline in salinity, associated increase in turbidity, and increase in sedimentation (not quantified)
- lateral adjustment of the pour-over channel (tug basin) (80 m^2 affected)

Excluding the zone of altered water quality, these changes would affect approximately 187 ha of aquatic habitat outside of the proposed Project footprint area, as shown on Figure 110 in Appendix 9.5-A.

Information is required to understand how the potential geomorphologic changes would affect the 58 functional groups that were modeled via the Roberts Bank ecosystem model (RB EwE model).

Information Request

Clarify how the geomorphologic changes adjacent to the proposed Project were captured by the RB EwE model.

Identify the environmental effects for modeled functional groups in areas within, and adjacent to, the zone of predicted geomorphologic changes shown on Figure 110 of Appendix 9.5-A.

Provide a table of habitat areas similar to Table 1-5 in Appendix 10-B and a habitat map similar to Figure 1 in Appendix 10-B showing the expected changes resulting from the predicted geomorphological alterations adjacent to the proposed Project footprint.

VFPA Response

Clarify how the geomorphologic changes adjacent to the proposed Project were captured by the RB EwE model.

To clarify, geomorphic conditions (expressed in terms of environmental variables, including depth, wave height, bottom current velocity, and salinity) were modelled for the entire Strait of Georgia, including Roberts Bank. The hydrodynamic modelling completed as part of the coastal geomorphology study was not restricted to the area adjacent to the proposed terminal (see EIS Section 9.5 and EIS Appendix 9.5-A). The Roberts Bank ecosystem model (RB model) captured geomorphic conditions by incorporating outputs of the hydrodynamic model by means of environmental variables, as described below.

The hydrodynamic model predicted that geomorphic conditions may change with the Project, but that detectable changes will be restricted within the polygons shown in **Figure IR3-02-1** (which is presented as Figure 110 in EIS Appendix 9.5-A and as Figure 9.5-35 in EIS Section 9.5; these polygons are henceforth referred to as 'zones'). As shown in **Figure IR3-02-1**, predicted changes in geomorphic conditions are localised to the Project footprint and do not extent beyond two kilometres. The extent of these zones was estimated conservatively to the outer edge of potential changes, but actual changes are likely to be more spatially limited and concentrated in the central portion of these zones (see EIS Section 9.5).

Figure IR3-02-1 **Approximate Spatial Extent of Potential Changes Associated with the Project** (Figure 110 in EIS Appendix 9.5-A and Figure 9.5-35 in EIS Section 9.5)

Note: This figure is the same as Figure 110 in EIS Appendix 9.5-A and Figure 9.5-35 in EIS Section 9.5. Eight zones of predicted geomorphic changes[1] were identified in the EIS Section 9.5 and shown here: zone 1 - scour around the northwest corner of terminal pad; zone 2 - deposition along the west side of terminal pad; zone 3 - accelerated tidal channel development; zone 4 - deposition off the northeast corner of terminal pad; zone 5 - reduction in wave in the lee of the structure; zone 6 - limited wave scour at the east of the terminal; zone 7 - increase in turbidity and sedimentation associated with a decrease in salinity; and zone 8 - lateral adjustment of the pour-over channel (tug basin).

To determine how changes to environmental conditions may affect productivity at Roberts Bank, the hydrodynamic model outputs across the entire RB model study area were used in the Ecospace component of the RB model (see Section 2.2 of EIS Appendix 10-C). The link between geomorphic conditions and system productivity was established by defining environmental preference functions for each functional group (see Section 2.12 of EIS Appendix 10-C). These functions describe how changes in environmental conditions

[1] See text above figure for information on how potential changes in coastal geomorphology from the Project were incorporated into the RB model. The material presented in this response is new material not previously presented in the EIS or information request responses.

(e.g., depth, salinity, etc.) influence changes in functional group productivity due to terminal and causeway footprints. The geomorphic changes associated with the tug basin expansion (80 m^2) were not included in the RB model for technical reasons (primarily relating to differences between the large scale of the RB model and the small scale associated with the tug basin expansion)[2].

Identify the environmental effects for modeled functional groups in areas within, and adjacent to, the zone of predicted geomorphologic changes shown on Figure 110 of Appendix 9.5-A.

Environmental effects for each modelled functional group (within the RB model) are expressed in terms of changes in productivity due to terminal and causeway footprints and are determined for the entire RB model study area using the hydrodynamic model outputs, as explained above.

For this information request, changes in productivity (expressed in terms of biomass, in tonnes (t)) for functional groups were extracted from the RB model using the Ecospace grid cells of the RB model study area that overlap with each zone of predicted geomorphic changes (shown in **Figure IR3-02-1**). Biomass changes for functional groups by zone of predicted geomorphic changes are presented in Tables IR3-02-A1 to IR3-02-A6 (**Appendix IR3-02-A**; biomass changes for functional groups within the zones of predicted deposition are presented in Table IR3-02-A2 for zones 2 and 4 combined; this is new information not presented in the EIS). For reasons explained below, however, biomass changes for functional groups should not be looked at nor are they meaningful when considered at the resolution of geomorphic zones. Biomass changes for functional groups adjacent to the zone of predicted geomorphic changes are captured by biomass changes forecasted for the entire RB model study area and are presented in Table 3.2 of EIS Appendix 10-C.

The RB model was constructed using the Ecopath with Ecosim and Ecospace (EwE) framework to capture productivity changes with the Project over the entire RB model study area. Because changes in productivity are driven by both changes in environmental variables and trophic linkages established in the RB model, productivity changes are not restricted to a subset region (e.g., zones of geomorphic changes), but are distributed across the entire RB model study area and hence the Roberts Bank ecosystem. Thus, by focusing on a subset region within the broader RB model study area (e.g., zones of geomorphic changes), RB model results are skewed and not realistic, as localised biomass losses for some groups within a subset region (of the RB model study area) may be counterbalanced by biomass gains of the same groups within the entire RB model study area, and vice versa.

[2] Changes in productivity from geomorphic changes associated with the tug basin expansion (80 m^2) have not been included at this time given it is not technically possible to predict the changes using the RB model (as explained in the accompanying text). Changes in productivity from this area will be minimised through the implementation of mitigation plans identified in the EIS (see EIS Sections 33.0 and 35.0) and will be included in mitigation (offsetting) pursuant to authorisation under the *Fisheries Act* and in consultation with Fisheries and Oceans Canada.

For some functional groups, biomass changes are manifested at locations outside the zones of geomorphic changes. For example, within the zone of increased turbidity (zone 7) and in the inter-causeway area, native eelgrass biomass is forecasted to decrease. However, biomass gains are forecasted for native eelgrass north of the proposed terminal as a decrease in waves and currents allows it to expand and shift from its current distribution (see Section 3.9.3 of EIS Appendix 10-C). These gains are expected to counterbalance localised forecasted losses resulting in a net biomass gain of approximately 11.5 t within the entire RB model study area. A spatial depiction of where Project footprint-related productivity changes are forecasted to occur for each functional group (i.e., maps of difference in production (with-without), tonnes per year) is included in Section 3.0 and Appendix 1 of EIS Appendix 10-C, and in appendix 2.18 of CEAR Document #547.

It should also be noted that for each functional group biomass changes across zones of geomorphic changes (presented in Tables IR3-02-A1 to IR3-02-A6 of **Appendix IR3-02-A**) cannot be summed, because zones of geomorphic changes overlap with one another. For example, zone 5 overlaps with zone 1 and partially with zones 2 and 4 (**Figure IR3-02-1**). Hence, biomass changes for a given functional group in the RB model grid cells within zone 1 are also included in biomass change calculations for the same functional group within zone 5. As a result, summing biomass changes for a given functional group for zones 1 and 5 would be double-counting those biomass changes forecasted within the area of overlap between zone 1 and zone 5. As such, an aggregate of biomass changes within the zones of geomorphic changes cannot be established nor is it technically valid, as the relative contribution of the factors influencing changes in biomass of functional groups at the zonal level cannot be teased out. Instead, biomass changes have been forecasted for the entire RB model study area, where changes to environmental conditions in combination with predator-prey interactions have been considered in the RB model in a holistic manner.

Additional confidence in the RB model forecasts is found in the results of sensitivity analyses, whereby environmental variables were removed for each functional group one at a time and the RB model was run both with and without the Project (see Section 2.2 of EIS Appendix 10-D). In addition, sensitivity to environmental variables was also explored by increasing or decreasing by 20% the difference between the forecasted values of each environmental variable with and without the Project (see Section 2.3 of EIS Appendix 10-D). The adjusted difference between with and without Project scenarios was then used to calculate new 'with Project' values of environmental variables.

Of the 52 functional groups (excluding marine mammals) used in sensitivity analyses, 40 showed consistent directions of change (increase or decrease) in biomass across all sensitivity analyses (see Section 3.2 of EIS Appendix 10-D). This pattern indicates that RB model outputs are generally robust to changes in their environmental preferences, providing confidence in the results of the RB model as articulated in the EIS.

Provide a table of habitat areas similar to Table 1-5 in Appendix 10-B and a habitat map similar to Figure 1 in Appendix 10-B showing the expected changes resulting from the predicted geomorphological alterations adjacent to the proposed Project footprint.

Consistent with the productivity-based approach used in the EIS, Tables IR3-02-A1 to IR3-02-A6 (**Appendix IR3-02-A**) depict changes in biomass within the seven zones of geomorphic changes. Geomorphic changes associated with the tug basin expansion were not included in the RB model for technical reasons, as explained above. Changes in functional group biomass within the zones of predicted deposition are presented in Table IR3-02-A2 for zones 2 and 4 combined.

Maps depicting potential production changes (in t/year) in habitat-forming groups across the RB model study area are included in Table IR3-02-A7 in **Appendix IR3-02-A** (these maps were previously included in Section 3.0 and Appendix 1 of EIS Appendix 10-C, and in appendix 2.18 of CEAR Document #547; these documents also include maps of production change for non-habitat forming groups).

The following discussion summarises biomass changes by zone and how these relate to productivity changes throughout the RB model study area (**Table IR3-02-2**). However, and for reasons explained above, biomass changes for functional groups forecasted across zones of geomorphic changes were not summed and an aggregate is not included here.

Table IR3-02-2 Summary of Forecasted Biomass Changes by Zone of Geomorphic Changes Identified in Figure IR3-02-1 Above (taken from Figure 110 of EIS Appendix 9.5-A and Figure 9.5-35 of EIS Section 9.5)

Zone (Zone #)	# Functional Groups with Negligible Changes in Biomass (t)	# Functional Groups with Minor Changes in Biomass (t)	# Functional Groups with Moderate Changes in Biomass (t)	# Functional Groups with High Changes in Biomass (t)	Total Biomass Change (with - without Project; t) by Zone
Scour (1)	10	13	8	27	30.1
Deposition (2 and 4)	16	21	7	14	-1.7
Accelerated tidal channel (3)	13	17	7	21	57.0
Wave shadow (5)	13	13	6	26	232.9
Wave scour (6)	10	15	10	23	6.3
Increased turbidity (7)	11	16	12	19	-62.4

Note: Biomass changes (in t) as a result of terminal and causeway footprints are characterised in the EIS as negligible (0-5%), minor (6-30%), moderate (31-60%), and high (>60%).

In summary, as shown in **Table IR3-02-2**, within the zones of forecasted geomorphic changes, biomass gains are forecasted within the zones of scour (30.1 t), the accelerated tidal channel (57.0 t), wave shadow (232.9 t), and wave scour (6.3 t). In contrast, biomass losses are forecasted within the zones of deposition (-1.7 t), and increased turbidity (-62.4 t; **Table IR3-02-1**).

However, as explained earlier, interpretation of biomass changes within the zones of geomorphic changes must be undertaken in the context of biomass changes in the entire RB model study area (i.e., the net changes across the Roberts Bank ecosystem). Localised biomass changes within a subset region (e.g., zones of geomorphic changes) do not reflect net biomass changes in the entire RB model study area. For example, biomass losses are forecasted within the zone of increased turbidity (-62.4 t); however, the net biomass change in the entire RB model study area is positive (i.e., 204.4 t).

Appendices

Appendix IR3-02-A Supporting Tables

APPENDIX IR3-02-A
SUPPORTING TABLES

Table IR3-02-A1 Biomass Estimates from the Roberts Bank Ecosystem Model Key Run within the Scour Zone (Zone 1; Figure IR3-02-1), Expressed Without and With the Project

No.	Functional Group	Biomass, Scour Zone (without Project, t)	Biomass, Scour Zone (with Project, t)	Difference, Scour Zone (with - without Project, t)	Total Biomass Change in the RB Model Study Area[a] (with - without Project, t)
1	Baleen whales	0.000	0.000	0.000	-0.023
2	Dolphins and porpoises	0.001	0.002	0.001	-0.009
3	Pinnipeds	0.033	0.034	0.000	-0.592
4	Southern resident killer whales	0.001	0.001	0.000	-0.015
5	Transient killer whales	0.001	0.001	0.000	-0.032
6	American wigeon	0.000	0.000	0.000	-0.400
7	Bald eagle	0.000	0.000	0.000	-0.008
8	Brant goose	0.000	0.004	0.003	-0.058
9	Diving waterbirds	0.005	0.008	0.003	-0.095
10	Dunlin	0.000	0.000	0.000	0.060
11	Great blue heron	0.000	0.000	0.000	-0.002
12	Gulls and terns	0.006	0.008	0.002	-0.038
13	Raptors	0.000	0.000	0.000	0.003
14	Shorebirds	0.000	0.000	0.000	-0.001
15	Waterfowl	0.005	0.010	0.005	1.345
16	Western sandpiper	0.000	0.000	0.000	0.008
17	Chinook salmon adult	0.424	0.488	0.064	-9.504
18	Chinook salmon juvenile	0.000	0.001	0.001	0.104
19	Chum salmon adult	0.227	0.246	0.020	-5.125
20	Chum salmon juvenile	0.001	0.001	0.000	0.070
21	Dogfish	0.077	0.097	0.020	-0.811
22	Flatfish	0.018	0.053	0.036	-0.308
23	Forage fish	1.015	0.979	-0.036	-8.096
24	Herring	0.873	1.226	0.353	-5.618
25	Large demersal fish	0.012	0.030	0.018	-0.101
26	Lingcod	0.000	0.366	0.366	-0.975
27	Rockfish	0.000	0.087	0.087	-1.631
28	Salmon adult	0.108	0.115	0.007	-2.281
29	Salmon juvenile	0.000	0.000	0.000	-0.003
30	Sandlance	0.015	0.024	0.009	0.645
31	Shiner perch	0.006	0.009	0.004	1.642
32	Skate	0.057	0.067	0.011	-1.018

No.	Functional Group	Biomass, Scour Zone (without Project, t)	Biomass, Scour Zone (with Project, t)	Difference, Scour Zone (with - without Project, t)	Total Biomass Change in the RB Model Study Area[a] (with - without Project, t)
33	Small demersal fish	0.002	0.017	0.015	-0.214
34	Starry flounder	0.012	0.038	0.026	0.692
35	Carnivorous zooplankton	3.831	3.938	0.107	-173.949
36	Dungeness crab	1.376	1.522	0.147	-8.843
37	Epifaunal grazer	2.316	1.477	-0.839	-65.951
38	Epifaunal omnivore	0.086	0.233	0.147	-2.420
39	Epifaunal sessile suspension feeder	0.000	2.129	2.129	9.465
40	Infaunal bivalve	26.003	26.257	0.254	-518.883
41	Jellyfish	1.913	2.708	0.795	-49.160
42	Macrofauna	0.066	1.812	1.746	733.258
43	Meiofauna	0.002	0.003	0.001	175.196
44	Omnivorous and herbivorous zooplankton	12.541	18.276	5.736	-208.879
45	Polychaetes	0.000	0.001	0.001	-120.180
46	Orange sea pen	0.064	0.006	-0.058	-4.229
47	Shrimp	0.063	0.058	-0.005	-3.530
48	Biofilm freshwater	0.000	0.000	0.000	1,468.419
49	Biofilm marine	0.000	0.000	0.000	-419.837
50	Brown algae	0.000	16.284	16.284	-53.157
51	Eelgrass (native)	0.019	0.530	0.511	11.489
52	Green algae	0.000	0.020	0.020	-582.947
53	Japanese eelgrass (non-native)	0.000	0.000	0.000	-0.048
54	Red algae	0.000	0.804	0.804	-1.572
55	Phytoplankton	3.519	4.493	0.974	68.840
56	Tidal marsh	0.000	0.000	0.000	335.059
57	Biomat	0.000	0.000	0.000	-356.115
58	Detritus	0.492	0.817	0.325	4.753
	TOTAL	55.190	85.284	30.094	204.390

Note: Estimates are rounded. Biomass information is at a point in time after equilibrium at Roberts Bank has been reached.

a. As indicated in the accompanying text, it is not valid in ecosystem modelling to analyse a subset of an ecosystem model domain, without considering the entire study area; hence, potential biomass differences with and without Project within the scour zone (zone 1; **Figure IR3-02-1**) are compared to the overall biomass differences, with and without Project, across the entire RB model study area. Using dunlin as an example, there are no changes in biomass (from terminal and causeway footprints) to dunlin within the scour zone; however, across the entire RB model study area, dunlin biomass is forecasted to increase by 0.060 t, and the increase is not anticipated within the scour zone.

Table IR3-02-A2 Biomass Estimates from the Roberts Bank Ecosystem Model Key Run within the Deposition Zones (Zones 2 and 4 Combined; Figure IR3-02-1), Expressed Without and With the Project

No.	Functional Group	Biomass, Deposition Zones (without Project, t)	Biomass, Deposition Zones (with Project, t)	Difference, Deposition Zones (with - without Project, t)	Total Biomass Change in the RB Model Study Area[a] (with - without Project, t)
1	Baleen whales	0.001	0.001	0.000	-0.023
2	Dolphins and porpoises	0.004	0.005	0.001	-0.009
3	Pinnipeds	0.095	0.096	0.000	-0.592
4	Southern resident killer whales	0.002	0.002	0.000	-0.015
5	Transient killer whales	0.002	0.002	0.000	-0.032
6	American wigeon	0.000	0.000	0.000	-0.400
7	Bald eagle	0.001	0.001	0.000	-0.008
8	Brant goose	0.001	0.002	0.001	-0.058
9	Diving waterbirds	0.015	0.017	0.003	-0.095
10	Dunlin	0.000	0.000	0.000	0.060
11	Great blue heron	0.000	0.000	0.000	-0.002
12	Gulls and terns	0.016	0.018	0.002	-0.038
13	Raptors	0.000	0.000	0.000	0.003
14	Shorebirds	0.000	0.000	0.000	-0.001
15	Waterfowl	0.012	0.018	0.005	1.345
16	Western sandpiper	0.000	0.000	0.000	0.008
17	Chinook salmon adult	1.015	0.928	-0.087	-9.504
18	Chinook salmon juvenile	0.001	0.002	0.000	0.104
19	Chum salmon adult	0.557	0.503	-0.054	-5.125
20	Chum salmon juvenile	0.002	0.002	0.000	0.070
21	Dogfish	0.213	0.233	0.020	-0.811
22	Flatfish	0.046	0.074	0.028	-0.308
23	Forage fish	2.917	2.951	0.034	-8.096
24	Herring	2.467	2.889	0.422	-5.618
25	Large demersal fish	0.033	0.050	0.018	-0.101
26	Lingcod	0.000	0.212	0.212	-0.975
27	Rockfish	0.000	0.044	0.044	-1.631
28	Salmon adult	0.262	0.231	-0.031	-2.281
29	Salmon juvenile	0.001	0.001	0.000	-0.003
30	Sandlance	0.044	0.055	0.011	0.645
31	Shiner perch	0.016	0.017	0.001	1.642
32	Skate	0.158	0.165	0.007	-1.018
33	Small demersal fish	0.006	0.019	0.013	-0.214

No.	Functional Group	Biomass, Deposition Zones (without Project, t)	Biomass, Deposition Zones (with Project, t)	Difference, Deposition Zones (with - without Project, t)	Total Biomass Change in the RB Model Study Area[a] (with - without Project, t)
34	Starry flounder	0.034	0.058	0.024	0.692
35	Carnivorous zooplankton	10.366	9.824	-0.542	-173.949
36	Dungeness crab	3.559	3.043	-0.516	-8.843
37	Epifaunal grazer	4.415	0.040	-4.375	-65.951
38	Epifaunal omnivore	0.239	0.266	0.027	-2.420
39	Epifaunal sessile suspension feeder	0.000	1.419	1.419	9.465
40	Infaunal bivalve	75.376	72.188	-3.188	-518.883
41	Jellyfish	4.980	5.411	0.431	-49.160
42	Macrofauna	1.068	0.871	-0.197	733.258
43	Meiofauna	0.002	0.002	0.000	175.196
44	Omnivorous and herbivorous zooplankton	35.447	39.124	3.678	-208.879
45	Polychaetes	0.000	0.000	0.000	-120.180
46	Orange sea pen	0.052	0.023	-0.028	-4.229
47	Shrimp	0.182	0.172	-0.010	-3.530
48	Biofilm freshwater	0.000	0.000	0.000	1,468.419
49	Biofilm marine	0.000	0.000	0.000	-419.837
50	Brown algae	0.000	0.225	0.225	-53.157
51	Eelgrass (native)	0.024	0.002	-0.023	11.489
52	Green algae	0.000	0.000	0.000	-582.947
53	Japanese eelgrass (non-native)	0.000	0.000	0.000	-0.048
54	Red algae	0.000	0.011	0.011	-1.572
55	Phytoplankton	10.171	10.812	0.641	68.840
56	Tidal marsh	0.000	0.000	0.000	335.059
57	Biomat	0.000	0.000	0.000	-356.115
58	Detritus	1.386	1.447	0.062	4.753
	TOTAL	155.188	153.476	-1.712	204.390

Note: Estimates are rounded. Biomass information is at a point in time after equilibrium at Roberts Bank has been reached.

a. As indicated in the accompanying text, it is not valid in ecosystem modelling to analyse a subset of an ecosystem model domain, without considering the entire study area; hence, potential biomass differences with and without Project within the deposition zones (zones 2 and 4 combined; **Figure IR3-02-1**) are compared to the overall biomass differences, with and without Project, across the entire RB model study area. Using dunlin as an example, there are no changes in biomass (from terminal and causeway footprints) to dunlin within the zones of deposition, however, across the entire RB model study area dunlin biomass is forecasted to increase by 0.060 t, and the increase is not anticipated within the deposition zones.

Table IR3-02-A3 Biomass Estimates from the Roberts Bank Ecosystem Model Key Run within the Accelerated Tidal Channel Zone (Zone 3; Figure IR3-02-1), Expressed Without and With the Project

No.	Functional Group	Biomass, Accelerated Tidal Channel Zone (without Project, t)	Biomass, Accelerated Tidal Channel Zone (with Project, t)	Difference, Accelerated Tidal Channel Zone (with - without Project, t)	Total Biomass Change in the RB Model Study Area[a] (with - without Project, t)
1	Baleen whales	0.001	0.001	0.000	-0.023
2	Dolphins and porpoises	0.001	0.002	0.000	-0.009
3	Pinnipeds	0.206	0.206	0.001	-0.592
4	Southern resident killer whales	0.002	0.001	0.000	-0.015
5	Transient killer whales	0.002	0.002	0.000	-0.032
6	American wigeon	0.005	0.005	-0.001	-0.400
7	Bald eagle	0.001	0.001	0.000	-0.008
8	Brant goose	0.001	0.002	0.001	-0.058
9	Diving waterbirds	0.010	0.015	0.006	-0.095
10	Dunlin	0.004	0.004	0.001	0.060
11	Great blue heron	0.005	0.005	0.000	-0.002
12	Gulls and terns	0.043	0.046	0.004	-0.038
13	Raptors	0.000	0.000	0.000	0.003
14	Shorebirds	0.000	0.000	0.000	-0.001
15	Waterfowl	0.035	0.036	0.001	1.345
16	Western sandpiper	0.000	0.000	0.000	0.008
17	Chinook salmon adult	1.062	0.044	-0.018	-9.504
18	Chinook salmon juvenile	0.000	0.002	0.001	0.104
19	Chum salmon adult	0.466	0.446	-0.021	-5.125
20	Chum salmon juvenile	0.001	0.002	0.002	0.070
21	Dogfish	0.201	0.213	0.012	-0.811
22	Flatfish	0.027	0.051	0.025	-0.308
23	Forage fish	5.901	6.137	0.236	-8.096
24	Herring	0.894	2.997	2.103	-5.618
25	Large demersal fish	0.034	0.070	0.036	-0.101
26	Lingcod	0.000	0.001	0.001	-0.975
27	Rockfish	0.000	0.000	0.000	-1.631
28	Salmon adult	0.269	0.260	-0.009	-2.281
29	Salmon juvenile	0.001	0.001	0.000	-0.003
30	Sandlance	0.018	0.063	0.044	0.645
31	Shiner perch	0.013	0.030	0.018	1.642
32	Skate	0.027	0.025	-0.003	-1.018

No.	Functional Group	Biomass, Accelerated Tidal Channel Zone (without Project, t)	Biomass, Accelerated Tidal Channel Zone (with Project, t)	Difference, Accelerated Tidal Channel Zone (with - without Project, t)	Total Biomass Change in the RB Model Study Area[a] (with - without Project, t)
33	Small demersal fish	0.006	0.021	0.015	-0.214
34	Starry flounder	0.157	0.175	0.018	0.692
35	Carnivorous zooplankton	3.118	8.866	5.748	-173.949
36	Dungeness crab	4.147	5.796	1.649	-8.843
37	Epifaunal grazer	3.159	3.792	0.632	-65.951
38	Epifaunal omnivore	0.475	0.643	0.168	-2.420
39	Epifaunal sessile suspension feeder	0.000	0.000	0.000	9.465
40	Infaunal bivalve	180.760	199.582	18.823	-518.883
41	Jellyfish	1.617	4.719	3.102	-49.160
42	Macrofauna	0.943	1.291	0.347	733.258
43	Meiofauna	0.015	0.010	-0.004	175.196
44	Omnivorous and herbivorous zooplankton	11.856	36.179	24.323	-208.879
45	Polychaetes	0.000	0.000	0.000	-120.180
46	Orange sea pen	0.005	0.005	0.001	-4.229
47	Shrimp	0.069	0.209	0.141	-3.530
48	Biofilm freshwater	0.000	0.000	0.000	1,468.419
49	Biofilm marine	0.000	0.000	0.000	-419.837
50	Brown algae	0.000	0.000	0.000	-53.157
51	Eelgrass (native)	0.080	0.568	0.488	11.489
52	Green algae	0.000	0.000	0.000	-582.947
53	Japanese eelgrass (non-native)	0.000	0.000	0.000	-0.048
54	Red algae	0.000	0.000	0.000	-1.572
55	Phytoplankton	35.885	34.364	-1.522	68.840
56	Tidal marsh	0.000	0.000	0.000	335.059
57	Biomat	0.000	0.000	0.000	-356.115
58	Detritus	1.708	2.338	0.629	4.753
	TOTAL	253.230	310.230	57.000	204.390

Note: Estimates are rounded. Biomass information is at a point in time after equilibrium at Roberts Bank has been reached.

a. As indicated in the accompanying text, it is not valid in ecosystem modelling to analyse a subset of an ecosystem model domain, without considering the entire study area; hence, potential biomass differences with and without Project within the accelerated tidal channel zone (zone 3; **Figure IR3-02-1**) are compared to the overall biomass differences, with and without Project, across the entire RB model study area. Using dunlin as an example, a slight increase in biomass (from terminal and causeway footprints) of up to 0.001 t is forecasted for dunlin within the accelerated tidal channel zone, which represents 1.6% of the overall increase of 0.060 t forecasted across the entire RB model study area. Overall increase in dunlin biomass is not anticipated within the zone of accelerated tidal channel.

Table IR3-02-A4 Biomass Estimates from the Roberts Bank Ecosystem Model Key Run within the Wave Shadow Zone (Zone 5; Figure IR3-02-1), Expressed Without and With the Project

No.	Functional Group	Biomass, Wave Shadow Zone (without Project, t)	Biomass, Wave Shadow Zone (with Project, t)	Difference, Wave Shadow Zone (with - without Project, t)	Total Biomass Change in the RB Model Study Area[a] (with - without Project, t)
1	Baleen whales	0.004	0.003	0.000	-0.023
2	Dolphins and porpoises	0.021	0.029	0.009	-0.009
3	Pinnipeds	0.499	0.507	0.007	-0.592
4	Southern resident killer whales	0.011	0.010	-0.001	-0.015
5	Transient killer whales	0.009	0.009	-0.001	-0.032
6	American wigeon	0.000	0.000	0.000	-0.400
7	Bald eagle	0.003	0.004	0.000	-0.008
8	Brant goose	0.011	0.082	0.071	-0.058
9	Diving waterbirds	0.083	0.103	0.019	-0.095
10	Dunlin	0.000	0.000	0.000	0.060
11	Great blue heron	0.000	0.000	0.000	-0.002
12	Gulls and terns	0.082	0.104	0.022	-0.038
13	Raptors	0.000	0.000	0.000	0.003
14	Shorebirds	0.000	0.000	0.000	-0.001
15	Waterfowl	0.083	0.163	0.080	1.345
16	Western sandpiper	0.000	0.000	0.000	0.008
17	Chinook salmon adult	6.137	6.515	0.378	-9.504
18	Chinook salmon juvenile	0.007	0.034	0.026	0.104
19	Chum salmon adult	3.270	3.289	0.019	-5.125
20	Chum salmon juvenile	0.012	0.031	0.019	0.070
21	Dogfish	1.164	1.511	0.346	-0.811
22	Flatfish	0.275	0.599	0.324	-0.308
23	Forage fish	15.224	15.405	0.181	-8.096
24	Herring	13.612	15.483	1.872	-5.618
25	Large demersal fish	0.203	0.452	0.250	-0.101
26	Lingcod	0.030	1.491	1.461	-0.975
27	Rockfish	0.014	0.473	0.460	-1.631
28	Salmon adult	1.560	1.559	-0.001	-2.281
29	Salmon juvenile	0.003	0.003	0.000	-0.003
30	Sandlance	0.247	0.366	0.120	0.645
31	Shiner perch	0.090	0.240	0.151	1.642
32	Skate	0.841	0.958	0.116	-1.018
33	Small demersal fish	0.045	0.203	0.158	-0.214

No.	Functional Group	Biomass, Wave Shadow Zone (without Project, t)	Biomass, Wave Shadow Zone (with Project, t)	Difference, Wave Shadow Zone (with - without Project, t)	Total Biomass Change in the RB Model Study Area[a] (with - without Project, t)
34	Starry flounder	0.213	0.702	0.489	0.692
35	Carnivorous zooplankton	57.846	44.104	-13.741	-173.949
36	Dungeness crab	21.036	21.473	0.437	-8.843
37	Epifaunal grazer	34.834	51.824	16.990	-65.951
38	Epifaunal omnivore	1.347	6.611	5.265	-2.420
39	Epifaunal sessile suspension feeder	0.015	8.288	8.273	9.465
40	Infaunal bivalve	410.887	328.287	-82.599	-518.883
41	Jellyfish	28.914	25.373	-3.541	-49.160
42	Macrofauna	1.958	119.084	117.126	733.258
43	Meiofauna	0.052	0.178	0.126	175.196
44	Omnivorous and herbivorous zooplankton	193.902	199.464	5.562	-208.879
45	Polychaetes	0.002	2.910	2.908	-120.180
46	Orange sea pen	1.853	0.712	-1.141	-4.229
47	Shrimp	0.962	0.913	-0.049	-3.530
48	Biofilm freshwater	0.000	0.000	0.000	1,468.419
49	Biofilm marine	0.000	0.000	0.000	-419.837
50	Brown algae	0.000	76.512	76.512	-53.157
51	Eelgrass (native)	1.251	34.138	32.888	11.489
52	Green algae	0.000	36.771	36.771	-582.947
53	Japanese eelgrass (non-native)	0.000	0.050	0.050	-0.048
54	Red algae	0.000	3.597	3.597	-1.572
55	Phytoplankton	54.638	73.086	18.448	68.840
56	Tidal marsh	0.000	0.000	0.000	335.059
57	Biomat	0.000	0.000	0.000	-356.115
58	Detritus	7.640	10.047	2.407	4.753
	TOTAL	860.889	1,093.753	232.864	204.390

Note: Estimates are rounded. Biomass information is at a point in time after equilibrium at Roberts Bank has been reached.

a. As indicated in the accompanying text, it is not valid in ecosystem modelling to analyse a subset of an ecosystem model domain, without considering the entire study area; hence, potential biomass differences with and without Project within the wave shadow zone (zone 5; **Figure IR3-02-1**) are compared to the overall biomass differences, with and without Project, across the entire RB model study area. Using dunlin as an example, there are no changes in biomass (from terminal and causeway footprints) to dunlin within the zone of wave shadow, however, across the entire RB model study area dunlin biomass is forecasted to increase by 0.060 t, and the increase is not anticipated within the zone of wave shadow.

Table IR3-02-A5 Biomass Estimates from the Roberts Bank Ecosystem Model Key Run within the Wave Scour Zone (Zone 6; Figure IR3-02-1), Expressed without and with the Project

No.	Functional Group	Biomass, Wave Scour Zone (without Project, t)	Biomass, Wave Scour Zone (with Project, t)	Difference, Wave Scour Zone (with - without Project, t)	Total Biomass Change in the RB Model Study Area[a] (with - without Project, t)
1	Baleen whales	0.000	0.000	0.000	-0.023
2	Dolphins and porpoises	0.000	0.000	0.000	-0.009
3	Pinnipeds	0.012	0.012	0.000	-0.592
4	Southern resident killer whales	0.001	0.001	0.000	-0.015
5	Transient killer whales	0.000	0.000	0.000	-0.032
6	American wigeon	0.000	0.000	0.000	-0.400
7	Bald eagle	0.000	0.000	0.000	-0.008
8	Brant goose	0.000	0.000	0.000	-0.058
9	Diving waterbirds	0.002	0.002	0.000	-0.095
10	Dunlin	0.000	0.000	0.000	0.060
11	Great blue heron	0.000	0.000	0.000	-0.002
12	Gulls and terns	0.003	0.003	0.001	-0.038
13	Raptors	0.000	0.000	0.000	0.003
14	Shorebirds	0.000	0.000	0.000	-0.001
15	Waterfowl	0.006	0.009	0.003	1.345
16	Western sandpiper	0.000	0.000	0.000	0.008
17	Chinook salmon adult	0.366	0.347	-0.019	-9.504
18	Chinook salmon juvenile	0.000	0.000	0.000	0.104
19	Chum salmon adult	0.213	0.211	-0.002	-5.125
20	Chum salmon juvenile	0.000	0.000	0.000	0.070
21	Dogfish	0.026	0.025	-0.001	-0.811
22	Flatfish	0.013	0.014	0.001	-0.308
23	Forage fish	0.365	0.292	-0.072	-8.096
24	Herring	0.259	0.121	-0.138	-5.618
25	Large demersal fish	0.002	0.000	-0.002	-0.101
26	Lingcod	0.025	1.029	1.004	-0.975
27	Rockfish	0.012	0.455	0.444	-1.631
28	Salmon adult	0.098	0.098	0.000	-2.281
29	Salmon juvenile	0.000	0.000	0.000	-0.003
30	Sandlance	0.006	0.003	-0.002	0.645
31	Shiner perch	0.001	0.001	-0.001	1.642
32	Skate	0.010	0.004	-0.006	-1.018
33	Small demersal fish	0.001	0.001	0.000	-0.214

No.	Functional Group	Biomass, Wave Scour Zone (without Project, t)	Biomass, Wave Scour Zone (with Project, t)	Difference, Wave Scour Zone (with - without Project, t)	Total Biomass Change in the RB Model Study Area[a] (with - without Project, t)
34	Starry flounder	0.003	0.001	-0.002	0.692
35	Carnivorous zooplankton	1.362	0.732	-0.630	-173.949
36	Dungeness crab	0.218	0.227	0.009	-8.843
37	Epifaunal grazer	0.004	1.280	1.277	-65.951
38	Epifaunal omnivore	0.010	0.009	0.000	-2.420
39	Epifaunal sessile suspension feeder	0.022	0.815	0.793	9.465
40	Infaunal bivalve	5.749	0.563	-5.186	-518.883
41	Jellyfish	0.740	0.414	-0.326	-49.160
42	Macrofauna	0.073	0.548	0.474	733.258
43	Meiofauna	0.000	0.000	0.000	175.196
44	Omnivorous and herbivorous zooplankton	3.825	2.886	-0.939	-208.879
45	Polychaetes	0.000	0.000	0.000	-120.180
46	Orange sea pen	0.014	0.001	-0.013	-4.229
47	Shrimp	0.013	0.002	-0.012	-3.530
48	Biofilm freshwater	0.000	0.000	0.000	1,468.419
49	Biofilm marine	0.000	0.000	0.000	-419.837
50	Brown algae	0.045	9.328	9.283	-53.157
51	Eelgrass (native)	0.000	0.046	0.046	11.489
52	Green algae	0.000	0.000	0.000	-582.947
53	Japanese eelgrass (non-native)	0.000	0.000	0.000	-0.048
54	Red algae	0.002	0.419	0.417	-1.572
55	Phytoplankton	1.016	0.837	-0.179	68.840
56	Tidal marsh	0.000	0.000	0.000	335.059
57	Biomat	0.000	0.000	0.000	-356.115
58	Detritus	0.146	0.189	0.043	4.753
	TOTAL	14.661	20.925	6.265	204.390

Note: Estimates are rounded. Biomass information is at a point in time after equilibrium at Roberts Bank has been reached.

a. As indicated in the accompanying text, it is not valid in ecosystem modelling to analyse a subset of an ecosystem model domain, without considering the entire study area; hence, potential biomass differences with and without Project within the wave scour zone (zone 6; **Figure IR3-02-1**) are compared to the overall biomass differences, with and without Project, across the entire RB model study area. Using dunlin as an example, there are no changes in biomass (from terminal and causeway footprints) to dunlin within the zone of wave scour, however, across the entire RB model study area dunlin biomass is forecasted to increase by 0.060 t, and the increase is not anticipated within the zone of wave scour.

Table IR3-02-A6 Biomass Estimates from the Roberts Bank Ecosystem Model Key Run within the Increased Turbidity Zone (Zone 7; Figure IR3-02-1), Expressed without and with the Project

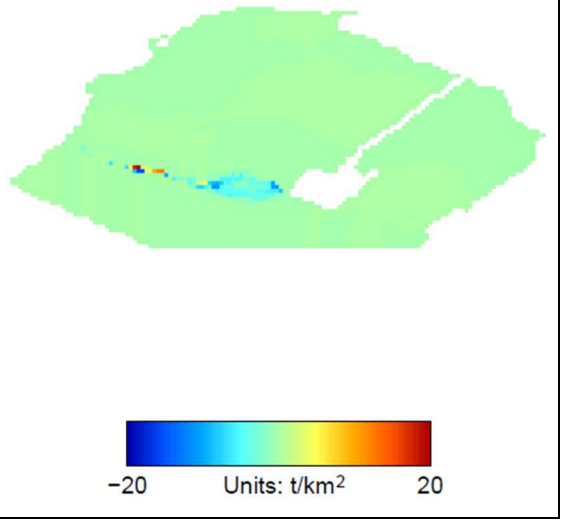
No.	Functional Group	Biomass, Increased Turbidity Zone (without Project, t)	Biomass, Increased Turbidity Zone (with Project, t)	Difference, Increased Turbidity Zone (with - without Project, t)	Total Biomass Change in the RB Model Study Area[a] (with - without Project, t)
1	Baleen whales	0.000	0.000	0.000	-0.023
2	Dolphins and porpoises	0.002	0.001	-0.001	-0.009
3	Pinnipeds	0.690	0.696	0.006	-0.592
4	Southern resident killer whales	0.000	0.000	0.000	-0.015
5	Transient killer whales	0.001	0.001	0.000	-0.032
6	American wigeon	0.219	0.207	-0.013	-0.400
7	Bald eagle	0.006	0.003	-0.003	-0.008
8	Brant goose	0.094	0.052	-0.042	-0.058
9	Diving waterbirds	0.066	0.035	-0.032	-0.095
10	Dunlin	0.038	0.032	-0.005	0.060
11	Great blue heron	0.052	0.049	-0.003	-0.002
12	Gulls and terns	0.198	0.182	-0.016	-0.038
13	Raptors	0.001	0.001	0.000	0.003
14	Shorebirds	0.005	0.005	0.000	-0.001
15	Waterfowl	0.605	0.519	-0.086	1.345
16	Western sandpiper	0.004	0.005	0.001	0.008
17	Chinook salmon adult	0.489	0.505	0.015	-9.504
18	Chinook salmon juvenile	0.068	0.073	0.005	0.104
19	Chum salmon adult	0.204	0.201	-0.003	-5.125
20	Chum salmon juvenile	0.043	0.048	0.005	0.070
21	Dogfish	0.080	0.096	0.016	-0.811
22	Flatfish	0.513	0.229	-0.284	-0.308
23	Forage fish	21.970	22.168	0.198	-8.096
24	Herring	16.182	3.416	-12.766	-5.618
25	Large demersal fish	1.170	0.666	-0.504	-0.101
26	Lingcod	0.033	0.002	-0.031	-0.975
27	Rockfish	0.016	0.001	-0.014	-1.631
28	Salmon adult	0.107	0.107	0.000	-2.281
29	Salmon juvenile	0.003	0.003	0.000	-0.003
30	Sandlance	0.697	0.533	-0.164	0.645
31	Shiner perch	0.715	0.954	0.238	1.642
32	Skate	0.055	0.011	-0.044	-1.018
33	Small demersal fish	0.529	0.176	-0.353	-0.214

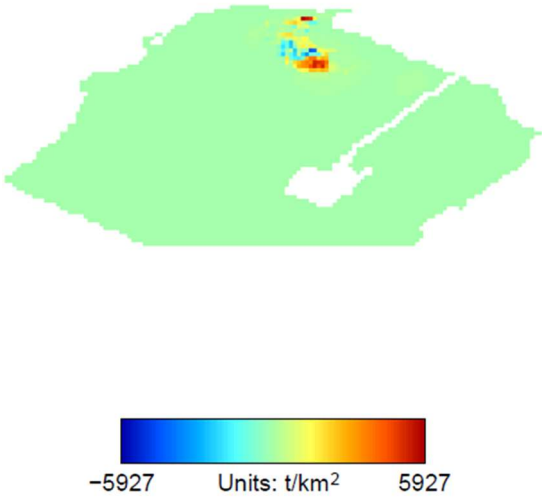
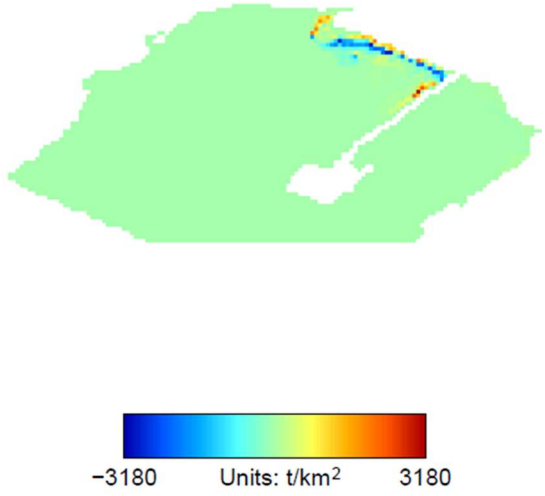
No.	Functional Group	Biomass, Increased Turbidity Zone (without Project, t)	Biomass, Increased Turbidity Zone (with Project, t)	Difference, Increased Turbidity Zone (with - without Project, t)	Total Biomass Change in the RB Model Study Area[a] (with - without Project, t)
34	Starry flounder	1.711	1.877	0.166	0.692
35	Carnivorous zooplankton	22.485	3.722	-18.763	-173.949
36	Dungeness crab	12.557	7.162	-5.396	-8.843
37	Epifaunal grazer	81.313	82.604	1.291	-65.951
38	Epifaunal omnivore	10.176	9.956	-0.220	-2.420
39	Epifaunal sessile suspension feeder	1.226	6.079	4.853	9.465
40	Infaunal bivalve	422.118	239.961	-182.157	-518.883
41	Jellyfish	12.056	1.253	-10.803	-49.160
42	Macrofauna	267.442	327.577	60.134	733.258
43	Meiofauna	109.826	176.554	66.728	175.196
44	Omnivorous and herbivorous zooplankton	144.345	0.164	-144.181	-208.879
45	Polychaetes	28.856	48.714	19.858	-120.180
46	Orange sea pen	0.002	0.000	-0.002	-4.229
47	Shrimp	1.058	0.424	-0.633	-3.530
48	Biofilm freshwater	0.000	0.000	0.000	1,468.419
49	Biofilm marine	0.000	0.000	0.000	-419.837
50	Brown algae	1.792	3.528	1.737	-53.157
51	Eelgrass (native)	33.186	11.013	-22.173	11.489
52	Green algae	140.357	276.006	135.649	-582.947
53	Japanese eelgrass (non-native)	0.236	0.504	0.268	-0.048
54	Red algae	0.039	0.135	0.095	-1.572
55	Phytoplankton	105.072	145.142	40.069	68.840
56	Tidal marsh	0.091	0.000	-0.091	335.059
57	Biomat	0.000	6.173	6.173	-356.115
58	Detritus	10.504	9.333	-1.172	4.753
	TOTAL	1,451.303	1,388.856	-62.448	204.390

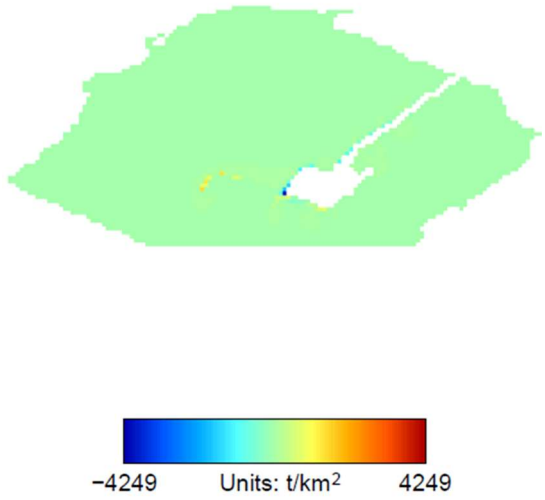
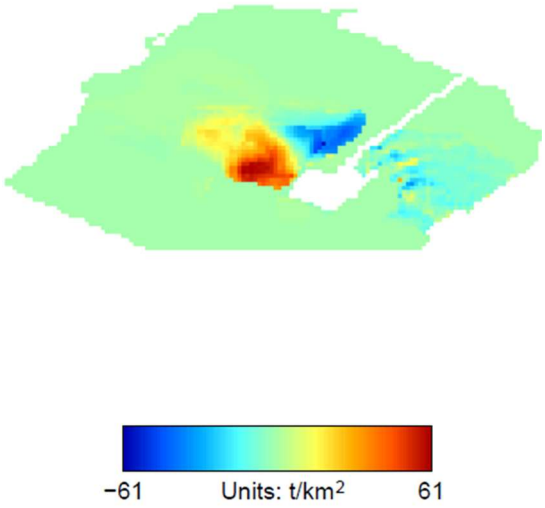
Note: Estimates are rounded. Biomass information is at a point in time after equilibrium at Roberts Bank has been reached.

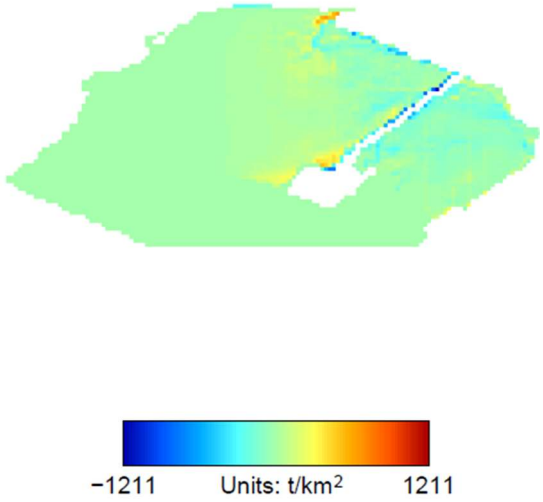
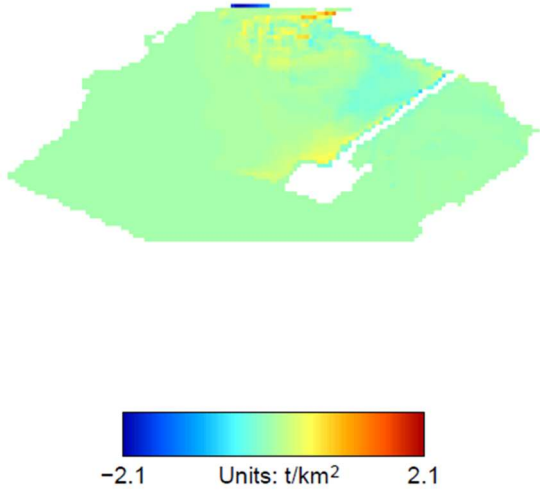
a. As indicated in the accompanying text, it is not valid in ecosystem modelling to analyse a subset of an ecosystem model domain, without considering the entire study area; hence, potential biomass differences with and without Project within the increased salinity zone (zone 7; **Figure IR3-02-1**) are compared to the overall biomass differences, with and without Project, across the entire RB model study area. Using dunlin as an example, biomass is forecasted to decrease (negative sign, see table) by 0.005 t (from terminal and causeway footprints) within the zone of increased turbidity; however, across the entire RB model study area dunlin biomass is forecasted to increase by 0.060 t, and the increase is not anticipated within the zone of increased turbidity.

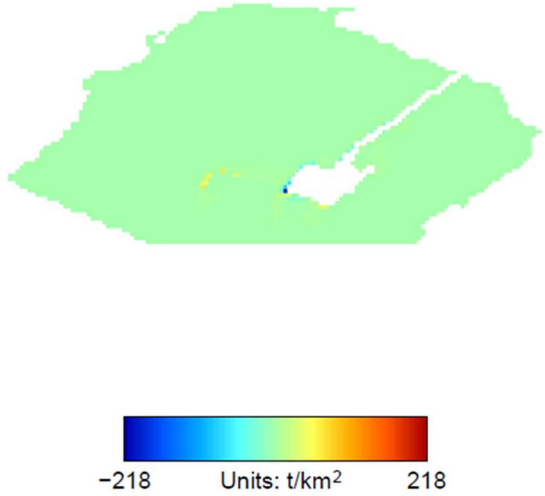
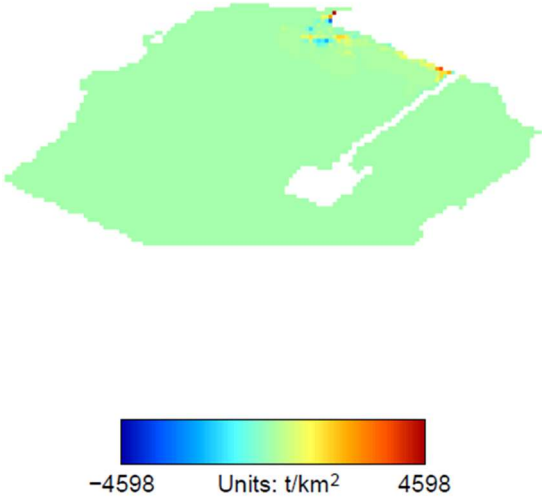
Table IR3-02-A7 Biomass Estimates (Without and With the Project) and Spatial Distribution of Forecasted Biomass Changes (Ecospace Difference, With-Without) across the Entire Roberts Bank Ecosystem Model Study Area for Habitat Forming Functional Groups

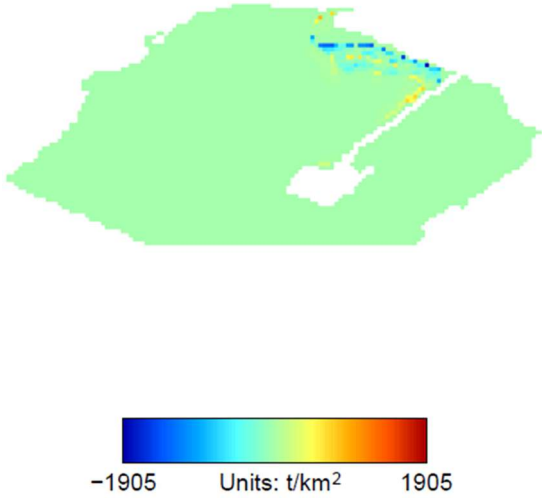
No.	Functional Group	Biomass (without, t)	Biomass (with, t)	Difference (with-without, t)	Ratio	Ecospace Difference (with-without, t)
46	Orange sea pen	7.692	3.463	-4.229	0.45	

No.	Functional Group	Biomass (without, t)	Biomass (with, t)	Difference (with-without, t)	Ratio	Ecospace Difference (with-without, t)
48	Biofilm (freshwater)	1,642.846	3,111.264	1,468.419	1.89	
49	Biofilm (marine)	1,819.684	1,399.847	-419.837	0.77	

No.	Functional Group	Biomass (without, t)	Biomass (with, t)	Difference (with-without, t)	Ratio	Ecospace Difference (with-without, t)
50	Brown algae	448.060	394.903	-53.157	0.88	
51	Eelgrass (native)	304.576	316.065	11.489	1.04	

No.	Functional Group	Biomass (without, t)	Biomass (with, t)	Difference (with-without, t)	Ratio	Ecospace Difference (with-without, t)
52	Green algae	6,894.604	6,311.657	-582.947	0.92	
53	Japanese eelgrass (non-native)	6.855	6.807	-0.048	0.99	

No.	Functional Group	Biomass (without, t)	Biomass (with, t)	Difference (with-without, t)	Ratio	Ecospace Difference (with-without, t)
54	Red algae	15.168	13.596	-1.572	0.90	
56	Tidal marsh	1,329.832	1,664.890	335.059	1.25	

No.	Functional Group	Biomass (without, t)	Biomass (with, t)	Difference (with-without, t)	Ratio	Ecospace Difference (with-without, t)
57	Biomat	1217.125	861.010	-356.115	0.71	

Note: Orange sea pens are included in the table because they are considered an invertebrate habitat forming group.

IR3-03 Roberts Bank Ecosystem Model – Study Area

Information Source(s)

EIS Volume 3: Section 10.0

EIS Volume 2: Figures 9.5-1, 9.6-1 and 9.7-1

Context

The Proponent reported in Section 10.3.3 of the EIS that the study area for the RB EwE model covered an area of 54.68 km^2 and included the intertidal and subtidal zones between Canoe Passage and the BC Ferries Tsawwassen Terminal, from shoreline to the 100 metre depth contour or the Canada – United States international border. This study area was selected by the Proponent based on the anticipated direct and indirect Project effects related to changes in coastal geomorphology, surficial geology and marine sediment, and marine water quality, and the influence of these changes on marine intermediate components and valued components.

There are differences in the study area used for the RB EwE model (Figure 10.3-1) and the study areas for Coastal Geomorphology (Figure 9.5-1), Surficial Geology and Marine Sediment (Figure 9.6-1) and Marine Water Quality (Figure 9.7-1). For example, the coastal geomorphology local assessment area includes all of Canoe Passage which is absent from the RB EwE study area.

Information Request

Clarify how the RB EwE model study area was extracted from the larger study areas that were adopted for Coastal Geomorphology, Surficial Geology and Marine Sediment and Marine Water Quality.

Provide rationale to support the use of spatial boundaries based on Coastal Geomorphology, Surficial Geology and Marine Sediment and Marine Water Quality to define the relevant spatial scale for modelling effects on functional groups in the RB EwE model study area.

Provide rationale as to why the RB EwE model study area was defined on the south by the Canada – United States of America border and not by ecosystem processes.

VFPA Response

Clarify how the RB EwE model study area was extracted from the larger study areas that were adopted for Coastal Geomorphology, Surficial Geology and Marine Sediment and Marine Water Quality.

The Roberts Bank ecosystem model (RB model) study area was not extracted from the larger study areas of coastal geomorphology, surficial geology and marine sediment, and marine water quality, but was informed by them.

Ecosystem processes are defined as the physical, chemical, and biological actions or events that link organisms and their environment, including decomposition, production, nutrient cycling, and energy flow (Hassan et al. 2005). Spatial boundaries are defined, in large part, by ecosystem processes since the model directly tracks the spatial extent of changes in production and energy flow. Spatial boundaries of the RB model were selected to satisfy the core objective of the model, which was to forecast changes in productivity with and without the terminal and causeway footprints. Spatial boundaries were selected at an appropriate scale so as to not over- or underestimate the effects of the Project. To take an illustrative and extreme example, if spatial boundaries were defined based on the extent over which the ecosystem process of nutrient cycling occurs, then the entire Fraser River basin might be included—an area of approximately 233,000 km^2 (ECCC 2010)—as upriver nutrient inputs drain into the Strait of Georgia. Such a large spatial scale would diminish the effects of the Project and is therefore not appropriate to fulfill model objectives.

The model computes how predicted changes in environmental conditions from the Project footprint drive changes in the productivity of functional groups. In particular, changes in coastal geomorphic processes underpin changes to surficial geology, marine sediment and marine water quality (EIS Sections 9.6.5.1 and 9.7.5.1, respectively) which collectively elicit changes in the productivity of functional groups. The spatial extent of the RB model needed to be large enough to capture all potentially significant ecological effects of the Project, and no larger.

To meet the above-stated RB model objective, the maximum spatial extent of geomorphic changes (from terminal and causeway placement) needed to be captured within the RB model, including any changes in surficial geology and marine sediment or water quality. This was accomplished by incorporating spatial outputs from the coastal geomorphology hydrodynamic model—salinity, depth, bottom current, wave height, and substrate type (soft or hard)—as inputs into the RB model. The areas of forecasted changes in these model outputs (and hence of the RB model) are smaller than the selected study areas for coastal geomorphology, surficial geology and marine sediment, and marine water quality, because the areas of predicted changes to coastal processes are smaller.

Other considerations in defining spatial boundaries included the ability to account for external exchanges (e.g., tides) and migratory species (see question 2.1 in CEAR Document #547), as well as to select a scale that was not too big, so as to dilute relative Project effects, nor too small, so as to miss areas where potential impacts might occur. The scale of the RB model is considered appropriate for detecting and quantifying changes to the local physical environment resulting from the Project, and that may in turn affect the ecosystem and its components. Additionally, as the selected spatial boundaries encompass the anticipated maximum extent of effects from the terminal and causeway footprints on both hydrodynamic processes and the productivity of marine functional groups, they are considered relevant and appropriate.

Provide rationale to support the use of spatial boundaries based on Coastal Geomorphology, Surficial Geology and Marine Sediment and Marine Water Quality to define the relevant spatial scale for modelling effects on functional groups in the RB EwE model study area.

As described above, the rationale for informing RB model spatial boundaries with intermediate component spatial boundaries is to capture the maximum extent of effects to processes that shape the physical environment and the productivity of biological functional groups.

Provide rationale as to why the RB EwE model study area was defined on the south by the Canada – United States of America border and not by ecosystem processes.

Model spatial boundaries were not "defined on the south by the Canada – United States of America border"; rather, the boundaries reflect the forecasted spatial extent of changes in coastal geomorphology, which drive changes in ecosystem processes (i.e., productivity and energy flow for functional groups; see the first subsection of this response). As outlined in EIS Section 9.5.8, and subsequently in the response to IR2-17 (see CEAR Document #931[1]), changes to coastal geomorphology and hydrodynamic conditions from the Project footprint do not extend past the south side of the B.C. Ferries Terminal. Therefore, the effects on productivity relating to terminal and causeway placement are also not forecasted to extend beyond the Canada-U.S.A. border, and it was not necessary for the RB model boundaries to extend beyond the south side of the B.C. Ferries Terminal.

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[1] CEAR Document #931 From the Vancouver Fraser Port Authority to the Review Panel re: Responses to Information Request Package 2 (See Reference Document #908).

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IR3-04 Roberts Bank Ecosystem Model – Sensitivity Analysis: Varying Number of Grid Cells

Information Source(s)

EIS Volume 3: Appendix 10-C, Appendix 10-D

Context

The Proponent defined the RB EwE model area as 54.68 km^2 (without the proposed Project) and utilized a uniform grid of 100 x 100 m (1 ha) cells, which generated 8694 grid cells, of which 5468 were included in the model calculations (Appendix 10-C, Figure 2-7)

Sensitivity analyses of the RB EwE model considered:

- increases and decreases in the predators' ability to influence prey dynamics;
- effects of omitting one abiotic factor at a time for each functional group;
- increases and decreases in the forecasted effects of the proposed Project on abiotic factors; and,
- sensitivity to input parameter uncertainty.

The Proponent's conclusion from the RB EwE modeling (Appendix 10-D) was that the proposed Project will have an effect on the study area, that the effect varies between species, and that the findings are robust to parameter uncertainty.

Further sensitivity analyses are required to understand the influence of different modeling boundaries and study area configurations and to determine their influence on model outputs.

Information Request

Undertake sensitivity analyses for 4 scenarios that compare model outputs corresponding to the following number of 100 x 100 m grid cells:

- 1400 (25% of 5468 cells utilized in the RB EwE model)
- 2700 (50% of 5468 cells utilized in the RB EwE model)
- 5468
- 8694

Present biomass estimates from key runs, without and with the Project, using the same format as Table 3.2 in Appendix 10-C, and present production estimates from key runs, without and with the Project using the same format as Table 3.3 in Appendix 10-C.

Provide a comparison of the biomass and production differences, without and with the Project, for the four different scenarios.

VFPA Response

Undertake sensitivity analyses for 4 scenarios that compare model outputs corresponding to the following number of 100 x 100 m grid cells: 1400 (25% of 5468 cells utilized in the RB EwE model), 2700 (50% of 5468 cells utilized in the RB EwE model), 5468, and 8694.

Sensitivity analyses comparing outputs of the Roberts Bank ecosystem model (RB model) for the four requested scenarios have not been undertaken because it would not yield technically valid results for the reasons explained below.

As explained in detail in IR3-03, spatial boundaries of the RB model were selected to satisfy the core objective of the model (i.e., to forecast changes in productivity with and without the terminal and causeway footprints), and at an appropriate scale so as not to over- or underestimate footprint effects. The spatial extent of the RB model study area is considered appropriate for detecting and quantifying changes to the local physical environment resulting from the terminal and causeway footprint placement, and that may in turn affect the ecosystem and its components. Further detail is provided below.

8,694 Grid Cells

The RB model study area was created and arranged in Ecospace as a rectangular grid with rows and columns using one hectare cells that were oriented north to south and east to west. Orientation of the RB model study area was also influenced by outputs of the hydrodynamic model that were incorporated into the RB model to evaluate changes in the system's productivity with the Project. Specifically, coastal geomorphology outputs were projected on a geospatial grid with the same orientation native to Ecospace (see Section 2.2 in EIS Appendix 10-C). As such, the true geographic orientation of the RB model study area (including the orientation of the Roberts Bank causeway and proposed terminal) is diagonal across this grid.

To accommodate the orientation and diagonal nature of the study area and fit it within the Ecospace model grid, more grid cells (i.e., 8,694 grid cells; grey and white cells shown in Figure 2-7 of EIS Appendix 10-C) were required to be defined within the Ecospace grid (see Section 2.9 of EIS Appendix 10-C for background on the methodology used in the RB model). Of the 8,694 grid cells, 3,226 grid cells were assigned a null value and were not used to run the RB model for the following reasons:

- Many cells are terrestrial in nature and were not used to run the RB model (i.e., grey cells in Figure 2-7 (top right corner) of EIS Appendix 10-C);
- Several of the grey cells not used to run the RB model are part of the existing causeway and terminal; and
- Many cells are outside of the area in which effects to ecosystem productivity from terminal and causeway footprints may change (see discussion for 5,468-cell grid below).

As such, running the RB model using the entire 8,694-cell grid is not technically valid given the limitations described above.

5,468 Grid Cells

The 5,468-cell grid used in the RB model (the white cells in Figure 2-7 of EIS Appendix 10-C) was selected to include all the marine grid cells where the hydrodynamic model predicted changes in physical attributes (i.e., depth, salinity, bottom current velocity, wave height conditions) of biophysical importance (i.e., have the potential to influence species distributions). See response to IR3-03 for additional explanation as to how the RB model study area relates to study areas for several intermediate components.

The RB model study area was also informed by the local assessment areas (LAAs) used for other valued components: marine vegetation, marine invertebrates, and marine fish. By definition, LAA boundaries were set based on the anticipated effects of the Project, and effects to ecosystem productivity from terminal and causeway footprints were anticipated to occur within the 5,468-cell grid used in the RB model.

Multiple sensitivity analyses[1] have been conducted that confirm RB model results as presented in the EIS are robust. This adds confidence that the 5,468-grid cell area used in the RB model is appropriate to evaluate changes in productivity from terminal and causeway footprints (see Section 3.0 of EIS Appendix 10-D for a description of the completed sensitivity analyses).

1,400 and 2,700 Grid Cells

Selecting fewer grid cells, as the information request suggests (i.e., 25% (1,400 grid cells) or 50% (2,700 grid cells) of the 5,468 grid cells), would eliminate information from the RB model and therefore would add error. For example, sub-sampling of the RB model study area would increase the risk of excluding from the analysis i) partial distributions of key functional groups such as eelgrass or intertidal marsh and ii) areas of forecasted Project footprint-related change, thereby likely skewing or over-magnifying Project footprint-related changes to ecosystem productivity. Selecting 25% or 50% of the grid cells would be similar to reading only 25% or 50% randomly selected pages from a book; much valuable content would be lost.

[1] Multiple sensitivity analyses were undertaken to understand how uncertainty in input parameters, as well as biotic and abiotic factors influence the results of the RB model presented in the EIS and evaluate the robustness of the RB model. Sensitivity analyses results are discussed in EIS Appendix 10-D, Section 3.1 (i.e., changes in biotic factors), Sections 3.2 and 3.3 (i.e., changes in abiotic factors), and Section 3.4 (i.e., uncertainty in input parameters).

Additional sensitivity analyses were undertaken in response to preliminary technical questions concerning the RB model and subsequent information requests, and are presented in CEAR Document #547, questions 2.7 and 2.13, as well as in IR3-09 and IR3-23.

Present biomass estimates from key runs, without and with the Project, using the same format as Table 3.2 in Appendix 10-C, and present production estimates from key runs, without and with the Project using the same format as Table 3.3 in Appendix 10-C. Provide a comparison of the biomass and production differences, without and with the Project, for the four different scenarios.

Tabulation of biomass and production estimates from key runs, as well as comparison of biomass and production differences without and with terminal and causeway footprints for the four different scenarios requested have not been provided for the reasons outlined above.

IR3-05 Roberts Bank Ecosystem Model – Exchange with Adjacent Ecosystems

Information Source(s)

Canadian Environmental Assessment Registry Document (CEAR Doc) #547

EIS Volume 3: Section 10.3, Appendix 10-B, Appendix 10-C, Appendix 10-D

Context

According to the Proponent, in CEAR Doc #547, the relatively small spatial scale of the RB EwE model was justified because the model was specifically chosen for assessing productivity changes, and because the relative influences of external exchanges were assumed to be identical with and without the proposed Project. The RB EwE model study area was limited only to Roberts Bank and parts of the foreslope even though the spatial extent of the coastal geomorphology model covered the central and southern parts of the Strait of Georgia and had forecasted minimal geomorphology changes outside Roberts Bank as a result of the Project.

As identified in Appendix 10-C, an assumption used for the RB EwE model was that highly mobile species with broad prey bases would be partially sustained by external energy from outside the model system. According to the Proponent, average annual biomasses were used to provide estimates that would reflect the highly mobile species energy supply and demand within the Roberts Bank system and to account for tidal exchanges and seasonal animal migrations through the study area. Seasonally varying parameters (such as salinity, bottom current, and wave height) were captured in the RB EwE model by the use of annual averages for abiotic parameters. The Proponent in Appendix C of Appendix 10-D, identified that the RB EwE model was also reviewed to ensure that there was no match-mismatch between predators and prey - that each predator only fed on prey that were present at the same time. A seasonal biomass matrix (Table C-1) was constructed for functional groups and compared to the diet matrix. The Proponent reported that while there were no match-mismatches between predators and their prey, there were some instances where predators were feeding on prey outside of the prey's peak season.

According to Fisheries and Oceans Canada, EwE models work best when the exchanges within the system being modelled are greater than the exchanges between the modelled system and the 'outside' world. The section of the Roberts Bank ecosystem that is included in the EwE model was comparatively small (54.68 km^2) and complex. It is an intertidally-dominated environment that is subject to strong seasonal influences of both freshwater and marine exchanges across relatively large seaward and shoreward boundaries. The processes taking place outside the modelled ecosystem will contribute to dynamics within the modelled ecosystem (for example, 'outside' food supporting predators which occur in the Roberts Bank ecosystem for only part of the year; predators which may feed in the Roberts Bank ecosystem but export this energy when they migrate out of the region), but which may not be well-resolved by the RB EwE model. The distributions of organisms may differ, however, with and without the Project, which may affect their interactions with areas outside of the modelled system, and the use of diets from outside the modelled system may not reflect the impacts

of the Project. An ecosystem which is open to frequent exchanges of water and organic matter from beyond its boundaries, such as the Roberts Bank ecosystem, would be more robust to local disturbances.

Information Request

Provide further clarification on how the RB EwE model captures exchanges and interactions with adjacent ecosystems, including exchanges of water and organic matter from beyond the boundaries of RB EwE model study area.

Provide a qualitative assessment of migration behavior and migration rates of marine mammals, birds and fish between the RB EwE model study area and adjacent areas.

Describe how the RB EwE model results for marine mammals, birds and fish functional groups would change by including net migration of these components, and/or including exchanges of water and organic matter into the RB EwE model study area, with and without, the proposed Project.

VFPA Response

For reference, in respect to coastal geomorphology changes, the area over which geomorphic changes are predicted to occur as a result of the Project are relatively localised to the proposed terminal and causeway footprint (as shown in Figure IR3-02-1). The Roberts Bank ecosystem model (RB model) study area extends several kilometres beyond those areas and is therefore of sufficient size to capture productivity changes associated with predicted geomorphic changes. Further discussion on the appropriateness of the RB model study area is provided in IR3-04.

Careful consideration was taken when developing the RB model to forecast productivity changes at Roberts Bank with and without the Project. As described in the Preamble at the beginning of this response package, the applicability of the RB model was reviewed by a diverse group of experts and thought leaders through the Productive Capacity Technical Advisory Group. The ability of the RB model to incorporate migratory species and its suitability for Roberts Bank were two key selection criteria supporting this use of the model to forecast changes. The RB model also takes into account exchanges and interactions with adjacent ecosystems, which is described in more detail below.

Best practices for ecosystem modelling (FAO 2008) indicates the scale of a model is best determined by basing boundaries on biological considerations, and when informed by the question being asked and limited by the resolution of the input data. This best practice advice was taken into account when developing the RB model.

Provide further clarification on how the RB EwE model captures exchanges and interactions with adjacent ecosystems, including exchanges of water and organic matter from beyond the boundaries of RB EwE model study area.

The RB model captured exchanges and interactions with adjacent ecosystems during estimation of input parameters (specifically biomass and diet) using methods described below to account for highly mobile groups and groups with broad prey bases partially sustained by external energy. These methods constitute best practice in building Ecopath with Ecosim and

Ecospace (EwE) models for open systems that are influenced by high levels of exchange with areas outside system boundaries (as is the case of Roberts Bank) (Heymans et al. 2016).

The EwE framework used to construct the RB model was developed by University of British Columbia researchers to be applicable to a variety of systems, and has been used extensively to examine the trophic structure and functioning of a host of open systems, including estuaries; bays; coral reefs; coastal, shelf, and upwelling systems; and open seas (Coll et al. 2008, Colléter et al. 2015).

Information on how exchange of water and organic matter was considered in the RB model is also provided below. Information on the RB model study area, as it relates to size and exchange, was previously provided in CEAR Document #547, question 2.1.

For highly mobile and migratory groups that use the RB model study area seasonally or partially in a year, biomass inputs to the RB model were estimated as annualised averages[1] (see EIS Appendix 10-B). For example, biomass for green algae was calculated using density data gathered during the 2012 and 2013 field surveys, corrected as follows. The turnover of green algae is likely at least every two weeks, but only for approximately half the year. Green algae at Roberts Bank are spatially and temporally ephemeral, with productivity occurring mainly between May to September. To account for this seasonality, a correction factor of 0.4 (or 40% of the growing season) was applied to green algae biomass (see Section 6.7.2 of EIS Appendix 10-B).

For 15 groups with broad prey bases that are partially sustained by external energy, an import function was used to account for the proportion of diets contributed from areas outside of the modelled area (see EIS Appendix 10-B and CEAR Document #547, question 2.1). Adult salmon (other than Chinook and chum salmon) are used as an example of the import function in IR3-06; in summary, an import function of 0.99 was applied to the salmon (adult) functional group, meaning they obtain 99% of their prey outside of the RB model study area (indicative of adult salmon not feeding in the estuary before entering freshwater on their way to spawning grounds).

The RB model also describes the potential for exchange of a group's biomass/production between the RB model study area and adjacent areas through the ecotrophic efficiency (EE) metric of Ecopath (see EIS Appendix 10-C and IR3-19 for further explanation of EEs). In summary, a group's EE is the fraction of production that is used or consumed within the study area. This value will approach 1 for groups subject to heavy predation, or be 0 for groups subject to no predation in the study area. Production that does not get consumed in the RB model study area (i.e., the remaining "1-EE" production) is available for export outside the study area (e.g., as part of ontogeny, such as early planktonic life history stages for some functional groups). To show how EE estimates exchanges and interactions with adjacent ecosystems, carnivorous zooplankton are used as an example. In the RB model, EE of carnivorous zooplankton is equal to 0.48, meaning 48% of their production is used in the RB

[1] Biomass for species that occur in the RB model study area throughout the year was also averaged annually.

model study area; the remaining production (1-EE = 52%) is available for export outside the RB model study area. The generally lower EEs in the RB model indicate that Roberts Bank is a productive estuarine system which may have a net export of production to deeper parts of the Strait of Georgia.

Water exchange (in terms of tidal exchange and freshwater input) was captured in the RB model by incorporating changes in coastal geomorphic conditions to inform potential changes in ecosystem productivity with RBT2 (see IR3-02 for information on how coastal geomorphic changes were captured in the RB model). In summary, coastal geomorphic changes (by means of environmental variables: depth, wave height, bottom current velocity, salinity) were investigated for the entire Strait of Georgia but were predicted to be restricted to the area immediately adjacent to the proposed terminal (see Figure 110 of EIS Appendix 9.5-A and EIS Figure 9.5-35). They were incorporated into the RB model to drive system productivity changes with RBT2 as presented in the EIS (see EIS Appendix 10-C). Coastal geomorphic changes with RBT2 are not predicted to occur outside of the RB model study area (see EIS Section 9.5); thus, water exchange with adjacent ecosystems are not predicted to deviate from existing conditions (nor to change with RBT2).

Organic matter[2] is incorporated in the RB model as detritus, which in the study area reflects the standing stock of organic matter in the sediments, organic matter suspended in the water, as well as flows to detritus of unassimilated or decomposing material from other functional groups. In the RB model, import of (suspended sediment-bound) organic matter into the system from freshwater flows and tidal exchange was not considered for the following reasons:

- Fine silt and clay carried in the freshwater is spread as a plume out into the Strait of Georgia resulting in very low sedimentation rates over the tidal flats (see Appendix C of EIS Appendix 9.5-A and IR2-06 in CEAR Document #961[3]); coarser sediments are also deposited in deeper waters of the Strait of Georgia as they exit the Fraser River;
- There is no mechanism for coarser sediments to be transported shoreward once deposited in deeper water (see Appendix C of EIS Appendix 9.5-A); and
- The available organic matter at Roberts Bank (i.e., detritus group in the RB model) does not appear to be limiting but rather underexploited, as the EE of detritus is 0.15, meaning only 15% of detritus is grazed upon by the system's primary consumers.

Incorporation of additional amounts of organic matter in the RB model (i.e., in the form of detritus import rate, in tonnes per square kilometre per year (t/km^2/year)) would slightly increase detritus biomass (and detritus availability), but would not change grazing pressure. As such, detritus would remain underexploited, and would not affect productivity forecasts of functional groups with and without RBT2. This is consistent with what is reported in the

[2] Organic matter refers to particulate organic matter produced by the decomposition (partial or not) of organisms (marine animals and plants) and is included within the system's detritus group.
[3] CEAR Document #961 From the Vancouver Fraser Port Authority to the Review Panel re: Revised Responses to Information Request Package 2 (See Reference Documents #946 and #908).

literature for other estuarine food webs, where a detritus import rate is considered (e.g., Lobry et al. 2008).

Provide a qualitative assessment of migration behavior and migration rates of marine mammals, birds and fish between the RB EwE model study area and adjacent areas.

Migration behaviour (including migration timing and residence time at Roberts Bank) was described as part of the environmental assessment and is included in existing conditions of the EIS, specifically Sections 13.5, 14.5, and 15.5 for marine fish, marine mammals, and coastal birds, respectively.

Information on migration behaviour included in the EIS was interpreted quantitatively and incorporated in the RB model using the approach described in the response provided in the first part of this information request. Specifically, migration between the RB model study area and adjacent areas, as well as seasonal presence by marine mammals, coastal birds, and marine fish in the RB model study area, were included in the RB model by averaging their annual biomass estimates and using the diet import function. This approach is considered best practice in accounting for migration of highly mobile groups and activity outside the modelled area by groups with broad prey bases (Heymans et al. 2016), as explained above. Examples are provided below. CEAR Document #547, question 2.1 provides additional information on this topic.

Marine mammal example: Pinniped abundance in the Strait of Georgia (including Roberts Bank) peaks in spring (e.g., Keple 2002). To reflect seasonal pinniped presence at Roberts Bank, an annual average biomass of 0.4 tonnes per square kilometre (t/km^2) was used in the RB model, extracted from previous EwE models for the Strait of Georgia (Preikshot 2007, Preikshot et al. 2012) (see Section 2.5 of EIS Appendix 10-B). In addition, 50% of their diet (classified as import) was considered to come from outside the study area boundaries (Section 2.6.1 of EIS Appendix 10-C), reflective of their observed tendency to swim in or out of the RB model study area in pursuit of prey (e.g., Keple 2002).

Coastal bird example: American wigeon migrate through Roberts Bank and are most abundant in the RB model study area during fall and winter (Hemmera et al. 2009, Hemmera 2014). The annual average biomass estimate used in the RB model was 0.087 t/km^2, calculated using field data collected during monthly surveys conducted for the Project from May 2012 to May 2013 (Hemmera 2014; for methods on bird biomass calculations see Section 3.2.1 of EIS Appendix 10-B). In addition, 50% of their diet (classified as import) was considered to come from nearby agricultural fields, reflective of American wigeon use of adjacent habitats for feeding during the winter months (see Section 3.13 of EIS Appendix 10-B).

Marine fish example: Juvenile Chinook salmon are present at Roberts Bank between one to three or more weeks (Quinn 2005). The annual average biomass estimate used in the RB model was 0.012 t/km^2, reflective of juvenile Chinook seasonal presence and calculated using field data collected during surveys conducted for the Project in 2012 and 2013 (TDR MF-1, TDR MF-3, and TDR MF-7 in Appendix AIR10-C of Additional Information Request

#10 (AIR-12.04.15-10 in CEAR Document #388[4]); for methods on fish biomass calculations see Section 4.2.1 of EIS Appendix 10-B). In addition, 23% of their diet was classified as import to reflect their temporary use of Roberts Bank as a rearing area and their migration out of the study area as they grow (Quinn 2005).

Describe how the RB EwE model results for marine mammals, birds and fish functional groups would change by including net migration of these components, and/or including exchanges of water and organic matter into the RB EwE model study area, with and without, the proposed Project.

Migration in and out of Roberts Bank is dealt with in the RB model using annualised average biomass estimations (described above), while feeding that occurs outside of the study area is dealt with in the RB model using the diet import function (also described above).

Water exchange between the RB model study area and adjacent areas is also accounted for (as described above) by incorporating into the RB model the hydrodynamic modelling outputs to forecast changes in the system's productivity with RBT2.

Import of additional organic matter (in the form of detritus) into the system (from freshwater flow and tidal exchange) is not accounted for in the RB model. However, as explained above, organic matter is not limiting in the system, but rather is underexploited. Hence, addition to the detritus biomass in the RB model would not change grazing pressure on detritus and would not affect productivity forecasts of functional groups with and without RBT2.

In the RB model, net migration[5] of marine mammals, birds, and fish was set to 0 (Christensen et al. 2005), meaning immigration into the system (expressed in terms of import rate, in t/km^2/year) is equal to emigration out of the system (expressed in terms of export rate, in t/km^2/year). Also, net migration is not expected to change with the Project, meaning immigration into and emigration out of the system will continue at current levels. The RB model is characterised by low mean EE values, meaning a large proportion of the system's production remains unused (due to short residence times of functional groups at Roberts Bank) and is available for export. For example, production of early life history stages of some functional groups (e.g., rockfish, forage fish, Dungeness crab, etc.) is exported in the form of pelagic larvae out of the system every year, driven by tides and currents. This is consistent with how Roberts Bank is understood to function as an open estuarine system (Heymans et al. 2014). The Project is not anticipated to affect the large-scale hydrodynamic drivers that influence export of unused production at Roberts Bank (EIS Section 9.5). Due to low EE values and the large amount of production available for export, the system has the capacity to absorb potential increases in emigration rates (for discussion on EEs of the RB model see IR3-19).

In contrast, immigration greater than emigration in the RB model would indicate additional production entering the Roberts Bank ecosystem. As such, RB model forecasts of productivity

[4] CEAR Document #388 From Port Metro Vancouver to the Canadian Environmental Assessment Agency re: Completeness Review - Responses to Additional Information Requirements Follow-Up (See Reference Document #345) including 22 Technical Data Reports.
[5] Net migration is defined as the difference between immigration and emigration.

changes as a result of terminal and causeway footprints would be expected to be lower. This is because the import comes from outside the modelled system, and must be assumed constant over time and independent of whether the Project is constructed. Hence, the 'with' Project forecasts would be estimated to be lower.

Additional confidence in RB model forecasts for migratory species or seasonal restrictions in the RB model study area is found in sensitivity analyses results (which increased and decreased input biomass, production, and consumption parameters for all groups up to 80%). These sensitivity analyses showed little change in RB model outputs, demonstrating that even with large changes to annual biomass (and by extension migration/seasonality) estimates, the with and without terminal and causeway footprint productivity forecasts do not change.

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IR3-06 Roberts Bank Ecosystem Model – Diet Import Rates

Information Source(s)

CEAR Doc #547

EIS Volume 3: Section 10.3, Appendix 10-B, Appendix 10-C, Appendix 10-D

Context

The Proponent, in CEAR Doc #547, identified that the RB EwE model used biomass and productivity as metrics of energy flow. The consideration of energy flow from outside the system and movements of mobile functional groups with widely distributed prey such as baleen whales were included in the RB EwE model by:

- averaging biomass estimates to reflect groups with large daily or seasonal migrations such as zooplankton and adult salmon;
- using the diet import function to reflect consumption outside the study area; and
- including a conservative movement rate for functional groups within the model.

According to the Proponent, energy from outside the system was included by using an import function in the diet preferences. The diet import function adjusted the level of consumption for mobile functional groups with widely distributed prey to be proportional to amount of time in the system. The Proponent identified that the diet preferences reflected the utilization of prey outside of the study area through the diet import function and allowed the model to include groups that were present in the study area, while acknowledging the openness of the system (for example, salmon staging in the area but primarily feeding outside of the study area). The Proponent also stated that these groups were unlikely to respond to local environmental changes at Roberts Bank, though their trophic role as predators or prey in the ecosystem needed to be accounted for.

According to Fisheries and Oceans Canada, mobile functional groups bring energy (food) captured from outside the system into the modelled Roberts Bank ecosystem. Mobile functional groups like migratory birds and Pacific salmon use the Roberts Bank ecosystem to obtain food to continue their migrations.

While the RB EwE model had used a diet import factor to reflect the consumption of prey from outside the modelled study area, the Proponent had made the assumption that groups with high diet import rates were unlikely to respond to local changes on Roberts Bank and no justification was provided for this assumption.

Information Request

Provide justification, at the functional group level, for the stated assumption that functional groups with high diet import rates are unlikely to respond to local environmental changes at Roberts Bank.

VFPA Response

The VFPA's statement referred to in the context originates from CEAR Document #547: "These groups are unlikely to respond to local environmental changes at Roberts Bank, though their trophic role as predators or prey in the ecosystem needs to be accounted for." The 'groups' this statement is referring to are characterised by three traits (CEAR Document #547, line 429-436):

1. Groups that have large ranges;
2. Groups that are highly mobile; and
3. Groups that have widely distributed prey.

The above statement was meant to indicate that these groups are likely to be less sensitive to decreases in prey availability in the modelled area and was not intended to suggest that they are less sensitive to changes in environmental conditions (as determined by their environmental preference functions described in Section 2.12 of EIS Appendix 10-C). For example, if a species has a large distribution (e.g., entire west coast of British Columbia), is highly mobile (can travel hundreds of kilometres per day), and its prey is widely distributed (e.g., food is consumed within the species' entire distribution), then its use of Roberts Bank is likely to be low and therefore its exposure to environmental effects from RBT2[1] is expected to be low.

To incorporate the three group characteristics identified above and account for supply and demand of production in the study area of the Roberts Bank ecosystem model (RB model), two approaches were required:

1. Annual biomass averaging; and
2. Diet import application.

Annual biomass averaging was used to reflect the annual usage of the RB model study area by a group; it is important for groups that have large ranges, are highly mobile, and are present in the study area for only a portion of the year. Diet import rate incorporates prey consumption outside of the study area, reflecting consumption habitat of highly mobile groups with large ranges and broadly distributed prey. Further information on these two points is provided below.

Annual Biomass Averaging

Annual biomass averaging accounts for biomass exchanges across study area boundaries due to seasonal migration and non-seasonal movement by weighting the biomass estimate to the annual usage of the study area (biomass estimates are described in EIS Appendix 10-B; annual biomass averaging is also described in CEAR Document #547, question 2.17, and in IR3-05). Annual averages allow us to describe the use of the study area more accurately and

[1] Potential effects to all marine biophysical valued components from all Project activities are assessed in the EIS in Sections 11.0, 12.0, 13.0, 14.0, and 15.0 using multiple lines of evidence; the RB model is one line of evidence only.

to include groups that use the study area at different times of the year. For example, western sandpiper and juvenile salmon are present for short periods of time only, but both groups are present at different times of the year. Annual averages allow us to include both groups while not inflating their usage of the area over the course of a year.

Diet Import Application

To account for movement to and from the RB model study area (and resultant biomass exchanges across the study area boundaries), a diet import function was applied (whereby the diet import proportion represents the proportion of prey a functional group consumes outside the system; diet import rates by functional group are included in Appendix A of EIS Appendix 10-B). Diet import function decreases a group's reliance on the study area for food, but still makes them available as prey. Functional groups with diet import will be less sensitive to changes in local prey availability but remain sensitive to changes in predation pressure.

This approach acknowledges the openness of the Roberts Bank system (e.g., a diet import of 50% was applied to American wigeon based on their usage of adjacent agricultural fields for feeding; Section 3.13 in EIS Appendix 10-B), and is applied to groups that have large migratory ranges, are highly mobile, and have widely distributed prey (e.g., baleen whales, salmon). The use of the diet import function is also generally considered best practice in constructing Ecopath with Ecosim and Ecospace (EwE) models (Heymans et al. 2016).

In summary, functional groups that have large ranges, are highly mobile, and have widely distributed prey are less sensitive to changes in prey availability within the study area caused by local environmental changes (though they are sensitive to changes in environmental conditions as determined by their environmental preferences). Moreover, annual biomass averaging more accurately reflects usage of the study area for highly mobile groups with large ranges. Both annual biomass averaging and application of the diet import function were used to accommodate group characteristics described above, following best practices for the development of EwE models (Heymans et al. 2016), such as the RB model.

References

Heymans, J. J., M. Coll, J. S. Link, S. Mackinson, J. Steenbeek, C. Walters, and V. Christensen. 2016. Best Practice in Ecopath with Ecosim Food-web Models for Ecosystem-based Management. Ecological Modelling 331:173-184.

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IR3-07 Roberts Bank Ecosystem Model – Diet

Information Source(s)

EIS Volume 3: Section 10.3, Appendix 10-B

Context

The Proponent, in Appendix 10-B of the EIS, provided information about the biomass, production, diet and consumption, and environmental preferences of functional groups used in the RB EwE model. The diet composition of each functional group was also quantified in a diet matrix table in Appendix A of Appendix 10-B.

Fisheries and Oceans Canada identified some inconsistencies in the diet matrix. For example, the diet of sand lance was described in the EIS as consisting mostly of zooplankton, whereas the diet matrix for the model runs included 20% macrofauna, 10% green algae and 10% detritus. It is not clear why and how these additional prey were included in the diet used for the model runs. In a further example, the diet matrix for spiny dogfish did not adequately represent the spiny dogfish diet comprising of euphausiids, herring and shrimp as described in the EIS. It was also identified by Fisheries and Oceans Canada that more recent references for biomass estimates of spiny dogfish in the study area are available than those used in the EIS.

Additional documentation is required to clarify the RB EwE model input parameters.

Information Request

Describe how the diet matrix parameters were derived for the RB EwE model for functional groups and the ranges of uncertainty for each parameter.

Provide a table that summarizes dietary information from available information sources, both qualitative and quantitative, for vertebrate and invertebrate functional groups within the RB EwE model study area. Provide figures that display these summaries.

Rationalize all discrepancies in the diet matrix used in the RB EwE model with the information developed for the above table and evaluate the implications of the discrepancies on model outputs.

Explain how the Monte Carlo routine that was used to create multiple model runs captured the uncertainty about the diet data.

VFPA Response

Describe how the diet matrix parameters were derived for the RB EwE model for functional groups and the ranges of uncertainty for each parameter.

The diet matrix parameters for the Roberts Bank ecosystem model (RB model) were derived using a step-wise approach (see Section 1.5.1 of EIS Appendix 10-B; Sections 2.6.1 and 2.6.2 of EIS Appendix 10-C; CEAR Document #547, questions 2.9 and 2.16).

The first step involved extracting diet composition information from the literature, giving preference to quantitative information on diets (i.e., percent contribution of prey in the diet of a predator) where possible. Because site-specific quantitative diet data were not available for any of the functional groups, published diet preferences from nearby similar systems were considered, which were adjusted (using existing knowledge of species composition of the Roberts Bank ecosystem) to account for local availability of prey (or lack thereof).

In the second step, diet preferences were transcribed in the diet matrix using published qualitative information, in the absence of quantitative data. Qualitative diet descriptions were converted into quantitative data by applying the 'fixed selectivity principle' (see Section 2.6.2 of EIS Appendix 10-C and CEAR Document #547, question 2.16). Fixed selectivity is a standardised approach for populating a diet matrix (when quantitative data are absent), which enables qualitative prey preferences to be quantified based on the relative availability or abundance of prey within the modelled study area (see Section 2.6.2 of EIS Appendix 10-C, CEAR Document #547, question 2.16, and IR3-08 for more information on the fixed selectivity principle applied to the RB model's diet matrix).

The third step is specific to functional groups consisting of multiple species, where diet was averaged for each species and then adjusted for biomass of the species in the functional group. For example, diet composition for dolphins and porpoises was the result of the weighted relative diet contribution of Pacific harbour porpoise (contributing to the group's biomass by 45%), Dall's porpoise (contributing to the group's biomass by 35%), and Pacific white-sided dolphin (contributing to the group's biomass by 20%).

Lastly, the fourth step is specific to functional groups that have large migratory ranges, are highly mobile, and have widely distributed prey (e.g., baleen whales, salmon), and involved classifying elements of their diet as import (i.e., originating from outside the study area boundaries). For a discussion on the application of import rates in the diet of functional groups that are highly mobile and have widely distributed prey, including examples, see IR3-06.

The range of uncertainty in the diet matrix was evaluated with the implementation of a pedigree[1]. Depending on the origin of the information, diet input for each functional group was assigned a pedigree category and associated confidence interval (see Table 3.1 of EIS Appendix 10-C; for pedigree definitions as they pertain to diets of functional groups see Table 2.4 of EIS Appendix 10-C). For example, a pedigree of 3 (reflective of general knowledge of the group's diet preference, but not based on quantitative/qualitative studies) was defined for forage fish diet input parameters, which in turn assigned a range of uncertainty (i.e., confidence interval) equal to 80% to this diet input (Section 3.1 of EIS Appendix 10-C).

Provide a table that summarizes dietary information from available information sources, both qualitative and quantitative, for vertebrate and invertebrate functional groups within the RB EwE model study area. Provide figures that display these summaries.

Table IR3-07-A1 (in **Appendix IR3-07-A**) summarises qualitative and quantitative vertebrate and invertebrate dietary information (from available literature within the RB model study area). Information sources for Table IR3-07-A1 include 'Diet and Consumption' sections of EIS Appendix 10-B, along with references to original studies used to extract diet information, as well as quantitative diet composition recorded in the RB model's diet matrix (Appendix A of EIS Appendix 10-B). Table IR3-07-A1 also explains how a qualitative description of a functional group's diet was interpreted quantitatively in the RB model's diet matrix, and identifies discrepancies.

Rows shaded grey represent functional groups for which the fixed selectivity principle was applied. Section 2.6.2 of EIS Appendix 10-C and CEAR Document #547, question 2.16 describe the fixed selectivity principle, and IR3-08 discusses why the fixed selectivity principle was applied to the RB model's diet matrix.

Table IR3-07-A2 (in **Appendix IR3-07-A**) provides figures (pie charts) that summarise quantitative diet composition recorded in the RB model's diet matrix (Appendix A of EIS Appendix 10-B) for each functional consumer group.

[1] Pedigree is a routine within the Ecopath with Ecosim and Ecospace (EwE) modelling framework that quantifies the uncertainty associated with the input data, by assigning pedigree categories (and corresponding confidence interval (CI)) to input parameter values based on the data origin. Inputs derived from local data (e.g., field sampling within the modelled study area) are assigned a higher pedigree category (and a narrower CI) because they represent local conditions better than inputs from elsewhere (e.g., similar ecosystems outside the boundaries of the modelled study area) (see Section 2.5 of EIS Appendix 10-C).

In the RB model, diet inputs were assigned a pedigree of 5 (CI=40%) if based on quantitative studies, a pedigree of 4 (CI=50%) if based on qualitative studies, or a pedigree of 3 (CI=80%), if reflective of general knowledge of the species/group's diet (but not based on analytical studies) (see Table 3.1 in EIS Appendix 10-C).

Rationalize all discrepancies in the diet matrix used in the RB EwE model with the information developed for the above table and evaluate the implications of the discrepancies on model outputs.

Review of existing materials and development of **Appendix IR3-07-A** identified two errors in the data incorporated in the RB model's diet matrix:

- Pinnipeds: A small percentage (equal to 0.6%) of pinniped diet was erroneously assigned to bivalves (included in epifaunal sessile suspension feeder and infaunal bivalve functional groups; see Appendix A of EIS Appendix 10-B); and
- Sandlance: Green algae and detritus were erroneously included in the diet matrix as contributing to the diet of Pacific sandlance by 20% (see Appendix A of EIS Appendix 10-B).

These errors do not influence EIS key run results (and therefore will not influence EIS conclusions) for the following reasons:

- The mixed trophic impact (MTI) routine[2] (see Section 2.7 of EIS Appendix 10-C for explanation), which uses as input the RB model's diet matrix, was applied to evaluate how each functional group in the ecosystem influences all other groups directly or indirectly within the food web. For example, a direct negative influence of a predator on its prey will have an indirect positive influence on the prey's prey. The MTI routine analysis revealed no interaction with (and hence no influence on) bivalves and green algae/detritus from pinnipeds and sandlance, respectively (see Figure 3-1 of EIS Appendix 10-C);
- The diets for pinnipeds and sandlance were corrected (i.e., contribution of bivalves and green algae/detritus in the diet of pinnipeds and sandlance, respectively, was removed and re-allocated to the prey group contributing the most in the predators' diet (i.e., forage fish)), and the RB model was re-run to evaluate influence on RB model outcomes and in turn EIS key run results. The results of the model re-run showed a change of 1% in productivity ratio (with/without Project) for three functional groups (i.e., flatfish, Dungeness crab and epifaunal sessile suspension feeders) and no change in productivity ratios of any other group (see numbers in bold font in Table IR3-07-A3 in **Appendix IR3-07-A**). Productivity ratio with corrected diets for flatfish (0.99) and Dungeness crab (0.96) remain negligible (within the ±5% error margin of the RB model). Productivity ratio with corrected diets for epifaunal sessile suspension feeders (1.20 – increase from 1.19 (Table 3.2 of EIS Appendix 10-C)) remains minor. This slight change in productivity does not influence key run results presented in the EIS; and

[2] Results of the MTI routine are presented in Figure 3-1 of EIS Appendix 10-C. Impacting groups are listed in rows, and impacted groups are listed in columns. The influence of a predator (impacting group) on its prey (impacted group) is depicted using a circle. Black circle denotes negative influence, while open circle denotes positive influence. Influence strength determines the size of the circle and ranges from -1 (maximum negative influence) to +1 (maximum positive influence).

- The RB model is robust to variability in diet inputs, as evaluated through multiple sensitivity analyses explained below.

Upon review of the diet matrix and development of **Appendix IR3-07-A**, no error or discrepancy was identified for spiny dogfish (contrary to information provided in the context).

Dogfish diet recorded in Appendix A of EIS Appendix 10-B reflects published information on diet being largely the result of opportunistic feeding and consisting primarily of a variety of fish and invertebrates, as described in Section 4.6.3 of EIS Appendix 10-B. To capture opportunistic feeding behaviour in the RB model, the principle of fixed selectivity was applied to the fish component of dogfish diet (see Section 2.6.2 of EIS Appendix 10-C) and the results of this fixed selectivity approach are identified in **Appendix IR3-07-A**.

A literature review was undertaken for newer citations on dogfish feeding habits. Beamish and Sweeting (2009) report that dogfish in the Strait of Georgia feed primarily on carnivorous zooplankton (euphausiids) and fish, followed by jellyfish (ctenophores); in addition, dogfish rely on a variety of species within the ecosystem for food, and the relative contribution of prey into dogfish diet varies with body size/age (Beamish and Sweeting 2009). This more recently published diet information is consistent with opportunistic feeding behaviour captured in the RB model (as described above; Appendix A of EIS Appendix 10-B).

Other minor errors identified during review of existing materials and development of **Appendix IR3-07-A** that are not relevant to data inputs in the diet matrix, and hence do not influence RB model results presented in the EIS, include the following:

- Chinook salmon (adult): Diet text in Section 4.4.3 of EIS Appendix 10-B is erroneously described as primarily consisting of herring, and erroneously citing Healey (1980), instead of Brodeur (1990). As reported by Brodeur (1990), Chinook adult diet consists primarily of various fish taxa, but also includes euphausiids, decapod larvae, and cephalopods. The diet matrix correctly reflects information on diet published by Brodeur (1990) consisting primarily of various fish. This was captured by applying the principle of 'fixed selectivity' to the fish component of the adult Chinook diet;
- Salmon (adult): The diet source in Section 4.5.3 of EIS Appendix 10-B is not recorded; diet description has been extracted from Brodeur (1990), as indicated in Table IR3-07-A1 of **Appendix IR3-07-A**. The diet matrix correctly reflects published diet of adult salmon;
- Jellyfish: The principle of 'fixed selectivity' was not applied to the invertebrate component of the jellyfish diet, as erroneously stated in Section 2.6.2 of EIS Appendix 10-C; and
- Omnivorous and herbivorous zooplankton: Section 5.4.3 of EIS Appendix 10-B does not include a description of this group's diet. Diet information for this group was extracted from published ecosystem models for the Strait of Georgia (i.e., Preikshot et al. 2012), as indicated in Table IR3-07-A1 of **Appendix IR3-07-A**.

No other errors or discrepancies were identified in the diet matrix used in the RB model.

Explain how the Monte Carlo routine that was used to create multiple model runs captured the uncertainty about the diet data.

The sensitivity of the RB model to parameter variability was evaluated through multiple sensitivity analyses (or otherwise called Monte Carlo analyses; EIS Appendix 10-D).

Variability (and assumed uncertainty) in diet composition values was not directly considered in the Monte Carlo sensitivity analyses. However, the influence of diet on RB model performance was indirectly analysed in the following way:

- Modifying biomass and production, and consumption values (using a Monte Carlo approach; Section 2.4 of EIS Appendix 10-D), thereby altering relative proportions of prey and predators in the system and consumption rates for each functional group; and
- Varying predator vulnerabilities (Section 2.1 of EIS Appendix 10-D), thereby altering levels of predation mortality on prey.

Moreover, supplemental (see CEAR document #547, question 2.7) sensitivity analyses were undertaken by analysing performance of the RB model pedigree (i.e., an indicator for how well rooted the RB model is in local data; Appendix 10-C of the EIS). Specifically, a series of Monte Carlo runs were conducted in which the pedigree classification for input parameters (including diet) for each functional group was reduced by one pedigree category, thereby increasing the confidence interval of input parameters (see table 3 in CEAR document #547, question 2.7).

Results of sensitivity analyses demonstrate that the RB model outputs are robust to uncertainty and show little change with variability in input data including diets of functional groups.

References

Beamish, R. J. and R. M. Sweeting. 2009. 8. Spiny Dogfish in the Pelagic Waters of the Strait of Georgia and Puget Sound. pp. 101-118. *In*: V. F. Gallucci, G. A. McFarlane, and G. G. Bargmann (Eds.), Biology and Management of Dogfish Sharks. American Fisheries Society, Bethesda, MD.

Brodeur, R. D. 1990. A Synthesis of the Food Habits and Feeding Ecology of Salmonids in Marine Waters of the North Pacific. INPFC Document FRI-UW-9016, Fisheries Research Institute, University of Washington, Seattle, WA.

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Appendices

Appendix IR3-07-A Supporting Tables

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APPENDIX IR3-07-A
SUPPORTING TABLES

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Table IR3-07-A1 Summary of Functional Group Diet Description (Text in EIS Appendix 10-B), Diet Composition (Appendix A of EIS Appendix 10-B), and Explanation Regarding Diet Interpretation and Identification of Potential Discrepancies (grey boxes indicate when the fixed selectivity principle was applied to the diet of functional groups)

No.	Functional Groups	References	Diet Description (EIS Appendix 10-B)	Diet Matrix (Appendix A of EIS Appendix 10-B)	Explanation
1	Baleen Whales	Johnson and Wolman 1984 Kvitek and Oliver 1986 Weitkamp et al. 1992 Ford et al. 1998 Reeves et al. 2002 Tamura and Fujise 2002	North Pacific minke whale opportunistically feed on zooplankton (e.g., euphausiids, copepods), and fish (e.g., anchovy, dogfish, capelin, sablefish, Pacific cod, Pacific herring, mackerel, Pacific salmon, Pacific sandlance, Pacific saury, wolfish). In the North Pacific, they feed on euphausiids, Japanese anchovy, Pacific saury, walleye pollock. Eastern North Pacific grey whale feed on bottom-dwelling decapods (e.g., ghost shrimp), amphipods (e.g., gammarid amphipod), isopods, polychaetes, mollusks, and other invertebrates. North Pacific humpback whale feed on large zooplankton (mostly krill and copepods), and small fish (including herring, salmon, sardine, sandlance, mackerel, cod, and anchovies).	Chinook Salmon (Juvenile) (0.0056) Chum Salmon (Juvenile) (0.0056) Forage Fish (0.1200) Herring (0.0540) Large Demersal Fish (0.0580) Salmon (Juvenile) (0.0090) Sandlance (0.0400) Carnivorous Zooplankton (0.06448) Epifaunal Grazer (0.0360) Epifaunal Omnivore (0.0300) Epifaunal Sessile (0.0420) Infaunal Bivalve (0.0540) Macrofauna (0.25199) Omnivorous/Herbivorous Zooplankton (0.2174) Polychaetes (0.0120)	The diet matrix reflects published information on diet consisting primarily of fish and zooplankton; however, diet is adjusted to include prey items present at Roberts Bank. Invertebrates (e.g., mussels, polychaetes) are also included as they are preyed upon by grey whales and their pelagic larvae are available as prey to other whale groups. Diet composition is the result of the weighted relative diet contribution of minke whale (20%), grey whale (60%), and humpback whale (20%).
2	Dolphins and Porpoises	Heise 1996 Nichol et al. 2013	Pacific white-sided dolphin feed on Pacific herring, salmon, cod, shrimp, capelin, Pacific sardine, squid, anchovies, rockfish, pollock, hake and other small fish. Pacific harbour porpoise feed mostly on market squid and Pacific herring, and to a lesser degree on Pacific hake, walleye pollock, shiner perch, and fathead sculpins. Dall's porpoise feed mostly on Pacific herring and walleye pollock and to a lesser extent on Pacific hake, fathead sculpins, lantern fish, and deep sea sculpins.	Chinook Salmon (Juvenile) (0.003199) Chum Salmon (Juvenile) (0.003199) Dogfish (0.0020) Flatfish (0.0070) Forage Fish (0.0920) Herring (0.4468) Large Demersal Fish (0.0880) Lingcod (0.0020) Rockfish (0.0080) Salmon (Juvenile) (0.0030) Sandlance (0.0020) Shiner Perch (0.0290) Small Demersal Fish (0.1579) Starry Flounder (0.0020) Epifaunal Omnivore (0.1359) Shrimp (0.0180)	The diet matrix reflects published information on diet consisting primarily of fish and epifaunal invertebrates. Diet composition is the result of the weighted relative diet contribution of Pacific harbour porpoise (45%), Dall's porpoise (35%), and Pacific white-sided dolphin (20%).
3	Pinnipeds	Everitt et al. 1981 Olesiuk et al. 1990 Sinclair and Zeppelin 2002 Trites et al. 2007 Lance and Jeffries 2009	Pacific harbour seals feed mostly on Pacific hake, Pacific herring, Pacific tomcod, salmon, starry flounder, English sole, lingcod, shiner perch, market squid, red octopus, Pacific sandlance, plainfin midshipman, staghorn sculpin, Northern anchovy, three spine stickleback, and rockfish. Steller sea lions feed on walleye pollock, sandlance, Atka mackerel, salmon, herring, Pacific cod, rockfish, sculpins, flatfish, squid, and octopus. California sea lions feed on Pacific hake, walleye pollock, Pacific cod, and English sole.	Chinook Salmon (Adult) (0.0033) Chinook Salmon (Juvenile) (0.0001) Chum Salmon (Adult) (0.0075) Chum Salmon (Juvenile) (0.0002) Flatfish (0.0002) Forage Fish (0.3882) Herring (0.0161) Large Demersal Fish (0.0008) Lingcod (0.0010)	Diet composition is the result of the weighted relative diet contribution of Steller sea lion (30%), harbour seal (60%), and California sea lion (10%). 50% of the diet elements were assumed to have come from outside the study area (classified as import). Bivalves were erroneously included in the diet matrix of pinnipeds, albeit representing a small proportion of <1%.

No.	Functional Groups	References	Diet Description (EIS Appendix 10-B)	Diet Matrix (Appendix A of EIS Appendix 10-B)	Explanation
				Rockfish (0.0006) Salmon (Adult) (0.0253) Shiner Perch (0.0036) Small Demersal Fish (0.0014) Starry Flounder (0.0015) Epifaunal Omnivore (0.0441) Epifaunal Sessile Suspension Feeder (0.0015) Infaunal Bivalve (0.0045)	The principle of 'fixed selectivity' was applied to the fish component of the pinniped diet.
4	Southern Resident Killer Whales	Ford et al. 1998 Ford and Ellis 2006	Diet consists primarily of adult salmon with preference for Chinook. Other prey items include Pacific herring, Pacific halibut, yellow rockfish, and quillback rockfish.	Chinook Salmon (Adult) (0.7000) Chum Salmon (Adult) (0.0550) Herring (0.0100) Rockfish (0.0100) Salmon (Adult) (0.2250)	The diet matrix reflects published information on diet consisting of marine fish, primarily Chinook salmon.
5	Transient Killer Whales	Ford et al. 1998	Diet consists primarily of marine mammals (i.e., seals, sea lions, porpoises, dolphins, occasionally calves or juveniles of grey whales), and seabirds.	Baleen whales (0.0001) Dolphins and Porpoises (0.0120) Pinnipeds (0.9859) Waterfowl (0.0020)	The diet matrix reflects published information on diet consisting primarily of marine mammals.
6	American Wigeon	Baldwin and Lovvorn 1994a, b Poole 2005	At Roberts Bank, diet consists mainly of intertidal vegetation (e.g., *Zostera japonica*, *Z. marina*, *Ulva lactuca*, *Ruppia maritima*). American wigeon also consume seeds of salt marsh plants, and algae. During the winter, diet also includes grasses from nearby agricultural fields.	Brown Algae (0.0259) Eelgrass (Native) (0.0249) Green Algae (0.4341) Japanese Eelgrass (Non-native) (0.0030) Red Algae (0.0074) Tidal March (0.0043) Biomat (0.0005)	The diet matrix reflects published information on diet consisting of marine vegetation at Roberts Bank. 50% of the diet elements were assumed to have come from outside the study area (classified as import), to capture consumption of grasses from nearby agricultural fields during the winter.
7	Bald Eagle	Blood and Anweiler 1994 Poole 2005	Bald eagles are carnivorous. At Roberts Bank, diet consists primarily of fish and waterfowl. Bald eagles may also feed on mammals and marine invertebrates, and will also scavenge carrion and anthropogenic wastes.	American Wigeon (0.0400) Brant Goose (0.0010) Diving Waterbirds (0.0050) Gulls and Terns (0.1000) Waterfowl (0.0200) Chinook Salmon (Adult) (0.0700) Chum Salmon (Adult) (0.0700) Forage Fish (0.0100) Herring (0.1000) Rockfish (0.0100) Salmon (Adult) (0.0700) Sandlance (0.0100) Shiner Perch (0.0100)	The diet matrix reflects published information on diet consisting primarily of fish and invertebrates at Roberts Bank. It also incorporates local knowledge (from professional observations at Roberts Bank); specifically, the diet was adjusted to reflect greater consumption of gulls and terns than salmon, as gulls and terns are available locally as prey year-round. 48.4% of the diet elements were assumed to have come from outside the study area (classified as import).
8	Brant Goose	Baldwin and Lovvorn 1994a, b	Diet consists exclusively of marine plants (i.e., *Zostera marina*, *Z. japonica*, *Ulva lactuca*).	Eelgrass (Native) (0.5200) Green Algae (0.0065) Japanese Eelgrass (Non-native) (0.1235)	The diet matrix reflects published information on diet consisting of marine plants. 35% of the diet elements were assumed to have come from outside the study area (classified as import; e.g., consumption of eelgrass at Boundary Bay).

No.	Functional Groups	References	Diet Description (EIS Appendix 10-B)	Diet Matrix (Appendix A of EIS Appendix 10-B)	Explanation
9	Diving Waterbirds	Vermeer and Levings 1977 Poole 2005 Williams et al. 2009	Diving waterbirds tend to be carnivorous; however, vegetative matter is equally important for the greater scaup. Surf scoters, buffleheads, and white-winged scoters feed most heavily on benthic invertebrates. Cormorants, loons, and grebes feed more heavily on fish, such as juvenile flounders, pricklebacks, surf smelt, salmonids, and sculpins.	Chinook Salmon (Juvenile) (0.0004) Chum Salmon (Juvenile) (0.0004) Forage Fish (0.2300) Herring (0.1222) Large Demersal Fish (0.0111) Salmon (Juvenile) (0.0001) Sandlance (0.0100) Shiner Perch (0.0511) Small Demersal Fish (0.0100) Starry Flounder (0.0133) Dungeness Crab (0.0200) Epifaunal Grazer (0.0511) Epifaunal Omnivore (0.0400) Epifaunal Sessile (0.0289) Infaunal Bivalve (0.1950) Macrofauna (0.0067) Polychaetes (0.0233) Shrimp (0.0730) Eelgrass (Native) (0.0056) Green Algae (0.0667) Japanese Eelgrass (Non-native) (0.0056) Tidal March (0.0056) Detritus (0.0300)	The principle of 'fixed selectivity' was applied to the fish and invertebrate components of the diving waterbird diet.
10	Dunlin	Wilson 1994 Pomeroy 2005 Elner et al. 2005 Fernández et al. 2010 Mathot et al. 2010	Diet consists primarily of macrofaunal and meiofaunal invertebrates, but also includes biofilm.	Epifaunal Grazer (0.0100) Epifaunal Omnivore (0.0100) Epifaunal Sessile (0.0010) Infaunal Bivalve (0.2980) Macrofauna (0.1000) Meiofauna (0.1000) Polychaetes (0.0100) Shrimp (0.0010) Biofilm (Freshwater) (0.1000) Biofilm (Marine) (0.1000)	The diet matrix reflects published information on diet consisting primarily of invertebrates and biofilm. 27% of the diet elements were assumed to have come from outside the study area (classified as import).
11	Great Blue Heron	Butler 1995	Diet generally consists of fish (e.g., gunnel, sculpin, shiner perch), but will also include small mammals, amphibians, and reptiles taken in nearby terrestrial habitats.	Forage Fish (0.5470) Herring (0.0227) Large Demersal Fish (0.0012) Shiner Perch (0.0052) Small Demersal Fish (0.0019) Starry Flounder (0.00206) Dungeness Crab (0.0290) Epifaunal Grazer (0.0290) Epifaunal Omnivore (0.0120)	The diet matrix reflects published information on diet consisting primarily of fish. 35% of the diet elements were assumed to have come from outside the study area (classified as import). The principle of 'fixed selectivity' was applied to the fish component of the great blue heron diet.

No.	Functional Groups	References	Diet Description (EIS Appendix 10-B)	Diet Matrix (Appendix A of EIS Appendix 10-B)	Explanation
12	Gulls and Terns	Poole 2005	Gulls at Roberts Bank consume a broad variety of invertebrates and fish that they either catch or scavenge nearshore or in intertidal areas. Tern diet consists entirely of fish.	Chinook Salmon (Juvenile) (0.0001) Chum Salmon (Juvenile) (0.0002) Flatfish (0.00024) Forage Fish (0.3804) Herring (0.0158) Rockfish (0.00061) Salmon (Juvenile) (0.00001) Sandlance (0.00004) Small Demersal Fish (0.0010) Starry Flounder (0.00143) Dungeness Crab (0.0600) Epifaunal Grazer (0.0200) Epifaunal Omnivore (0.0700) Epifaunal Sessile (0.0300) Infaunal Bivalve (0.10005) Polychaetes (0.10005)	Diet composition was averaged across diets of bird species comprising this functional group. The diet matrix reflects published information on diet consisting primarily of fish and invertebrates. 22% of the diet elements were assumed to have come from outside the study area (classified as import).
13	Raptors	Poole 2005	At Roberts Bank, peregrine falcons feed mainly on passerines and waterfowl, merlins on insects and passerines, osprey on fish, and hawks, harriers and owls on small mammals.	American Wigeon (0.0029) Brant Goose (0.0014) Diving Waterbirds (0.0346) Dunlin (0.0188) Shorebirds (0.0202) Waterfowl (0.0346) Sandpiper (0.0188) Chinook Salmon (Juvenile) (0.0144) Chum Salmon (Juvenile) (0.0144) Forage Fish (0.0404) Pacific Herring (0.0144) Large Demersal Fish (0.0144) Salmon (Juvenile) (0.0144) Shiner Perch (0.0144) Starry Flounder (0.0144)	Diet composition was averaged across diets of bird species comprising this functional group. The diet matrix reflects published information on diet consisting primarily of small bird species, as well as fish preyed upon specifically by osprey. 72.71% of the diet elements (i.e., passerines, insects, and small mammals) were assumed to have come from outside the study area (classified as import).
14	Shorebirds	Poole 2005	Diet consists primarily of benthic invertebrates (e.g., infaunal bivalves, polychaetes).	Dungeness Crab (0.0200) Epifaunal Grazer (0.0200) Epifaunal Omnivore (0.0200) Epifaunal Sessile (0.0200) Infaunal Bivalve (0.2500) Macrofauna (0.2000) Meiofauna (0.2000) Polychaetes (0.2500) Shrimp (0.0200)	The principle of 'fixed selectivity' was applied to the invertebrate component of the shorebird diet.
15	Waterfowl	Poole 2005 Williams et al. 2009	During winter and throughout their migration, waterfowl feed on intertidal marsh vegetation (seeds, leaves, and stems), roots (grasses, sedges, and rushes), and other aquatic plants (such as eelgrass and macroalgae).	Brown Algae (0.0259) Eelgrass (Native) (0.0249) Green Algae (0.4341)	Diet composition was averaged across diets of bird species comprising this functional group.

No.	Functional Groups	References	Diet Description (EIS Appendix 10-B)	Diet Matrix (Appendix A of EIS Appendix 10-B)	Explanation
				Japanese Eelgrass (Non-native) (0.0030) Red Algae (0.0074) Tidal Marsh (0.0043) Biomat (0.0005)	50% of the diet elements were assumed to have come from outside the study area (classified as import). The principle of 'fixed selectivity' was applied to the vegetation component of the waterfowl diet.
16	Western Sandpiper	Wilson 1994 Pomeroy 2005 Elner et al. 2005 Kuwae et al. 2008, 2012 Fernández et al. 2010 Mathot et al. 2010	Diet consists largely of macrofaunal and meiofaunal invertebrates, as well as biofilm.	Epifaunal Grazer (0.0100) Epifaunal Omnivore (0.0100) Epifaunal Sessile (0.0100) Infaunal Bivalve (0.0100) Macrofauna (0.2800) Meiofauna (0.2800) Polychaetes (0.0100) Biofilm (Freshwater) (0.1950) Biofilm (Marine) (0.1950)	The diet matrix reflects published information on diet consisting primarily of benthic invertebrates and biofilm. Section 15.5.3 of the EIS states that conservatively, biofilm comprises an estimated 50% to 68% of western sandpiper diet. This range is conservative and based on published western sandpiper diet data from Roberts Bank during their northward (spring) migration (e.g., biofilm comprising 37% to 58% (Kuwae et al. 2008, 2012), or 22% to 53% (Jardine et al. 2015) of western sandpiper diet). It is also understood that western sandpiper diet is more variable during their southward (fall) migration. Thus, the diet matrix reflects annual variability in western sandpiper diet during their north- and southward migration.
17	Chinook Salmon (Adult)	Healey 1980	In the Strait of Georgia, herring is the dominant food of sub-adult and adult Chinook salmon.	Chinook Salmon (Juvenile) (0.00002) Chum Salmon (Juvenile) (0.00004) Flatfish (0.00004) Forage Fish (0.0704) Herring (0.0029) Large Demersal Fish (0.0001) Lingcod (0.0002) Rockfish (0.0001) Salmon (Juvenile) (0.000002) Sandlance (0.00001) Shiner Perch (0.0007) Small Demersal Fish (0.0002) Starry Flounder (0.0003) Carnivorous Zooplankton (0.0050) Epifaunal Omnivore (0.0100) Jellyfish (0.0100)	Diet in Section 4.4.3 of EIS Appendix 10-B is erroneously described as primarily consisting of herring. The correct diet information is reported by Brodeur (1990), with Chinook adult diet consisting primarily of various fish taxa, but also including euphausiids, decapod larvae, and cephalopods. Reference in EIS Appendix 10-B is erroneously recorded as Healey 1980, instead of Brodeur 1990. The discrepancy identified in the diet description does not influence EIS key run results as the diet matrix correctly reflects published information on diet consisting primarily of various fish. This was captured by applying the principle of 'fixed selectivity' to the fish component of the adult Chinook diet. 90% of the diet elements were assumed to have come from outside the study area (classified as import).
18	Chinook Salmon (Juvenile)	Brodeur 1990 Levings et al. 1991 Weitkamp and Sturdevant 2008 Harvey et al. 2012	Diet consists mainly of macrofauna and a variety of small forage fish species. Other important prey items include euphausiids, amphipods, cephalopods, copepods, pteropods, shrimp, and larvae.	Chinook Salmon (Juvenile) (0.0002) Chum Salmon (Juvenile) (0.0004) Flatfish (0.0004) Forage Fish (0.0150) Herring (0.0150) Large Demersal Fish (0.0100) Salmon (Juvenile) (0.0003) Sandlance (0.0001)	The principle of 'fixed selectivity' was applied to the fish component of the juvenile Chinook diet. 23.4% of the diet elements were assumed to have come from outside the study area (classified as import).

No.	Functional Groups	References	Diet Description (EIS Appendix 10-B)	Diet Matrix (Appendix A of EIS Appendix 10-B)	Explanation
				Shiner Perch (0.0050) Small Demersal Fish (0.0100) Carnivorous Zooplankton (0.1199) Jellyfish (0.04997) Macrofauna (0.3798) Meiofauna (0.00999) Omnivorous/Herbivorous Zooplankton (0.0500) Polychaetes (0.0500) Shrimp (0.0500)	
19	Chum Salmon (Adult)	Scott and Crossman 1973	Diet consists of small fish species as well as euphausiids, amphipods, zooplankton (mostly crustacean), and squid.	Carnivorous Zooplankton (0.0100) Jellyfish (0.0100)	The diet matrix reflects published information on diet consisting primarily of zooplankton. 98% of the diet elements were assumed to have come from outside the study area (classified as import).
20	Chum Salmon (Juvenile)	Brodeur 1990	Diet consists primarily of fish but also copepods, euphausiids, hyperiid amphipods, larvae (predominately crab and fish) and chaetognaths.	Chinook Salmon (Juvenile) (0.0002) Chum Salmon (Juvenile) (0.0004) Flatfish (0.0004) Forage Fish (0.0150) Herring (0.0150) Large Demersal Fish (0.0100) Salmon (Juvenile) (0.0003) Sandlance (0.0001) Shiner Perch (0.0050) Small Demersal Fish (0.0100) Carnivorous Zooplankton (0.1199) Jellyfish (0.04997) Macrofauna (0.3798) Meiofauna (0.00999) Omnivorous/Herbivorous Zooplankton (0.0500) Polychaetes (0.0500) Shrimp (0.0500)	The principle of 'fixed selectivity' was applied to the fish component of the juvenile chum diet. 23.4% of the diet elements were assumed to have come from outside the study area (classified as import).
21	Dogfish	Jones and Geen 1977	Spiny dogfish are opportunistic and highly active feeders, with adult diet predominantly consisting of fish and large invertebrates, such as crabs, jellyfish, amphipods, squid, and octopus.	Chinook Salmon (Juvenile) (0.0002) Chum Salmon (Juvenile) (0.0003) Dogfish (0.00003) Flatfish (0.0003) Forage Fish (0.4959) Herring (0.0206) Large Demersal Fish (0.0010) Lingcod (0.0013) Rockfish (0.0008) Salmon (Juvenile) (0.00002) Sandlance (0.0001) Shiner Perch (0.0047) Skate (0.0013)	The diet matrix reflects published information on diet being largely the result of opportunistic feeding and consisting primarily of a variety of fish and epifaunal invertebrates. The principle of 'fixed selectivity' was applied to the fish component of the dogfish diet.

No.	Functional Groups	References	Diet Description (EIS Appendix 10-B)	Diet Matrix (Appendix A of EIS Appendix 10-B)	Explanation
				Small Demersal Fish (0.0017) Starry Flounder (0.0019) Carnivorous Zooplankton (0.1000) Dungeness Crab (0.0200) Epifaunal Grazer (0.0500) Epifaunal Omnivore (0.1500) Epifaunal Sessile (0.0100) Infaunal Bivalve (0.0100) Jellyfish (0.0100) Macrofauna (0.0100) Omnivorous/Herbivorous Zooplankton (0.0100) Polychaetes (0.0100) Shrimp (0.0100) Detritus (0.0800)	
22	Flatfish	Hagerman 1952 Hart 1973 Pearcy and Hancock 1978 Quéro et al. 1986 Levings and Ong 2003 Froese and Pauly 2011	Sand sole diet consists of fish, worms, crustaceans and mollusks. Rock sole diet consists of mollusks, polychaete worms, crustaceans, brittle stars, and fish. Pacific sanddab diet consists of crustaceans, smaller fish, squid, and octopus. Flathead sole diet consists of clams, worms and crustaceans. English sole diet consists of polychaetes, bivalve mollusks, foraminifera, amphipods, and unidentified crustaceans. Dover sole diet consists of small crustaceans, bottom dwelling organisms like worms, clams, and crabs. Butter sole diet consists of crabs, shrimps, chaetopod marine worms and sand dollars, as well as young herring.	Chinook Salmon (Juvenile) (0.0001) Chum Salmon (Juvenile) (0.0001) Flatfish (0.0001) Forage Fish (0.2157) Herring (0.0090) Large Demersal Fish (0.0005) Rockfish (0.0003) Salmon (Juvenile) (0.00001) Sandlance (0.00002) Shiner Perch (0.0020) Skate (0.0006) Small Demersal Fish (0.0008) Starry Flounder (0.0008) Carnivorous Zooplankton (0.0100) Dungeness Crab (0.0200) Epifaunal Grazer (0.0100) Epifaunal Omnivore (0.1800) Epifaunal Sessile (0.0700) Infaunal Bivalve (0.0900) Macrofauna (0.1900) Meiofauna (0.0100) Omnivorous/Herbivorous Zooplankton (0.0100) Polychaetes (0.0200) Shrimp (0.1600)	Diet composition was averaged across diets of flatfish species comprising this functional group. The diet matrix reflects published information on diet consisting primarily of fish and epifaunal/infaunal invertebrates. The principle of 'fixed selectivity' was applied to the fish component of the flatfish diet.
23	Forage Fish	Wilson et al. 2009 Froese and Pauly 2011	Surf smelt diet consists of jellyfish, insects, euphausiids, fish larvae, and other planktonic crustaceans. Northern anchovy diet consists of phytoplankton, mysids, euphausiids, copepods, fish larvae, and other planktonic zooplankton.	Carnivorous Zooplankton (0.1074) Epifaunal Grazer (0.0166) Epifaunal Omnivore (0.0051) Infaunal Bivalve (0.0107) Jellyfish (0.1652)	Diet composition was averaged across diets of forage fish species comprising this functional group. The diet matrix reflects published information on diet consisting primarily of planktonic zooplankton.

No.	Functional Groups	References	Diet Description (EIS Appendix 10-B)	Diet Matrix (Appendix A of EIS Appendix 10-B)	Explanation
			Long fin smelt diet consists of insects, euphausiids, mysids, copepods, and other planktonic crustaceans. Eulachon diet consists primarily of euphausiids.	Macrofauna (0.0871) Meiofauna (0.1133) Omnivorous/Herbivorous Zooplankton (0.4444) Polychaetes (0.0494) Shrimp (0.0009)	The principle of 'fixed selectivity' was applied to the invertebrate component of the forage fish diet.
24	Herring	Foy and Norcross 1999	Diet consists primarily of zooplankton and macrofauna.	Carnivorous Zooplankton (0.1678) Macrofauna (0.1361) Omnivorous/Herbivorous Zooplankton (0.6947) Shrimp (0.0014)	The principle of 'fixed selectivity' was applied to the invertebrate component of the herring diet.
25	Large Demersal Fish	Froese and Pauly 2011	Most of the species within this functional group are piscivorous, though benthic invertebrates (such as crabs, molluscs, and polychaetes), zooplankton, and cephalopods are also consumed.	Chinook Salmon (Juvenile) (0.0001) Chum Salmon (Juvenile) (0.0001) Flatfish (0.0001) Forage Fish (0.2011) Herring (0.0083) Large Demersal Fish (0.0004) Lingcod (0.0005) Rockfish (0.0003) Salmon (Adult) (0.0131) Salmon (Juvenile) (0.00001) Sandlance (0.00002) Shiner Perch (0.0019) Skate (0.0006) Small Demersal Fish (0.0007) Starry Flounder (0.0008) Carnivorous Zooplankton (0.0900) Dungeness Crab (0.0200) Epifaunal Grazer (0.0500) Epifaunal Omnivore (0.1300) Epifaunal Sessile (0.0500) Infaunal Bivalve (0.0100) Jellyfish (0.0100) Macrofauna (0.2620) Omnivorous/Herbivorous Zooplankton (0.0900) Polychaetes (0.0100) Shrimp (0.0500)	Diet composition was averaged across diets of large demersal fish species comprising this functional group. The diet matrix reflects published information on diet consisting primarily of fish, with a lesser contribution of benthic invertebrates. The principle of 'fixed selectivity' was applied to the fish component of the large demersal fish diet.
26	Lingcod	Miller 2007 Tinus 2009	Lingcod are generalist piscivorous predators that also consume octopus and benthic invertebrates (e.g., crab, shrimp).	Chinook Salmon (Juvenile) (0.0003) Chum Salmon (Juvenile) (0.0004) Dogfish (0.0001) Flatfish (0.0005) Forage Fish (0.7953) Herring (0.0330) Large Demersal Fish (0.0017) Lingcod (0.0020)	The diet matrix reflects published information on diet consisting primarily of fish, with a lesser contribution of benthic invertebrates. The principle of 'fixed selectivity' was applied to the fish component of the lingcod diet.

No.	Functional Groups	References	Diet Description (EIS Appendix 10-B)	Diet Matrix (Appendix A of EIS Appendix 10-B)	Explanation
				Rockfish (0.0013) Salmon (Juvenile) (0.00002) Sandlance (0.0001) Shiner Perch (0.0075) Skate (0.0022) Small Demersal Fish (0.0028) Starry Flounder (0.0030) Dungeness Crab (0.0200) Macrofauna (0.0500) Polychaetes (0.0100) Shrimp (0.0700)	
27	Rockfish	Murie 1995	Quillback rockfish are opportunistic predators and diet consists primarily of demersal and pelagic fish (predominantly Pacific herring), as well as benthic crustaceans (e.g., decapods). Copper rockfish diet consists primarily of pelagic (mainly Pacific herring) and demersal fish, as well as benthic crustaceans (e.g., decapods).	Chinook Salmon (Juvenile) (0.0002) Chum Salmon (Juvenile) (0.0003) Dogfish (0.00004) Flatfish (0.0004) Forage Fish (0.6173) Herring (0.0256) Large Demersal Fish (0.0113) Lingcod (0.0016) Rockfish (0.0010) Salmon (Adult) (0.0102) Salmon (Juvenile) (0.00002) Sandlance (0.0001) Shiner Perch (0.0058) Skate (0.0017) Small Demersal Fish (0.0022) Starry Flounder (0.0023) Carnivorous Zooplankton (0.0100) Dungeness Crab (0.0200) Epifaunal Grazer (0.0100) Epifaunal Omnivore (0.1400) Epifaunal Sessile (0.0500) Macrofauna (0.0300) Shrimp (0.0600)	Diet composition was averaged across diets of rockfish species comprising this functional group. The diet matrix reflects published information on diet consisting primarily of forage fish, with a lesser contribution of demersal fish and benthic invertebrates. The principle of 'fixed selectivity' was applied to the fish component of the rockfish diet.
28	Salmon (Adult)		Diet consists primarily of fish but also squid, octopus, benthic and pelagic invertebrate species.	Herring (0.0100)	Diet source in Section 4.5.3 of EIS Appendix 10-B is not recorded; diet description has been extracted from Brodeur (1990). 99% of the diet elements (e.g., pelagic and benthic invertebrates) were assumed to have come from outside the study area (classified as import). The remaining 1% of the diet was allocated to herring based on preference by adult coho and pink salmon.

No.	Functional Groups	References	Diet Description (EIS Appendix 10-B)	Diet Matrix (Appendix A of EIS Appendix 10-B)	Explanation
29	Salmon (Juvenile)	Godin 1981 Brodeur 1990	Diet consists of small fish species (including smaller salmon), as well as invertebrates like euphausiids, decapod larvae, hyperiid amphipods, pteropods, insects, and copepods.	Chinook Salmon (Juvenile) (0.0001) Chum Salmon (Juvenile) (0.0002) Flatfish (0.0002) Forage Fish (0.0509) Herring (0.0147) Large Demersal Fish (0.0007) Rockfish (0.0006) Salmon (Juvenile) (0.00001) Sandlance (0.00004) Shiner Perch (0.0033) Small Demersal Fish (0.0012) Starry Flounder (0.0013) Carnivorous Zooplankton (0.1833) Jellyfish (0.0509178) Macrofauna (0.2546) Omnivorous/Herbivorous Zooplankton (0.1018) Polychaetes (0.0509) Shrimp (0.0550)	The principle of 'fixed selectivity' was applied to the fish component of the juvenile salmon diet. Invertebrate diet composition was averaged across diets of salmon species (other than Chinook and chum) comprising this functional group. 23% of the diet elements were assumed to have come from outside the study area (classified as import).
30	Sandlance	Simenstad et al. 1979 Ciannelli 1997	Diet consists primarily of zooplankton (e.g., calanoid and cyclopoid copepods) with lower proportions of crustacean zoeae and nauplii, gammarid amphipods, larvaceans, and epibenthic invertebrates. Adults will also feed on herring larvae and eggs.	Carnivorous Zooplankton (0.2000) Macrofauna (0.2000) Omnivorous/Herbivorous Zooplankton (0.4000) Green Algae (0.1000) Detritus (0.1000)	The diet matrix reflects published information on diet consisting primarily of zooplankton. Green algae and detritus have been erroneously included in the diet matrix as contributing to the diet of Pacific sandlance.
31	Shiner Perch	Gordon 1965	Shiner perch are opportunistic feeders. Prey items include copepods, diatoms, barnacles, as well as large crustaceans.	Carnivorous Zooplankton (0.1200) Dungeness Crab (0.0300) Epifaunal Grazer (0.0100) Epifaunal Omnivore (0.0300) Macrofauna (0.4000) Meiofauna (0.0300) Omnivorous/Herbivorous Zooplankton (0.1600) Polychaetes (0.0700) Eelgrass (Native) (0.0100) Green Algae (0.1000) Japanese Eelgrass (Non-native) (0.0100) Phytoplankton (0.0300)	The diet matrix reflects published information on diet being largely the result of opportunistic feeding and consisting primarily of benthic invertebrates, and to a lesser extent by primary producers.
32	Skate	Yang 2007	Big skate feed primarily on flatfish and crustaceans, including crabs and shrimp.	Chinook Salmon (Juvenile) (0.0001) Chum Salmon (Juvenile) (0.0001) Flatfish (0.0001) Forage Fish (0.2251) Herring (0.0093) Large Demersal Fish (0.0005) Rockfish (0.0004) Salmon (Juvenile) (0.00001)	Diet of skate described in Section 4.15.3 of EIS Appendix 10-B was extracted from a study undertaken in the Aleutian Islands, North Pacific Ocean. To account for variety of fish prey available to skate at Roberts Bank, the principle of 'fixed selectivity' was applied to the fish component of the skate diet, and was not restricted to flatfish as the only fish prey.

No.	Functional Groups	References	Diet Description (EIS Appendix 10-B)	Diet Matrix (Appendix A of EIS Appendix 10-B)	Explanation
				Sandlance (0.00002) Shiner Perch (0.0021) Skate (0.0006) Small Demersal Fish (0.0008) Starry Flounder (0.0008) Dungeness Crab (0.1000) Epifaunal Omnivore (0.1200) Epifaunal Sessile (0.0100) Infaunal Bivalve (0.1700) Macrofauna (0.2000) Meiofauna (0.0100) Omnivorous/Herbivorous Zooplankton (0.0100) Polychaetes (0.0300) Shrimp (0.1100)	
33	Small Demersal Fish	Froese and Pauly 2011	Small demersal fish feed on small invertebrates that occur as zooplankton or macrofauna. Many small demersal fish are scavengers.	Carnivorous Zooplankton (0.0800) Dungeness Crab (0.0267) Epifaunal Grazer (0.0533) Epifaunal Omnivore (0.1333) Epifaunal Sessile (0.0800) Infaunal Bivalve (0.0533) Jellyfish (0.0133) Macrofauna (0.3467) Meiofauna (0.0133) Omnivorous/Herbivorous Zooplankton (0.0133) Polychaetes (0.0133) Shrimp (0.1467) Green Algae (0.0133) Detritus (0.0133)	Diet composition was averaged across diets of small demersal fish species comprising this functional group. The diet matrix reflects published information on diet consisting primarily of macrofauna and other invertebrates.
34	Starry Flounder	Miller 1967 McCall 1992 Leet et al. 2001	Juvenile starry flounder feed almost exclusively on harpacticoid copepods. Adults feed on benthic and infaunal species such as bivalves (particularly clam siphons), worms, crabs, molluscs, echinoderms, and fish.	Chinook Salmon (Juvenile) (0.0001) Chum Salmon (Juvenile) (0.0001) Flatfish (0.0001) Forage Fish (0.1881) Herring (0.0078) Large Demersal Fish (0.0004) Rockfish (0.0003) Salmon (Juvenile) (0.00001) Sandlance (0.00002) Shiner Perch (0.0018) Small Demersal Fish (0.0007) Starry Flounder (0.0007) Carnivorous Zooplankton (0.0100) Dungeness Crab (0.0200) Epifaunal Grazer (0.0700)	The diet matrix reflects published information on diet consisting primarily of benthic invertebrates, and to a lesser extent of fish. The principle of 'fixed selectivity' was applied to the fish component of the starry flounder diet.

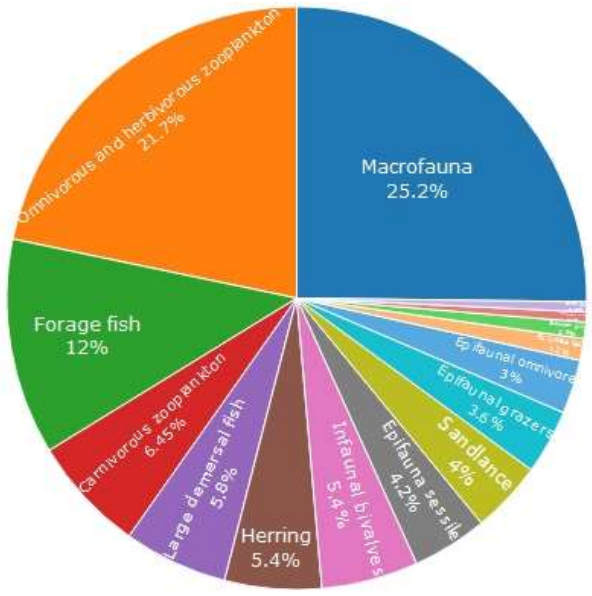
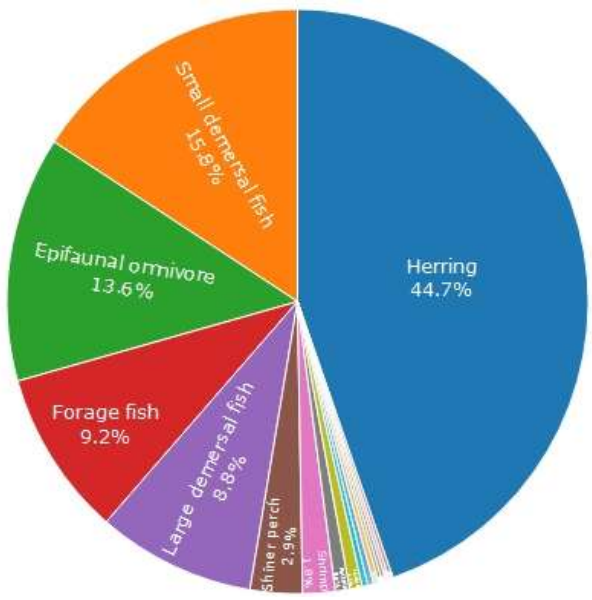
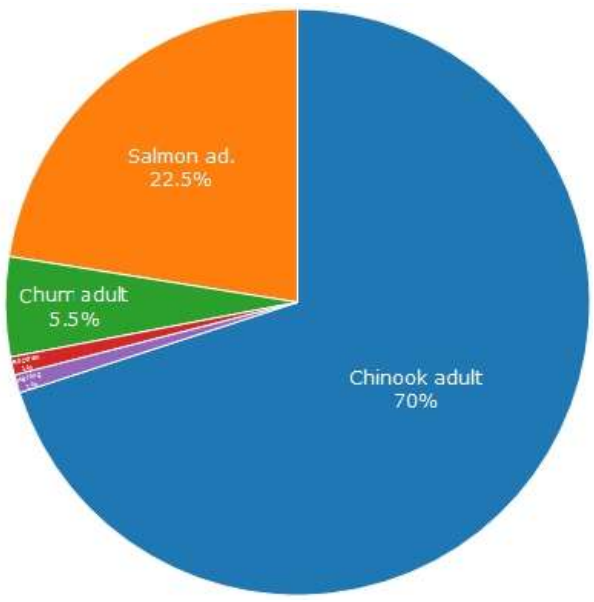
No.	Functional Groups	References	Diet Description (EIS Appendix 10-B)	Diet Matrix (Appendix A of EIS Appendix 10-B)	Explanation
				Epifaunal Omnivore (0.2900) Epifaunal Sessile (0.0800) Infaunal Bivalve (0.1800) Macrofauna (0.1400) Polychaetes (0.0100)	
35	Carnivorous Zooplankton	Hu 1978 Kearney et al. 2012	Diet consists primarily of other carnivorous zooplankton, as well as herbivorous and omnivorous zooplankton.	Carnivorous Zooplankton (0.0610) Macrofauna (0.0500) Omnivorous/Herbivorous Zooplankton (0.6010) Phytoplankton (0.0500) Detritus (0.2380)	Although not stated in Section 5.3.3 of EIS Appendix 10-B, primary producers make up a small percentage of euphausiid diet (e.g., Hu 1978, Silva et al. 2014), as reflected in the diet composition matrix. The principle of 'fixed selectivity' was applied to the invertebrate component of the carnivorous zooplankton diet.
36	Dungeness Crab	Stevens et al. 1982 Jensen and Asplen 1998 Holsman et al. 2003 Dudas et al. 2005 Dunham et al. 2011	Adults prey on bivalves, crustaceans, worms, and fish. Juveniles feed on bivalves (clams and mussels), small fish, molluscs, shrimp, and other crabs.	Flatfish (0.0009999) Forage Fish (0.0600) Herring (0.0250997) Sandlance (0.0010) Dungeness Crab (0.0050023) Epifaunal Grazer (0.1807) Epifaunal Omnivore (0.0050199) Epifaunal Sessile (0.0099) Infaunal Bivalve (0.3818) Polychaetes (0.0702792) Shrimp (0.0050) Detritus (0.2551)	The diet of Dungeness crab included small proportions of sandlance, which had a disproportionally high impact on the group. Thus, the diet composition of Dungeness crab was adjusted across all prey types, based on the 'fixed selectivity' principle.
37	Epifaunal Grazer	Kozloff and Price 1987	Epifaunal grazers consume primarily benthic algae and biofilm, except for sea cucumbers and sand dollars. Sea cucumbers are deposit feeders that consume detritus from the seafloor and water column with ciliated tentacles. Sand dollars are filter feeders feeding on detritus and phytoplankton at the benthic water column interface.	Carnivorous Zooplankton (0.0250) Epifaunal Sessile (0.0004) Macrofauna (0.0633) Omnivorous/Herbivorous Zooplankton (0.0441) Biofilm (Freshwater) (0.0001) Biofilm (Marine) (0.0001) Brown Algae (0.0104) Green Algae (0.1741) Red Algae (0.0030) Phytoplankton (0.4298) Biomat (0.0001) Detritus (0.2497)	The diet matrix reflects published information on diet consisting primarily of primary producers, and to a lesser extent of invertebrates. The principle of 'fixed selectivity' was applied to the vegetation component of the epifaunal grazer diet.
38	Epifaunal Omnivore	Kozloff and Price 1987	Sea stars are generalist predators. Species such as *Pycnopodia* and *Pisaster* feed mostly on clams and snails, but will also feed on barnacles, anemones, sponges, other sea stars, and detritus. Crabs are generalists that feed on clams, mussels, snails, macrofauna, other crabs, and detritus. Nudibranchs are predatory and feed on hydroids, cnidarians, and other nudibranchs.	Dungeness Crab (0.0198) Epifaunal Grazer (0.0597) Epifaunal Omnivore (0.0182) Epifaunal Sessile (0.0050) Infaunal Bivalve (0.0386) Macrofauna (0.3951) Polychaetes (0.1777)	The diet matrix reflects published information on generalists' diet consisting primarily of benthic invertebrates, and to a lesser extent of phytoplankton and detritus. The principle of 'fixed selectivity' was applied to the vegetation component of the epifaunal omnivore diet.

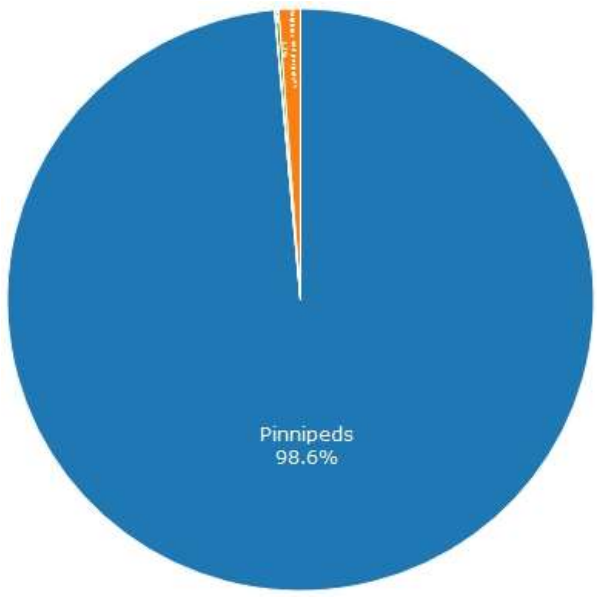
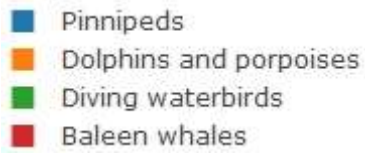
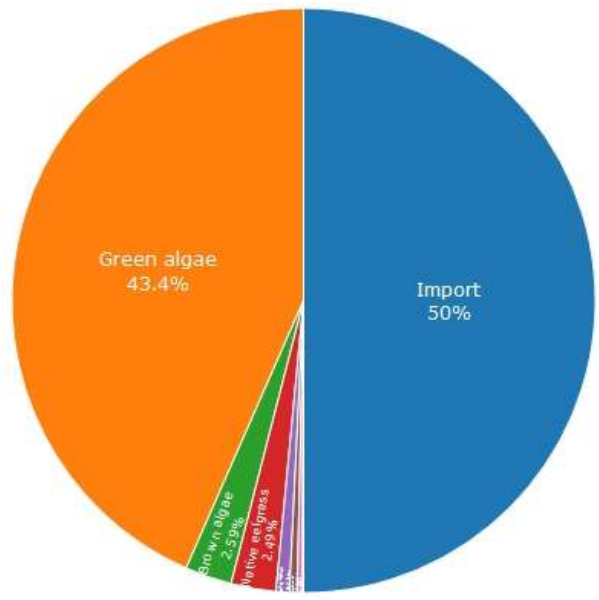
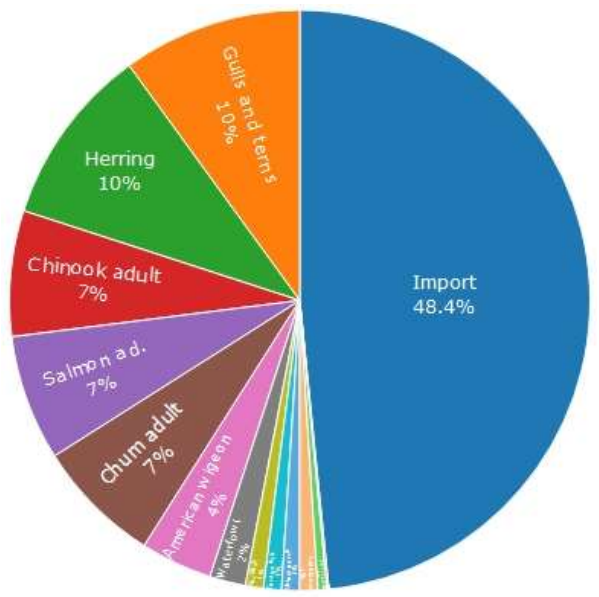
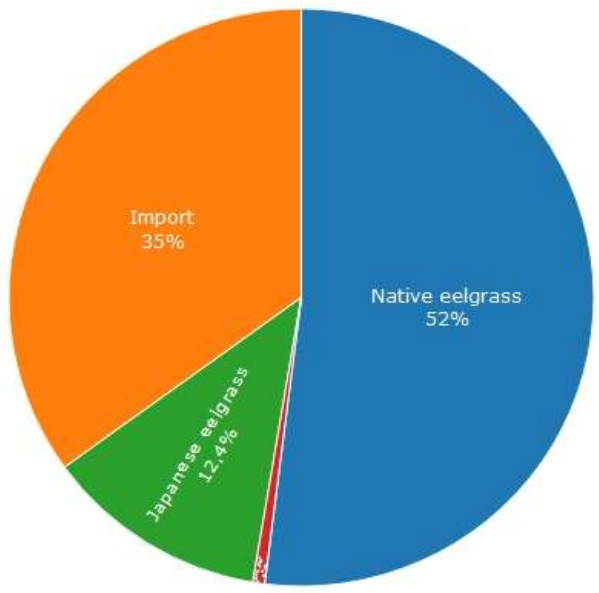
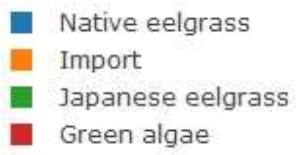
No.	Functional Groups	References	Diet Description (EIS Appendix 10-B)	Diet Matrix (Appendix A of EIS Appendix 10-B)	Explanation
			Whelks are specialist predators that feed primarily on barnacles.	Orange Sea Pen (0.00005) Shrimp (0.0032) Brown Algae (0.0036) Green Algae (0.0600) Japanese Eelgrass (Non-native) (0.0004) Red Algae (0.0010) Phytoplankton (0.1453) Detritus (0.0722)	
39	Epifaunal Sessile Suspension Feeder	Kozloff and Price 1987 Marchinko and Palmer 2003 Lidgard 2008	Diet consists predominantly of phytoplankton, zooplankton, and detritus.	Carnivorous Zooplankton (0.0611) Macrofauna (0.1222) Omnivorous/Herbivorous Zooplankton (0.0917) Phytoplankton (0.6300) Detritus (0.0950)	Diet composition was averaged across diets of epifaunal sessile suspension feeder species comprising this functional group.
40	Infaunal Bivalve	Kozloff and Price 1987 Ward et al. 2003 Dethier 2006	This functional group is primarily filter feeders though the bivalve *Macoma* sp. is a deposit feeder. These species feed primarily on phytoplankton and detritus from the water column and seafloor interface.	Phytoplankton (0.8571) Detritus (0.1429)	Diet composition was averaged across diets of infaunal bivalve species comprising this functional group.
41	Jellyfish	Mackas et al. 2013	Gelatinous zooplankton diet is composed primarily of phytoplankton (81%), herbivorous zooplankton, and macrofauna.	Carnivorous Zooplankton (0.1316) Macrofauna (0.1067) Omnivorous/Herbivorous Zooplankton (0.5448) Phytoplankton (0.1875) Detritus (0.0294)	The diet matrix reflects published information on jellyfish diet consisting primarily of zooplankton and phytoplankton. Diet information was extracted from previously constructed models for the Strait of Georgia, namely Preikshot (2007), and Li (2012). Diet source was erroneously reported as Mackas et al. (2013). Percent contribution for phytoplankton in Section 5.10.3 of EIS Appendix 10-B is erroneously reported to be 81%, but correctly entered in the diet matrix as 18%. The principle of 'fixed selectivity' was not applied to the invertebrate component of the jellyfish diet, as erroneously stated in Section 2.6.2 of EIS Appendix 10-C.
42	Macrofauna	Stoner 1983 Snelgrove 1998 Cruz-Rivera and Hay 2000 Ferraro and Cole 2007 Alarcón-Ortega et al. 2012	Diet composition information is determined by only a few of the taxa comprising this functional group (e.g., amphipods), and is made up predominately of detritus, phytoplankton, herbivorous zooplankton, and meiofauna.	Carnivorous Zooplankton (0.0419) Epifaunal Sessile (0.0002) Jellyfish (0.0645) Macrofauna (0.0340) Meiofauna (0.0442) Omnivorous/Herbivorous Zooplankton (0.1734) Orange Sea Pen (0.00000525) Biofilm (Freshwater) (0.00005) Biofilm (Marine) (0.00005) Brown Algae (0.0080) Green Algae (0.1344) Red Algae (0.0023) Phytoplankton (0.3341)	The principle of 'fixed selectivity' was applied to the invertebrate and vegetation components of the macrofauna diet.

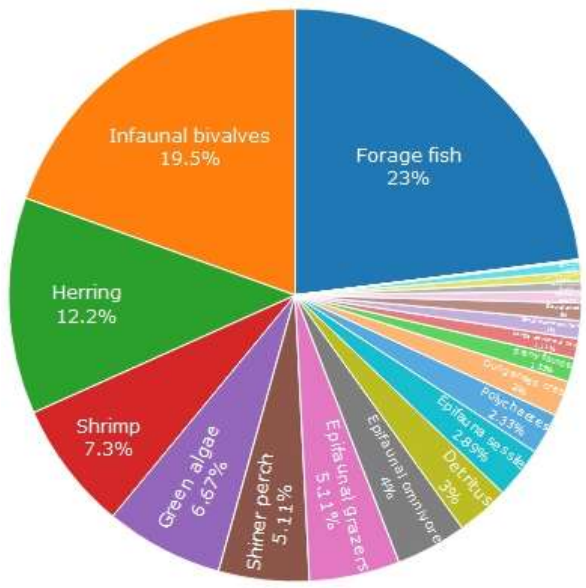
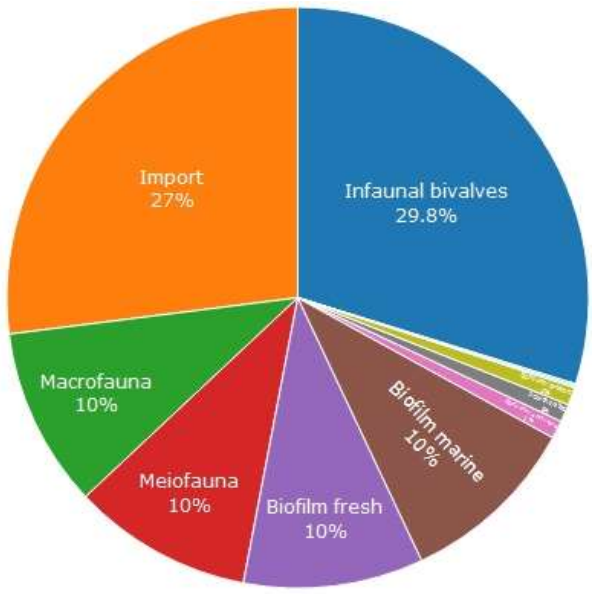
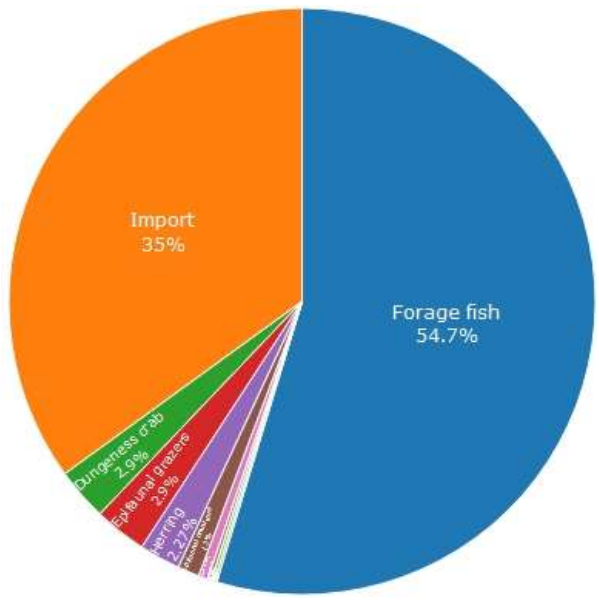
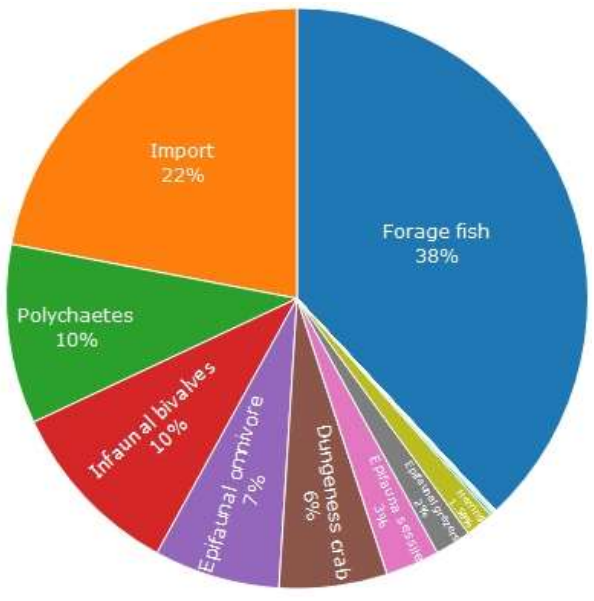
No.	Functional Groups	References	Diet Description (EIS Appendix 10-B)	Diet Matrix (Appendix A of EIS Appendix 10-B)	Explanation
				Biomat (0.0001) Detritus (0.1627)	
43	Meiofauna	Fenchel 1978 Kleppel 1993 Buffan-Dubau et al. 1996 Gasparini and Castelt 1997 De Troch et al. 2005	Diet is predominantly made up of detritus and phytoplankton, with some meiofauna eating other meiofauna, based on the group in general, and copepods more specifically.	Meiofauna (0.0500) Phytoplankton (0.2000) Detritus (0.7500)	The diet matrix reflects published information on meiofauna diet consisting primarily of detritus and phytoplankton.
44	Omnivorous and Herbivorous Zooplankton	Ainsworth et al. 2008 Li 2012 Mackas et al. 2013		Omnivorous/Herbivorous Zooplankton (0.0500) Phytoplankton (0.8500) Detritus (0.1000)	Diet information for this group was extracted from published ecosystem models for the Strait of Georgia (i.e., Preikshot et al. 2012). Section 5.4.3 of EIS Appendix 10-B does not include a description of omnivorous and herbivorous zooplankton diet.
45	Polychaetes	Fauchald and Jumars 1979 Braeckman et al. 2012	This group is broad, which is reflected in the diet matrix. The diet estimate references were only broadly representative of the variety of species in this group.	Epifaunal Grazer (0.0135) Epifaunal Omnivore (0.0041) Macrofauna (0.0709) Meiofauna (0.0922) Omnivorous/Herbivorous Zooplankton (0.3619)] Phytoplankton (0.3949) Detritus (0.0625)	The principle of 'fixed selectivity' was applied to the invertebrate component of the polychaete diet.
46	Orange Sea Pen	Best 1988	Sea pens are filter feeders and consume both phytoplankton and zooplankton.	Carnivorous Zooplankton (0.1667) Omnivorous/Herbivorous Zooplankton (0.2500) Phytoplankton (0.5000) Detritus (0.0833)	The diet matrix reflects published information on orange sea pen diet consisting primarily of phytoplankton and zooplankton.
47	Shrimp	Dunham and Boutillier 2001	Diet is dominated by detritus, macrofauna, and herbivorous zooplankton.	Carnivorous Zooplankton (0.0961) Epifaunal Sessile (0.0216) Macrofauna (0.0779) Meiofauna (0.1014) Omnivorous/Herbivorous Zooplankton (0.3977) Orange Sea Pen (0.00001) Shrimp (0.0008) Detritus (0.3045)	The diet matrix reflects published information on shrimp diet consisting primarily of zooplankton and detritus.

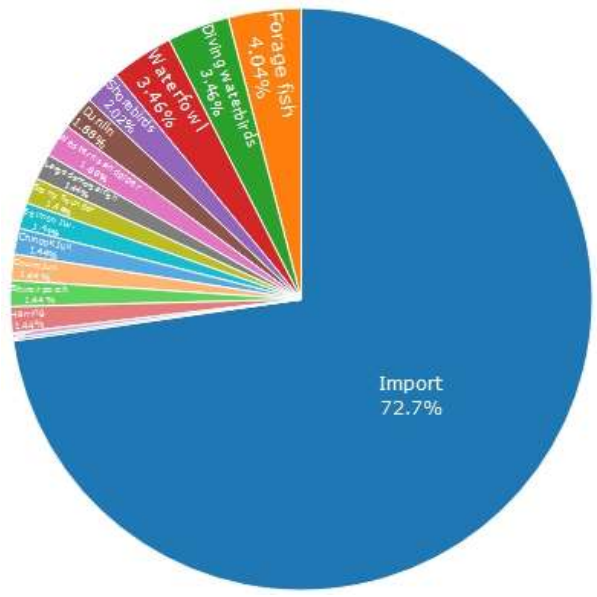
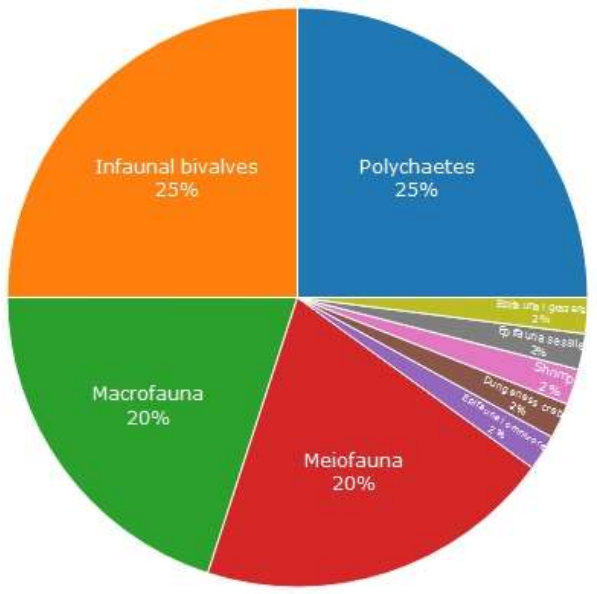
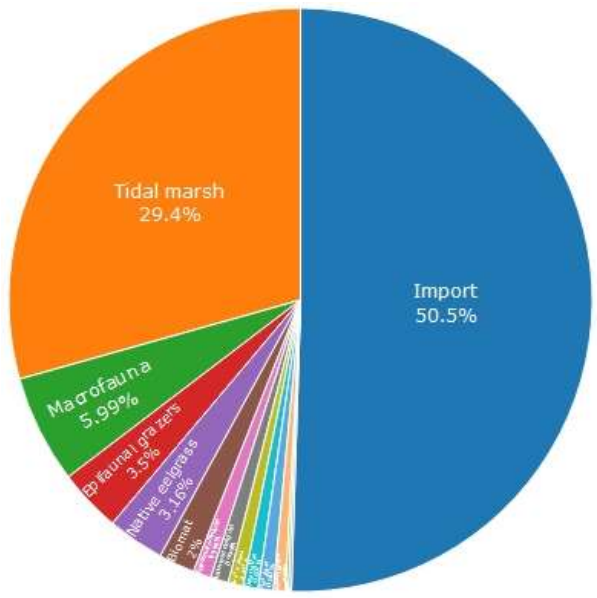
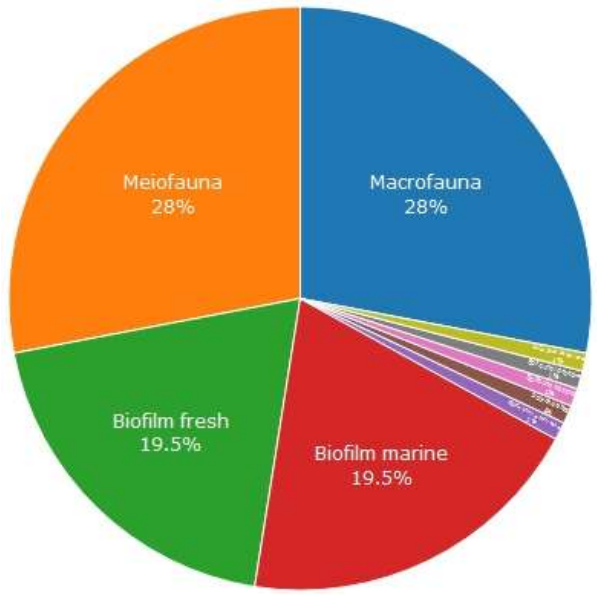
Note: Rows shaded grey represent functional groups for which the fixed selectivity principle was applied.
Full citations of references identified in this table are included in Section 9.0 of EIS Appendix 10-B, with the following exception:
Jardine, C. B., A. L. Bond, P. J. A. Davidson, R. W. Butler, and T. Kuwae. 2015. Biofilm Consumption and Variable Diet Composition of Western Sandpipers (*Calidris mauri*) during Migratory Stopover. PLoS One DOI:10.1371/journal.pone.0124164

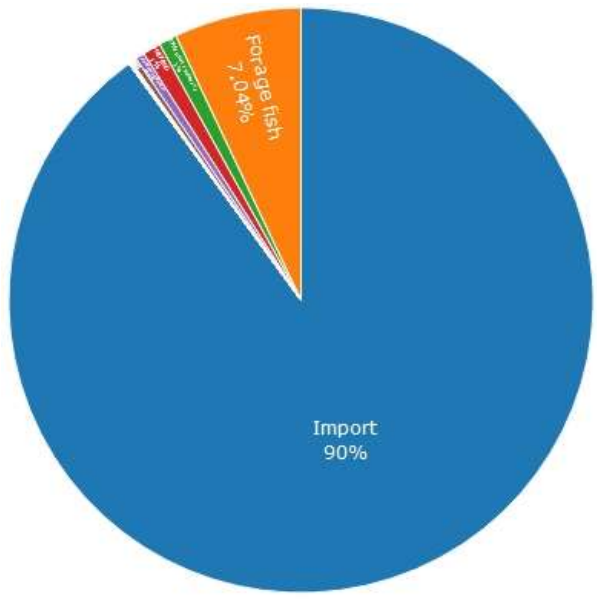
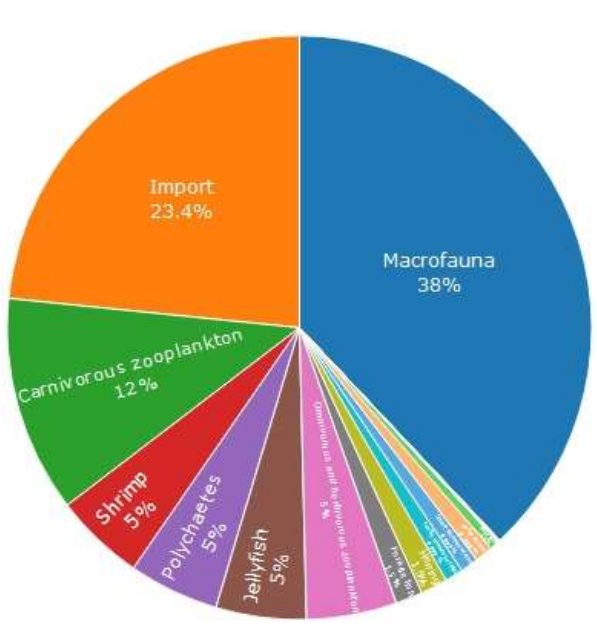
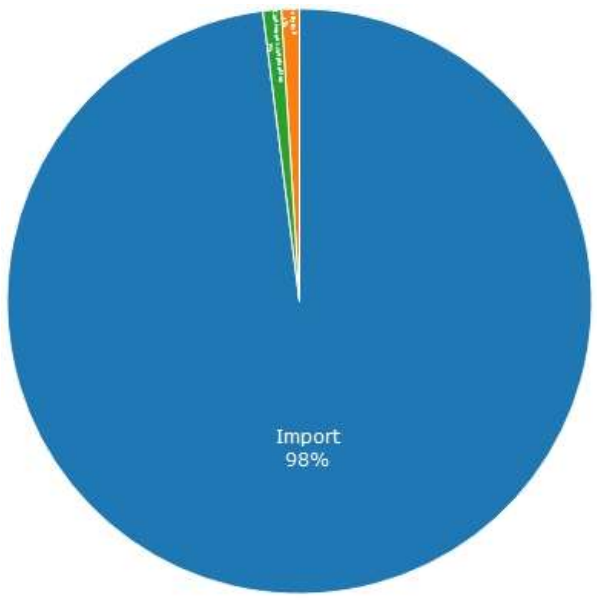
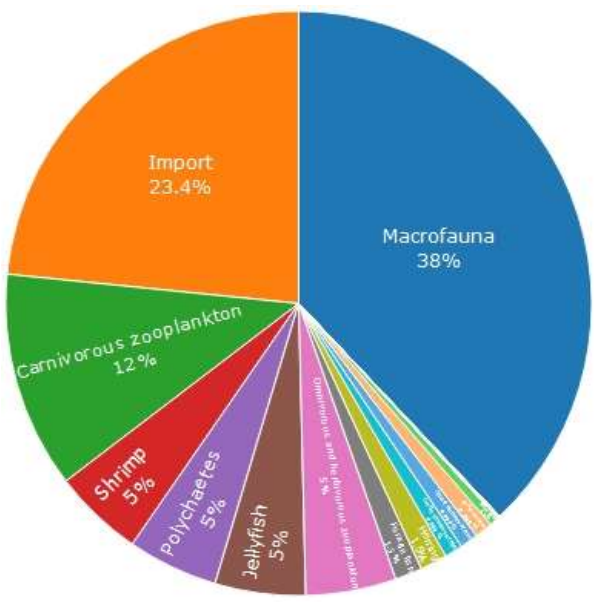
Table IR3-07-A2 Pie Charts of Diet Composition (Appendix A of EIS Appendix 10-B) per Functional Group

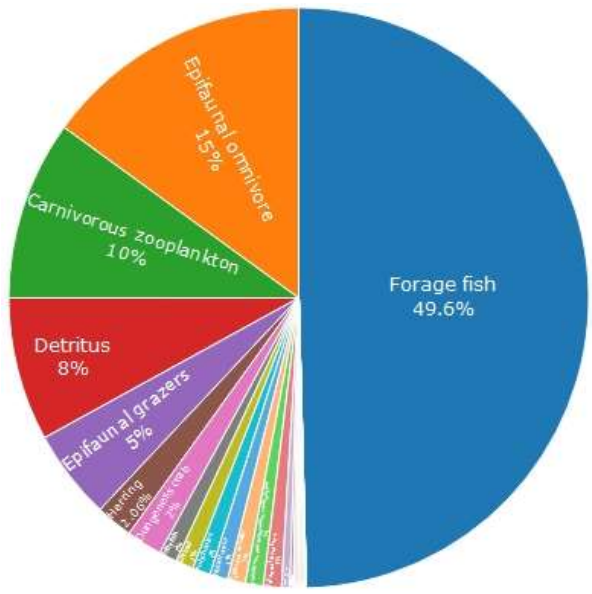
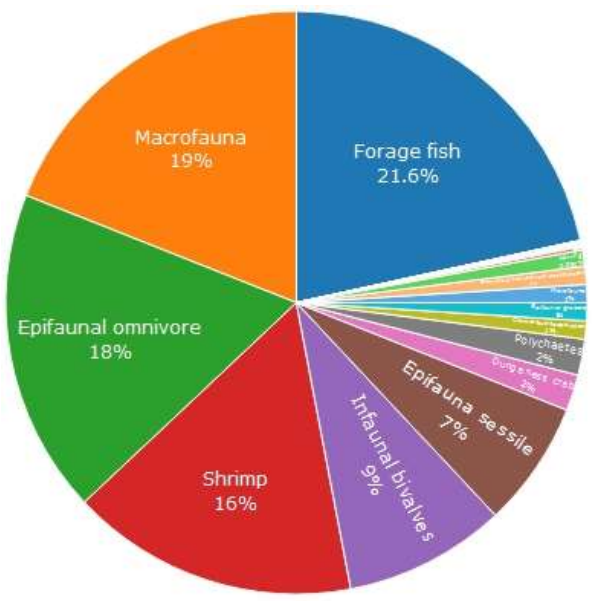
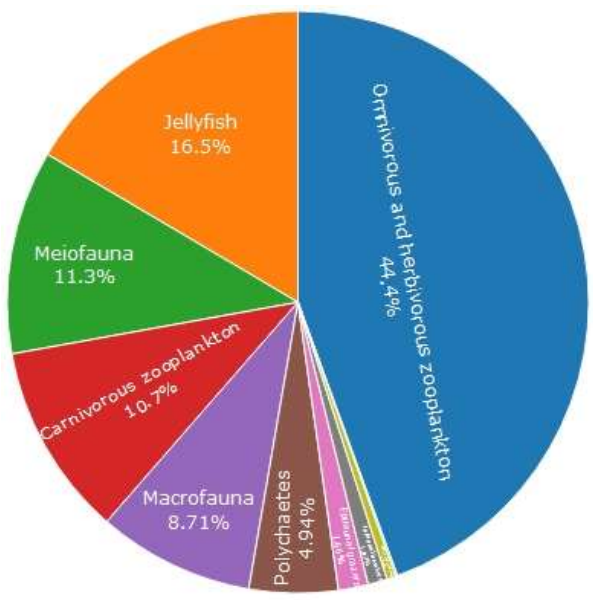
No.	Functional Group	Diet Composition (Appendix A of EIS Appendix 10-B)	Legend
1	Baleen Whales		Macrofauna Omnivorous and herbivorous zooplankton Forage fish Carnivorous zooplankton Large demersal fish Herring Infaunal bivalves Epifauna sessile Sandlance Epifaunal grazers Epifaunal omnivore Polychaetes Salmon juv. Chinook juv. Chum juv.
2	Dolphins and Porpoises		Herring Small demersal fish Epifaunal omnivore Forage fish Large demersal fish Shiner perch Shrimp Rockfish Flatfish Chinook juv. Chum juv. Salmon juv. Lingcod Dogfish Starry flounder Sandlance
3	Pinnipeds		Import Forage fish Epifaunal omnivore Salmon ad. Herring Chum adult Infaunal bivalves Shiner perch Chinook adult Starry flounder Epifauna sessile Small demersal fish Lingcod Large demersal fish Rockfish Flatfish Chum juv. Chinook juv.
4	Southern Resident Killer Whales		Chinook adult Salmon ad. Chum adult Rockfish Herring

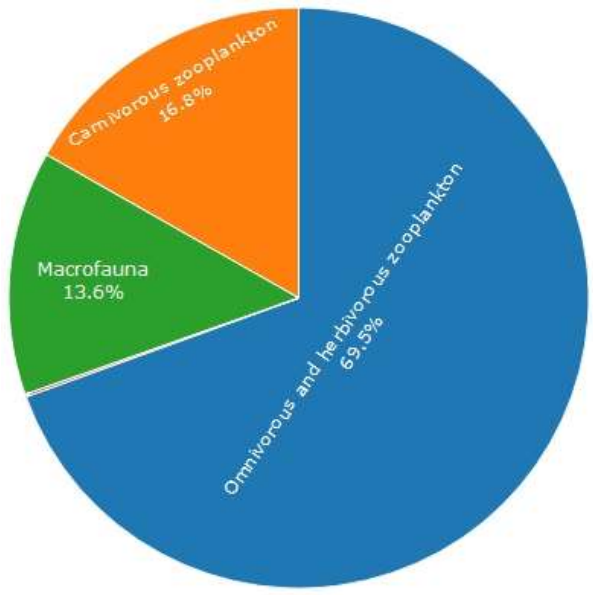
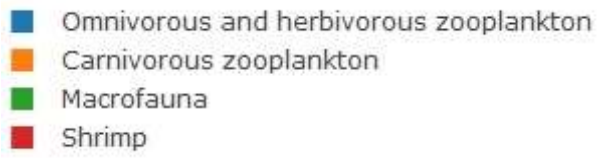
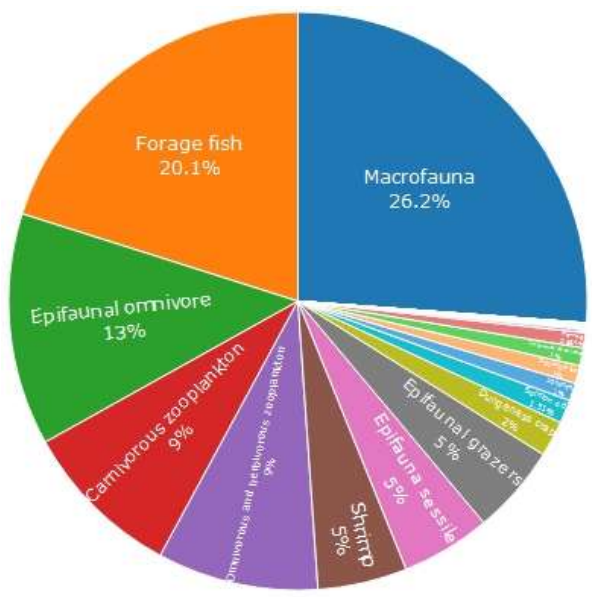
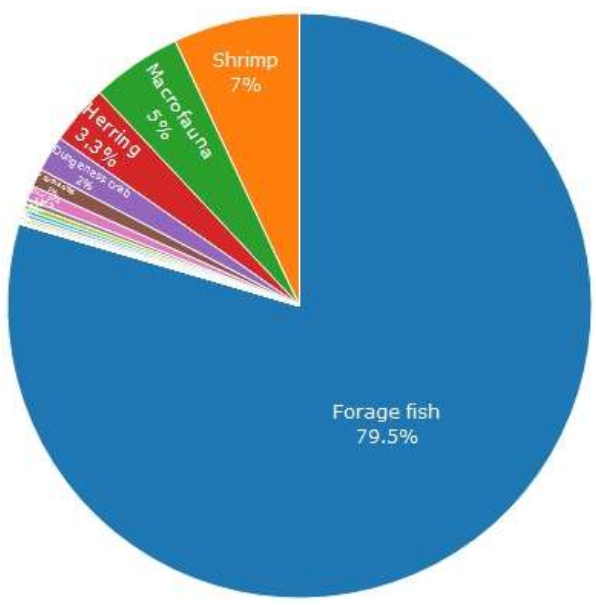
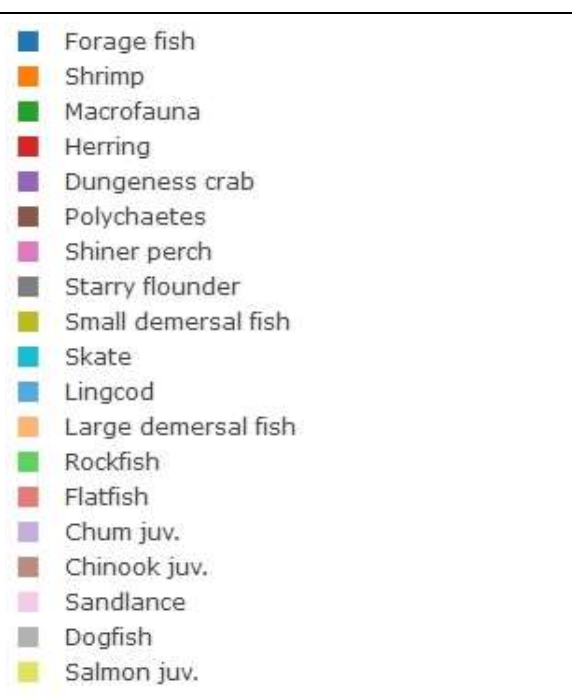
No.	Functional Group	Diet Composition (Appendix A of EIS Appendix 10-B)	Legend
5	Transient Killer Whales		
6	American Wigeon		
7	Bald Eagle		
8	Brant Goose		

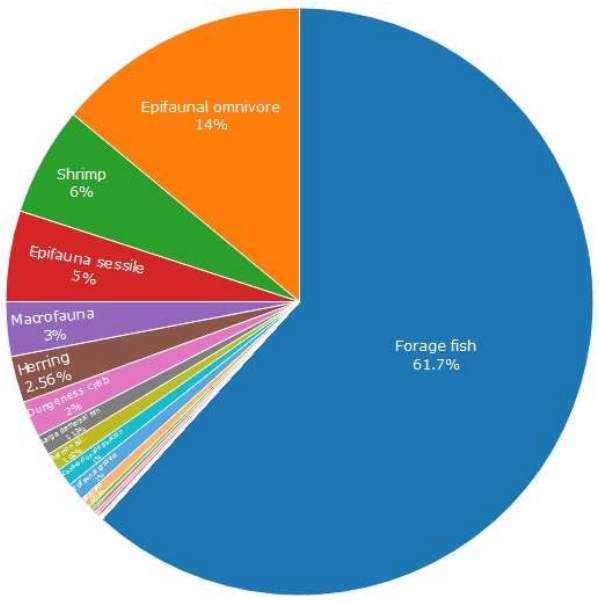
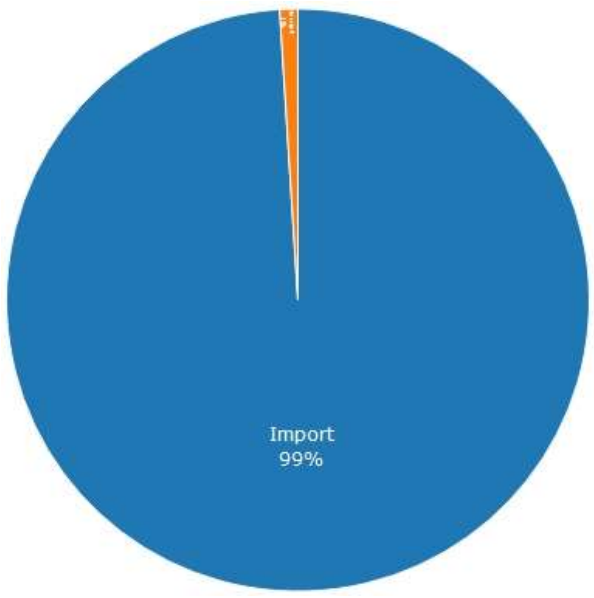
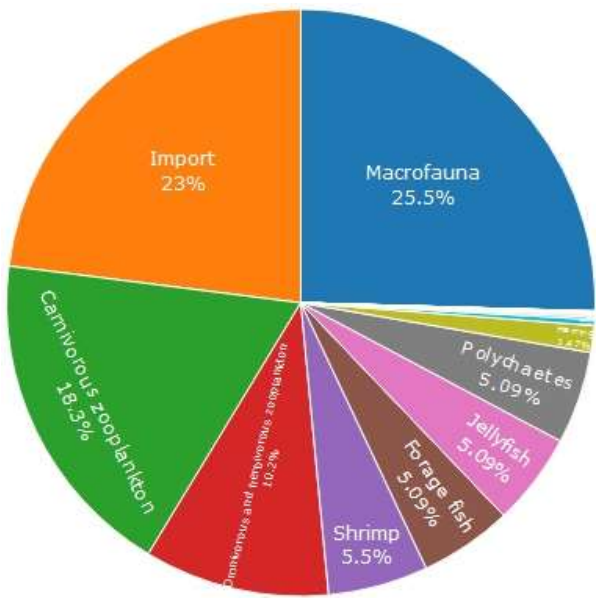
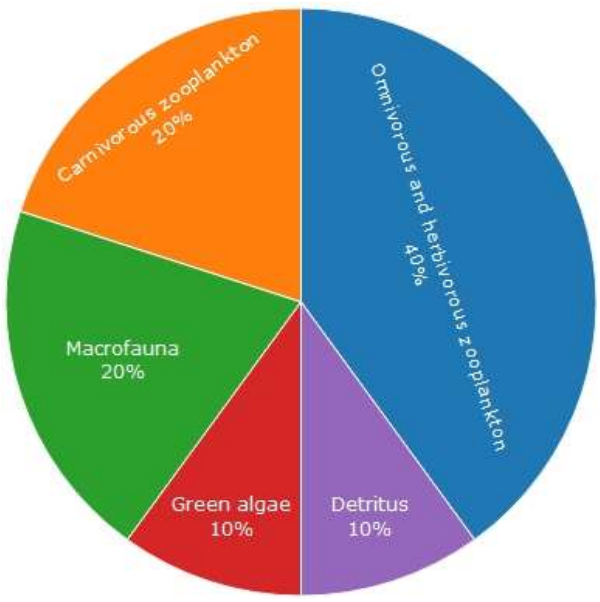
No.	Functional Group	Diet Composition (Appendix A of EIS Appendix 10-B)	Legend
9	Diving Waterbirds		Forage fish Infaunal bivalves Herring Shrimp Green algae Shiner perch Epifaunal grazers Epifaunal omnivore Detritus Epifauna sessile Polychaetes Dungeness crab Starry flounder Large demersal fish Small demersal fish Sandlance Macrofauna Native eelgrass Japanese eelgrass Tidal marsh
10	Dunlin		Infaunal bivalves Import Macrofauna Meiofauna Biofilm fresh Biofilm marine Epifaunal omnivore Polychaetes Epifaunal grazers Shrimp Epifauna sessile
11	Great Blue Heron		Forage fish Import Dungeness crab Epifaunal grazers Herring Epifaunal omnivore Shiner perch Starry flounder Small demersal fish Large demersal fish
12	Gulls and Terns		Forage fish Import Polychaetes Infaunal bivalves Epifaunal omnivore Dungeness crab Epifauna sessile Epifaunal grazers Herring Starry flounder Small demersal fish Rockfish Flatfish Chum juv. Chinook juv. Sandlance Salmon juv.

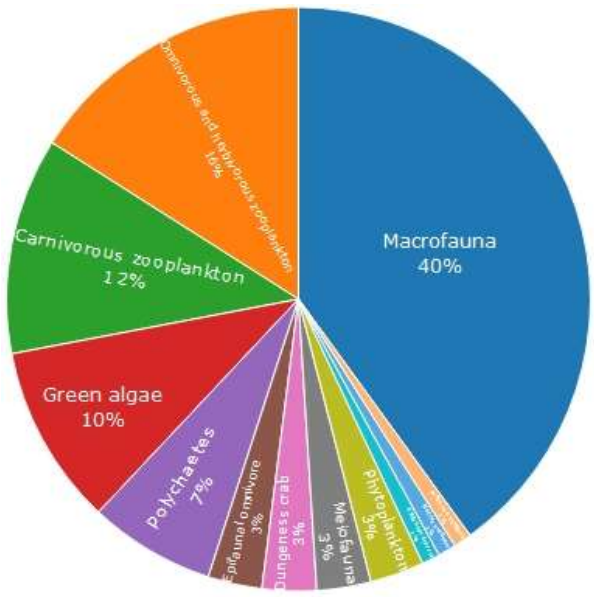
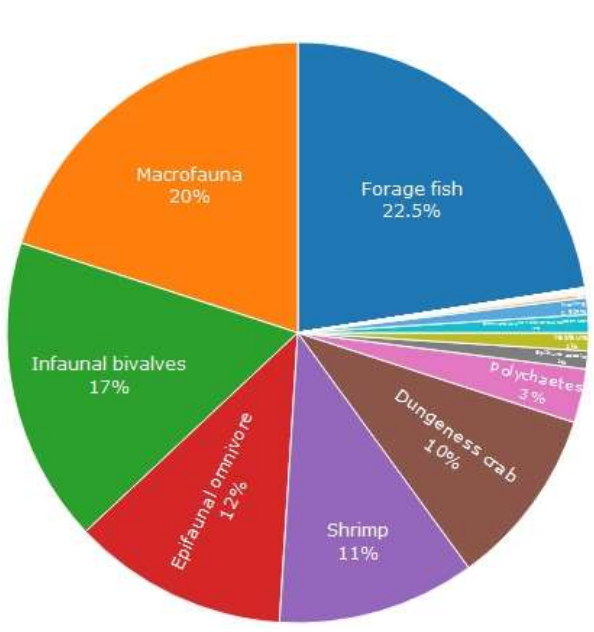
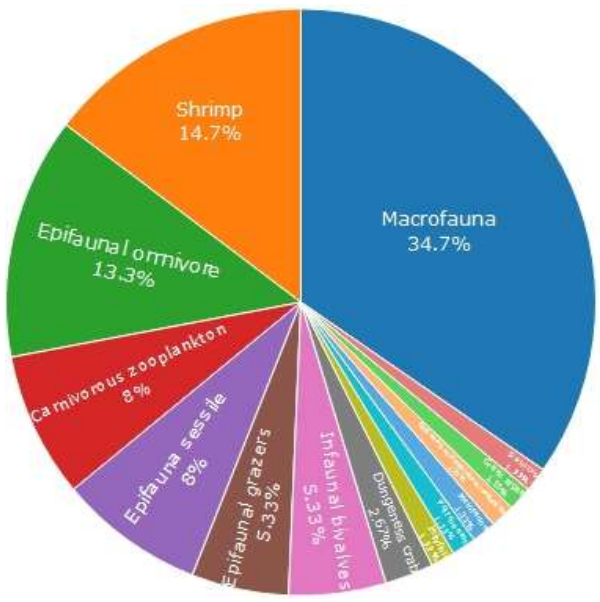
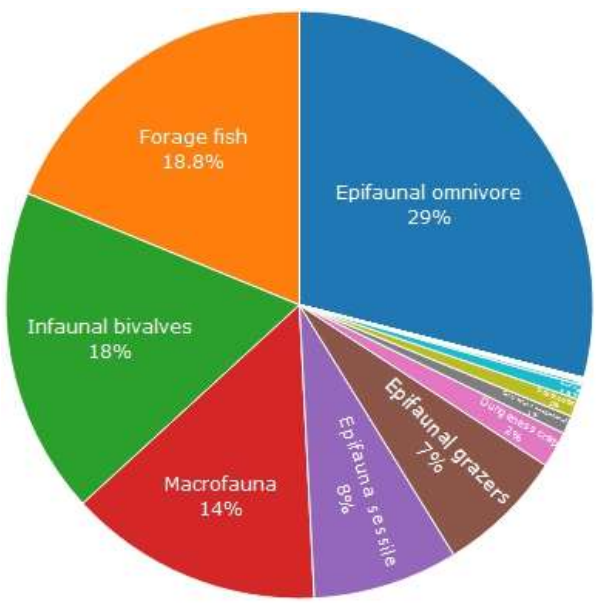
No.	Functional Group	Diet Composition (Appendix A of EIS Appendix 10-B)	Legend
13	Raptors		
14	Shorebirds		
15	Waterfowl		
16	Western Sandpiper		

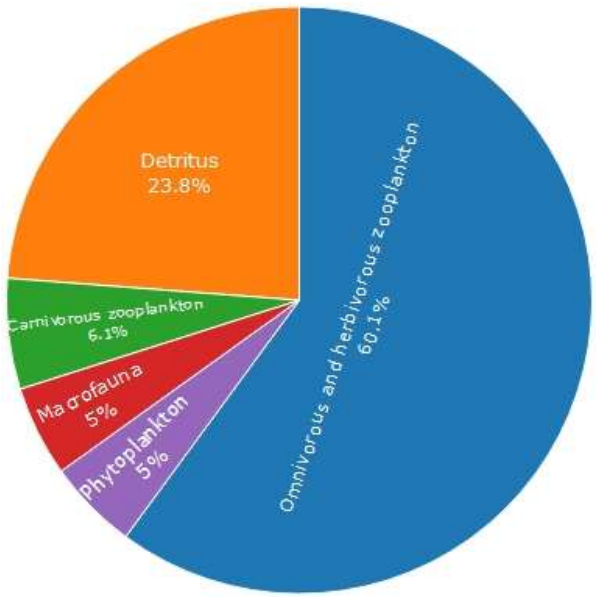
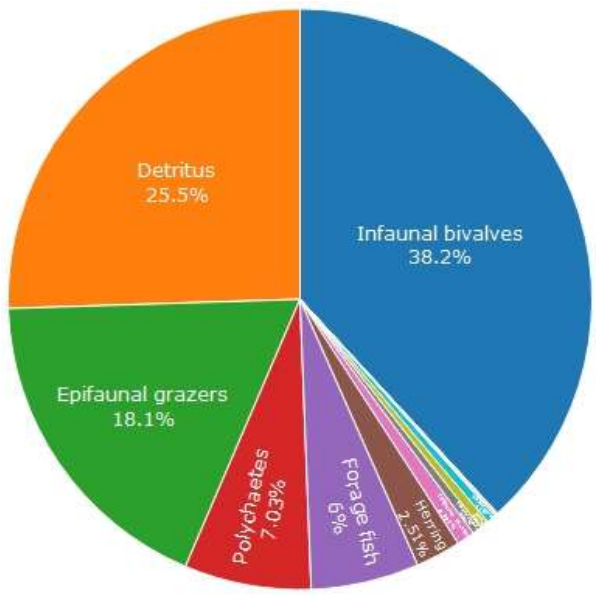
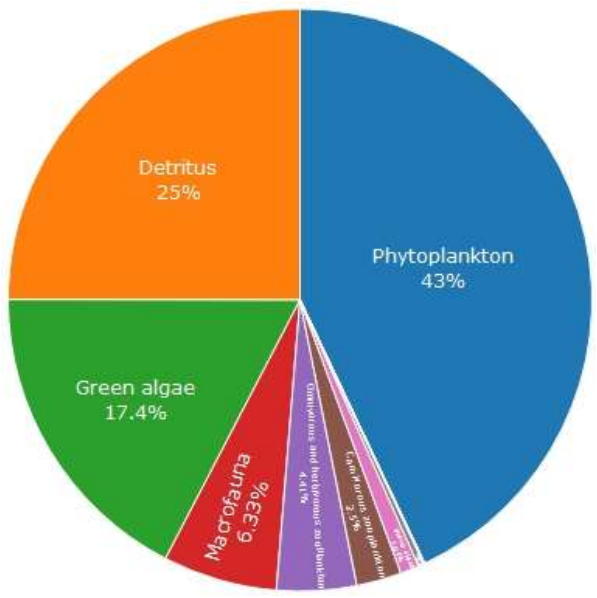
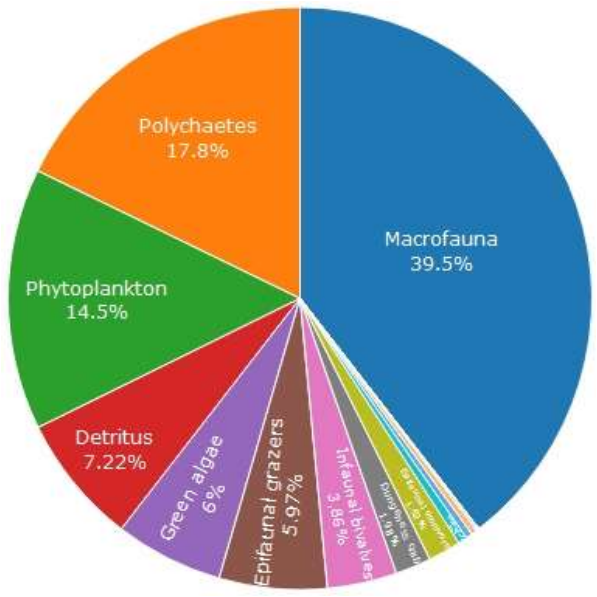
No.	Functional Group	Diet Composition (Appendix A of EIS Appendix 10-B)	Legend
17	Chinook Salmon (Adult)		Import Forage fish Epifaunal omnivore Jellyfish Carnivorous zooplankton Herring Shiner perch Starry flounder Small demersal fish Lingcod Large demersal fish Rockfish Flatfish Chum juv. Chinook juv. Sandlance Salmon juv.
18	Chinook Salmon (Juvenile)		Macrofauna Import Carnivorous zooplankton Shrimp Polychaetes Jellyfish Omnivorous and herbivorous zooplankton Forage fish Herring Large demersal fish Small demersal fish Meiofauna Shiner perch Flatfish Chum juv. Salmon juv. Chinook juv. Sandlance
19	Chum Salmon (Adult)		Import Jellyfish Carnivorous zooplankton
20	Chum Salmon (Juvenile)		Macrofauna Import Carnivorous zooplankton Shrimp Polychaetes Jellyfish Omnivorous and herbivorous zooplankton Forage fish Herring Large demersal fish Small demersal fish Meiofauna Shiner perch Flatfish Chum juv. Salmon juv. Chinook juv. Sandlance

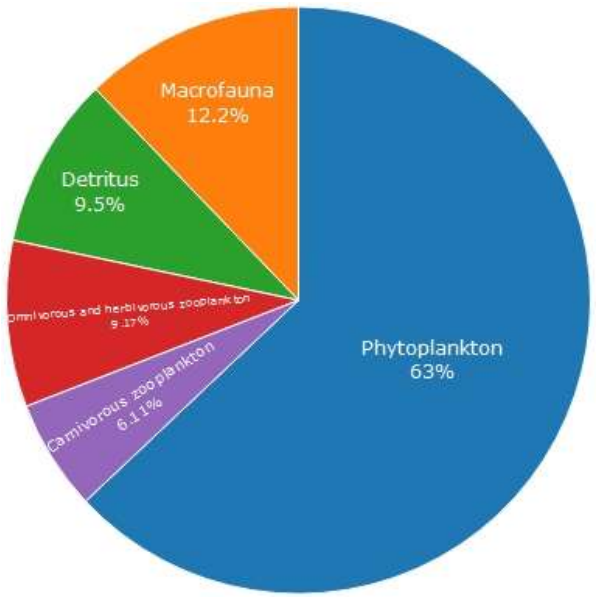
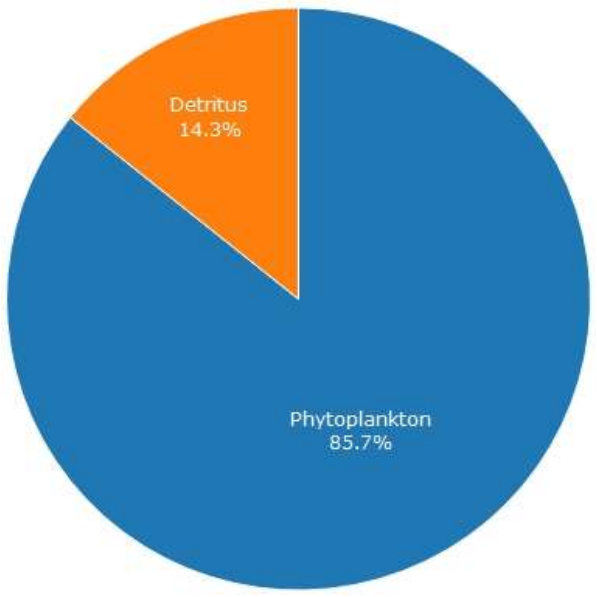
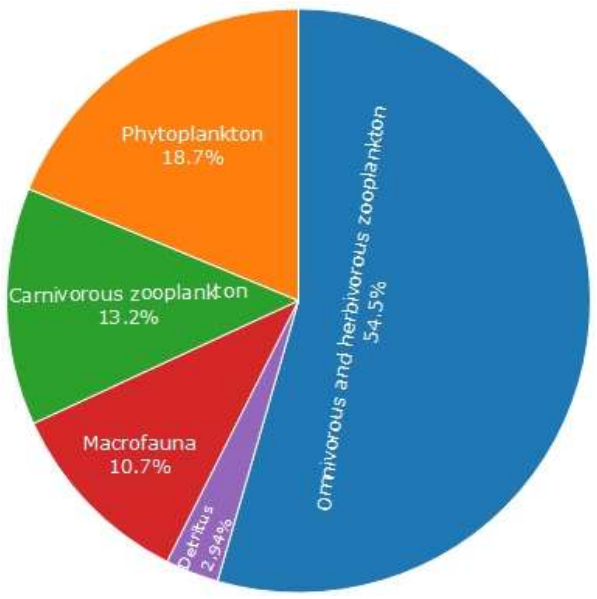
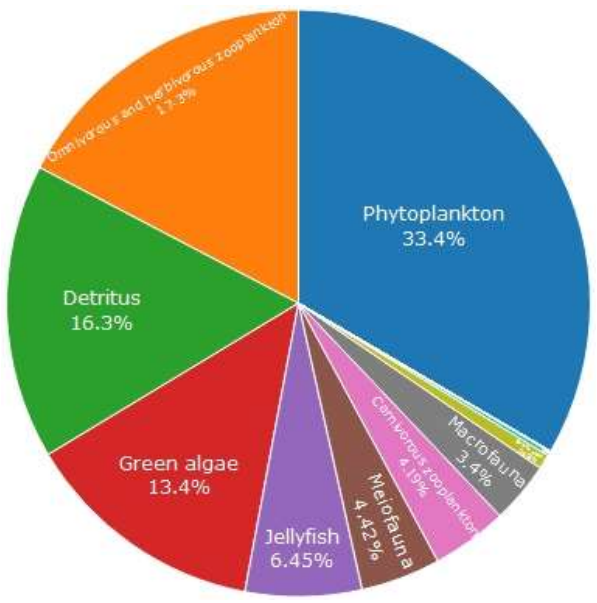
No.	Functional Group	Diet Composition (Appendix A of EIS Appendix 10-B)	Legend
21	Dogfish		Forage fish Epifaunal omnivore Carnivorous zooplankton Detritus Epifaunal grazers Herring Dungeness crab Jellyfish Shrimp Polychaetes Macrofauna Epifauna sessile Omnivorous and herbivorous zooplankton Infaunal bivalves Shiner perch Starry flounder Small demersal fish Skate Lingcod Large demersal fish
22	Flatfish		Forage fish Macrofauna Epifaunal omnivore Shrimp Infaunal bivalves Epifauna sessile Dungeness crab Polychaetes Carnivorous zooplankton Epifaunal grazers Meiofauna Omnivorous and herbivorous zooplankton Herring Shiner perch Starry flounder Small demersal fish Skate Large demersal fish Rockfish Flatfish
23	Forage Fish		Omnivorous and herbivorous zooplankton Jellyfish Meiofauna Carnivorous zooplankton Macrofauna Polychaetes Epifaunal grazers Infaunal bivalves Epifaunal omnivore Shrimp

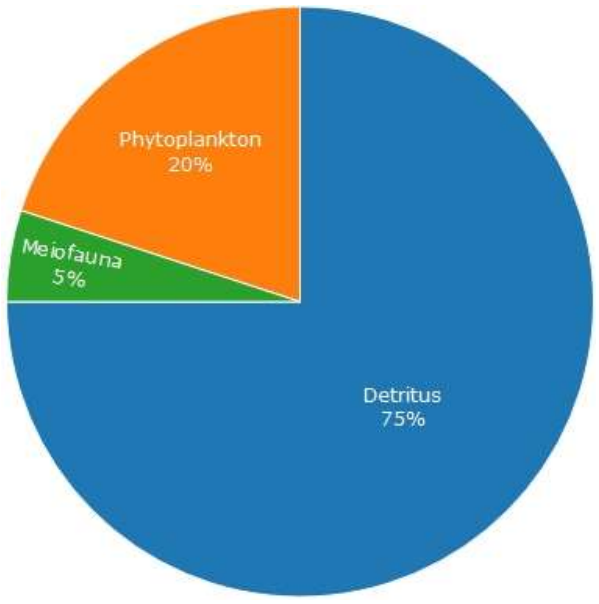
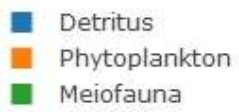
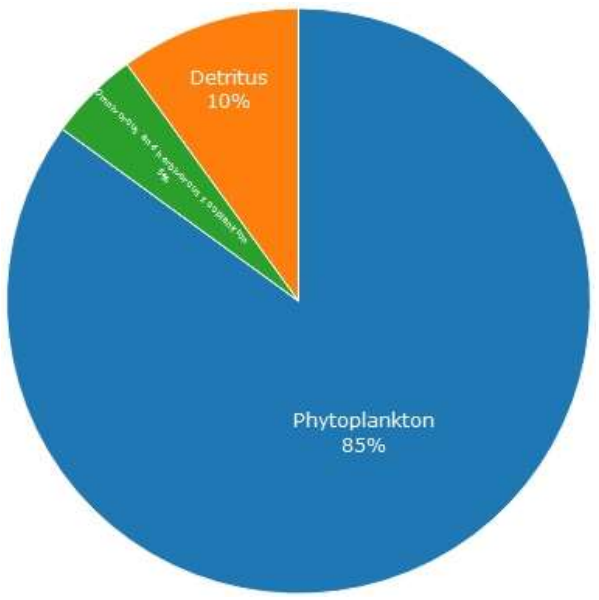
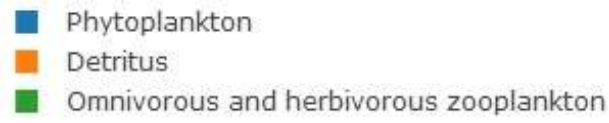
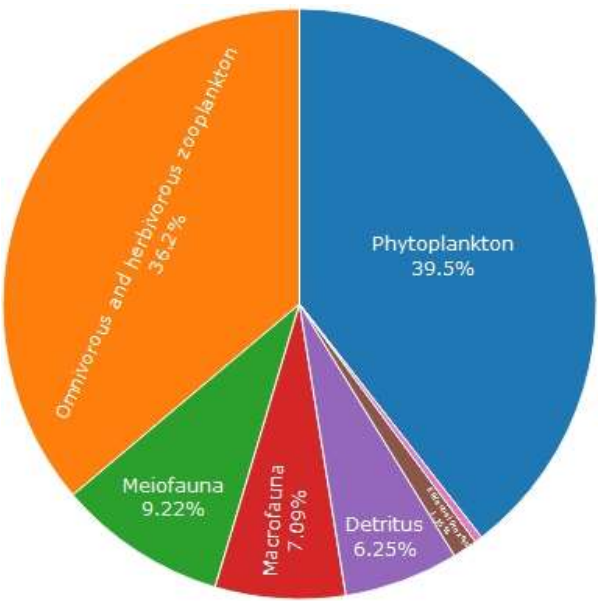
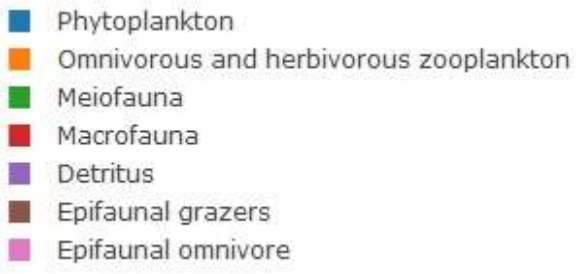
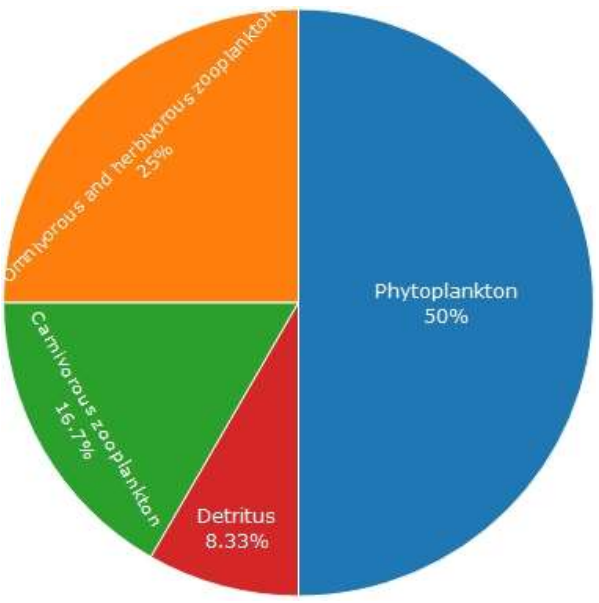
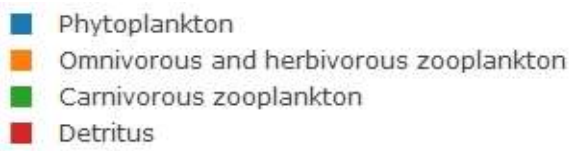
No.	Functional Group	Diet Composition (Appendix A of EIS Appendix 10-B)	Legend
24	Herring		
25	Large Demersal Fish		
26	Lingcod		

No.	Functional Group	Diet Composition (Appendix A of EIS Appendix 10-B)	Legend
27	Rockfish		Forage fish Epifaunal omnivore Shrimp Epifauna sessile Macrofauna Herring Dungeness crab Large demersal fish Salmon ad. Carnivorous zooplankton Epifaunal grazers Shiner perch Starry flounder Small demersal fish Skate Lingcod Rockfish Flatfish Chum juv. Chinook juv. Sandlance Dogfish Salmon juv.
28	Salmon (Adult)		Import Herring
29	Salmon (Juvenile)		Macrofauna Import Carnivorous zooplankton Omnivorous and herbivorous zooplankton Shrimp Forage fish Jellyfish Polychaetes Herring Shiner perch Starry flounder Small demersal fish Large demersal fish Rockfish Flatfish Chum juv. Chinook juv. Sandlance Salmon juv.
30	Sandlance		Omnivorous and herbivorous zooplankton Carnivorous zooplankton Macrofauna Green algae Detritus

No.	Functional Group	Diet Composition (Appendix A of EIS Appendix 10-B)	Legend
31	Shiner Perch		Macrofauna Omnivorous and herbivorous zooplankton Carnivorous zooplankton Green algae Polychaetes Epifaunal omnivore Dungeness crab Meiofauna Phytoplankton Epifaunal grazers Native eelgrass Japanese eelgrass
32	Skate		Forage fish Macrofauna Infaunal bivalves Epifaunal omnivore Shrimp Dungeness crab Polychaetes Epifauna sessile Meiofauna Omnivorous and herbivorous zooplankton Herring Shiner perch Starry flounder Small demersal fish Skate Large demersal fish Rockfish Flatfish Chum juv. Chinook juv. Sandlance Salmon juv.
33	Small Demersal Fish		Macrofauna Shrimp Epifaunal omnivore Carnivorous zooplankton Epifauna sessile Epifaunal grazers Infaunal bivalves Dungeness crab Jellyfish Polychaetes Meiofauna Omnivorous and herbivorous zooplankton Green algae Detritus
34	Starry Flounder		Epifaunal omnivore Forage fish Infaunal bivalves Macrofauna Epifauna sessile Epifaunal grazers Dungeness crab Carnivorous zooplankton Polychaetes Herring Shiner perch Starry flounder Small demersal fish Large demersal fish Rockfish Flatfish Chum juv. Chinook juv. Sandlance Salmon juv.

No.	Functional Group	Diet Composition (Appendix A of EIS Appendix 10-B)	Legend
35	Carnivorous Zooplankton		Omnivorous and herbivorous zooplankton Detritus Carnivorous zooplankton Macrofauna Phytoplankton
36	Dungeness Crab		Infaunal bivalves Detritus Epifaunal grazers Polychaetes Forage fish Herring Epifauna sessile Epifaunal omnivore Shrimp Dungeness crab Flatfish Sandlance
37	Epifaunal Grazer		Phytoplankton Detritus Green algae Macrofauna Omnivorous and herbivorous zooplankton Carnivorous zooplankton Brown algae Red algae Epifauna sessile Biomat Biofilm fresh Biofilm marine
38	Epifaunal Omnivore		Macrofauna Polychaetes Phytoplankton Detritus Green algae Epifaunal grazers Infaunal bivalves Dungeness crab Epifaunal omnivore Epifauna sessile Brown algae Shrimp Red algae Japanese eelgrass Orange sea pen

No.	Functional Group	Diet Composition (Appendix A of EIS Appendix 10-B)	Legend
39	Epifaunal Sessile Suspension Feeder		Phytoplankton Macrofauna Detritus Omnivorous and herbivorous zooplankton Carnivorous zooplankton
40	Infaunal Bivalve		Phytoplankton Detritus
41	Jellyfish		Omnivorous and herbivorous zooplankton Phytoplankton Carnivorous zooplankton Macrofauna Detritus
42	Macrofauna		Phytoplankton Omnivorous and herbivorous zooplankton Detritus Green algae Jellyfish Meiofauna Carnivorous zooplankton Macrofauna Brown algae Red algae Epifauna sessile Biomat Biofilm fresh Biofilm marine Orange sea pen

No.	Functional Group	Diet Composition (Appendix A of EIS Appendix 10-B)	Legend
43	Meiofauna		
44	Omnivorous and Herbivorous Zooplankton		
45	Polychaetes		
46	Orange Sea Pen		

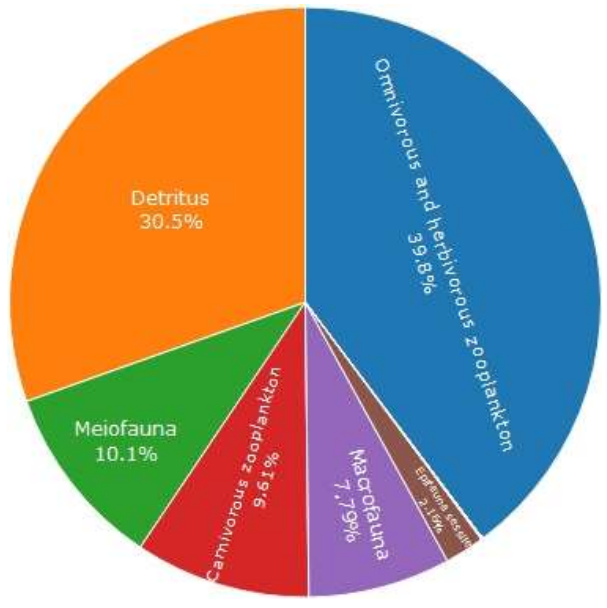
No.	Functional Group	Diet Composition (Appendix A of EIS Appendix 10-B)	Legend
47	Shrimp		Omnivorous and herbivorous zooplankton Detritus Meiofauna Carnivorous zooplankton Macrofauna Epifauna sessile Shrimp Orange sea pen

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Table IR3-07-A3 Biomass Estimates from the Roberts Bank Ecosystem Model Run, Including Diet Matrix Corrected for Pinnipeds and Sandlance (numbers in bold font indicate difference in biomass ratio between the RB model run with the corrected diet matrix and biomass ratio presented in the EIS (Table 3.2 of EIS Appendix 10-C)

No.	Functional Group	Biomass (without Project, t/km^2)	Biomass (with Project, t/km^2)	Difference (with – without Project, t/km^2)	Biomass Ratio (with/without Project, with corrected diets)	Biomass Ratio (with/without Project, as presented in the EIS)
1	Baleen whales	0.273	0.250	-0.023	0.92	0.92
2	Dolphins and porpoises	0.273	0.264	-0.009	0.97	0.97
3	Pinnipeds	21.832	21.240	-0.592	0.97	0.97
4	Southern resident killer whales	0.546	0.531	-0.015	0.97	0.97
5	Transient killer whales	0.284	0.251	-0.032	0.89	0.89
6	American wigeon	4.765	4.365	-0.400	0.92	0.92
7	Bald eagle	0.120	0.112	-0.008	0.93	0.93
8	Brant goose	1.088	1.031	-0.058	0.95	0.95
9	Diving waterbirds	1.506	1.412	-0.094	0.94	0.94
10	Dunlin	0.471	0.531	0.060	1.13	1.13
11	Great blue heron	0.671	0.669	-0.002	1.00	1.00
12	Gulls and terns	2.639	2.601	-0.039	0.99	0.99
13	Raptors	0.008	0.011	0.003	1.31	1.31
14	Shorebirds	0.045	0.044	-0.001	0.98	0.98
15	Waterfowl	16.559	17.904	1.345	1.08	1.08
16	Western sandpiper	0.058	0.066	0.008	1.13	1.13
17	Chinook salmon adult	187.099	177.596	-9.503	0.95	0.95
18	Chinook salmon juvenile	0.655	0.759	0.104	1.16	1.16
19	Chum salmon adult	111.643	106.514	-5.128	0.95	0.95
20	Chum salmon juvenile	0.491	0.561	0.070	1.14	1.14
21	Dogfish	35.953	35.143	-0.811	0.98	0.98

No.	Functional Group	Biomass (without Project, t/km^2)	Biomass (with Project, t/km^2)	Difference (with – without Project, t/km^2)	Biomass Ratio (with/without Project, with corrected diets)	Biomass Ratio (with/without Project, as presented in the EIS)
22	Flatfish	20.441	20.134	-0.306	**0.99**	0.98
23	Forage fish	573.086	564.989	-8.097	0.99	0.99
24	Herring	242.712	237.097	-5.616	0.98	0.98
25	Large demersal fish	8.386	8.286	-0.100	0.99	0.99
26	Lingcod	32.031	31.087	-0.943	0.97	0.97
27	Rockfish	18.475	16.862	-1.613	0.91	0.91
28	Salmon adult	55.454	53.174	-2.280	0.96	0.96
29	Salmon juvenile	0.092	0.090	-0.002	0.97	0.97
30	Sandlance	11.323	12.049	0.726	1.06	1.06
31	Shiner perch	8.921	10.561	1.640	1.18	1.18
32	Skate	12.584	11.565	-1.018	0.92	0.92
33	Small demersal fish	3.945	3.733	-0.212	0.95	0.95
34	Starry flounder	11.453	12.145	0.692	1.06	1.06
35	Carnivorous zooplankton	1,623.743	1,449.781	-173.962	0.89	0.89
36	Dungeness crab	252.769	243.917	-8.852	**0.96**	0.97
37	Epifaunal grazer	835.674	769.723	-65.950	0.92	0.92
38	Epifaunal omnivore	105.284	102.859	-2.425	0.98	0.98
39	Epifaunal sessile suspension feeder	48.876	58.419	9.543	**1.20**	1.19
40	Infaunal bivalve	6,590.176	6,071.267	-518.908	0.92	0.92
41	Jellyfish	599.746	550.583	-49.163	0.92	0.92
42	Macrofauna	2,743.430	3,476.594	733.164	1.27	1.27
43	Meiofauna	1,588.644	1,763.837	175.193	1.11	1.11
44	Omnivorous and herbivorous zooplankton	2,970.768	2,761.888	-208.879	0.93	0.93
45	Polychaetes	1,099.779	979.597	-120.182	0.89	0.89

No.	Functional Group	Biomass (without Project, t/km^2)	Biomass (with Project, t/km^2)	Difference (with – without Project, t/km^2)	Biomass Ratio (with/without Project, with corrected diets)	Biomass Ratio (with/without Project, as presented in the EIS)
46	Orange sea pen	7.692	3.463	-4.229	0.45	0.45
47	Shrimp	27.290	23.759	-3.531	0.87	0.87
48	Biofilm freshwater	1,642.846	3,111.264	1,468.419	1.89	1.89
49	Biofilm marine	1,819.684	1,399.847	-419.837	0.77	0.77
50	Brown algae	448.060	394.903	-53.157	0.88	0.88
51	Eelgrass (native)	304.576	316.065	11.490	1.04	1.04
52	Green algae	6,894.604	6,311.653	-582.951	0.92	0.92
53	Japanese eelgrass (non-native)	6.855	6.808	-0.048	0.99	0.99
54	Red algae	15.168	13.596	-1.572	0.90	0.90
55	Phytoplankton	2,183.184	2,252.023	68.839	1.03	1.03
56	Tidal marsh	1,329.832	1,664.892	335.060	1.25	1.25
57	Biomat	1,217.125	861.010	-356.115	0.71	0.71
58	Detritus	545.796	550.550	4.754	1.01	1.01

Note:

- Estimates are rounded. Biomass information is at a point in time after equilibrium at Roberts Bank has been reached.
- Marine mammals are included in the RB model for their important role as top predators, but the RB model has not been used to assess productivity changes to marine mammals.

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IR3-08 Roberts Bank Ecosystem Model – Diet Matrix

Information Source(s)

EIS Volume 3: Section 10.3, Appendix 10-B

CEAR Doc #547

Context

According to the Proponent, the formulation for the RB EwE model used a fixed selectivity approach where the distribution of prey among predator diets was estimated relative to prey productivity. In the RB EwE model, this approach was specifically applied to fish prey, marine invertebrate prey and vegetation to allow additional information to be integrated into the RB EwE model.

As reflected in CEAR Doc #547, the Proponent, using a step by step process, demonstrated the application of the fixed selectivity approach on a hypothetical example. However, there is still uncertainty about the use of the fixed selectivity approach and the relationships with the quantitative and qualitative diet descriptions used.

Information Request

Provide further clarification and rationale for why fixed diet matrices rather than dynamic diet matrices were used as inputs in the RB EwE model for the derivation of each diet.

Explain the link between the diets described in the text of Appendix 10-B, for each functional group, and the diet quantities present in Appendix A of Appendix 10-B.

VFPA Response

Provide further clarification and rationale for why fixed diet matrices rather than dynamic diet matrices were used as inputs in the RB EwE model for the derivation of each diet.

The information request suggests that "fixed diet matrices rather than dynamic diet matrices were used as inputs". To clarify, as is the case for all Ecopath with Ecosim and Ecospace (EwE) models, the Ecopath component of the Roberts Bank ecosystem model (RB model) represents a static, mass-balanced snapshot of the system. In other words, it comprises a fixed, or static, starting point from which to begin simulations; hence, it is not possible to input a dynamic matrix. However, once the model starts running, the Ecosim and Ecospace components treat the diet matrix dynamically, such that the diet matrix will vary with changes in abundances of predators and prey through time and space, respectively (see Christensen and Walters 2004, Walters et al. 2010). Therefore, the RB model used both fixed *and* dynamic diet matrices.

Further, dynamics were indirectly introduced to the RB model input diet matrix during Monte Carlo sensitivity analyses when input biomass and production values were adjusted by up to 80%, and consumption values were adjusted by up to 70%, thereby changing the abundance of predators (i.e., predation pressure) and of prey (i.e., prey availability) in the system, and changing the consumption rates of predators.

As further clarification, the fixed selectivity principle is unrelated to whether the model treats diet dynamically. Rather, fixed selectivity is a standardised approach for populating a diet matrix (in Ecopath), that enables qualitative prey preferences to be quantified based on the relative productivity of the prey within the modelled study area (see CEAR Document #547, question 2.16 for a description of the fixed selectivity principle). As noted above, the actual amount of prey consumed in Ecosim and Ecospace varies dynamically with the abundance of the prey and its predators.

For example, diet of shorebirds is described in the literature qualitatively as consisting primarily of benthic invertebrates (see Section 3.4.3 of EIS Appendix 10-B). Fixed selectivity was used to account for the variety and availability of benthic invertebrate prey at Roberts Bank. Specifically, the qualitative information from the literature was translated into quantitative proportions of invertebrate prey based on their relative production in the RB model (see Table IR3-07-A1 in Appendix IR3-07-A).

Explain the link between the diets described in the text of Appendix 10-B, for each functional group, and the diet quantities present in Appendix A of Appendix 10-B.

The link between the diets described in the text of EIS Appendix 10-B and the diet quantities present in Appendix A of EIS Appendix 10-B is presented in Table IR3-07-A1 in Appendix IR3-07-A (rows shaded grey represent functional groups to which the fixed selectivity principle was applied; the principle of fixed selectivity was not applied to the invertebrate component of the jellyfish diet, as erroneously stated in Section 2.6.2 of EIS Appendix 10-C).

The following is provided to further describe this linkage:

- Diets described in the text of EIS Appendix 10-B are general and high-level, and intended to give a brief overview of major prey items. They are not intended to be a comprehensive list of all prey species recorded in the diet of a predator functional group;
- Diets in the text of EIS Appendix 10-B were extracted from the literature. In some instances, prey species listed in the text are not found within the RB model study area (e.g., walleye pollock, Pacific hake, red octopus). Therefore, they are not included in the diet matrix (Appendix A of EIS Appendix 10-B), as this matrix is specific to Roberts Bank. Diet contributions from outside the study area are classified in the diet matrix as imports;
- Some prey items explicitly mentioned in the text of EIS Appendix 10-B correspond to general categories of functional groups (i.e., groups made up of more than one species) in the RB model. For example, threespine stickleback and Pacific staghorn sculpin are identified as pinniped prey in the text, but are included in the 'small

demersal fish' functional group in the diet matrix (Appendix A of EIS Appendix 10-B); and

- To account for prey variety and availability at Roberts Bank and to transcribe qualitative and general diet information into a quantitative diet matrix of relative proportions, the principle of fixed selectivity was applied to the fish, invertebrate, or vegetation component of functional groups, as indicated in Table IR3-07-A1 in Appendix IR3-07-A.

References

Christensen, V., and C. J. Walters. 2004. Ecopath with Ecosim: Methods, Capabilities and Limitations. Ecological Modelling 172:109–139.

Walters, C., V. Christensen, W. Walters, and K. Rose. 2010, Representation of Multi-stanza Life Histories in Ecospace Models for Spatial Organization of Ecosystem Trophic Interaction Patterns: Bulletin of Marine Science 86:439–459.

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IR3-09 Roberts Bank Ecosystem Model - Mortality: Fishing

Information Source(s)

EIS Volume 3: Section 10.3, Appendix 10-B, Appendix 10-C

Context

In Appendix 10-C the Proponent identified that the RB Ecopath model required the following parameters for each functional group:

- biomass (B);
- production/biomass ratio (P/B, equivalent to total mortality);
- consumption/biomass (Q/B) ratio; and
- ecotrophic efficiency (EE).

If all four basic parameters are available for a functional group, Ecopath can be used to estimate either biomass accumulation or net migration.

Two master equations, identified in Appendix 10-C, were used for parameterisation in Ecopath:

1. production = catch + predation + net migration + biomass accumulation + other mortality; and
2. consumption = production + respiration + unassimilated food.

As identified in Appendix 10-C, the RB EwE model did not consider catches or net migration, as the purpose of the analysis was to forecast productivity changes for the area as a result of the proposed Project.

The Proponent's rationale did not include fishing mortality in the RB EwE model, even though there is fishing activity in the study area. The Proponent identified that fishing was excluded because the focus of the RB EwE model study was how the proposed Project might change the productivity conditions in the study area.

According to Fisheries and Oceans Canada, while the assumption used that fishing mortality would not change, with or without the Project, may be correct, the RB EwE model had been parameterised with the exclusion of a source of mortality that could influence total production.

Information Request

Re-run the RB Ecopath model to incorporate the influence of fishing mortality. Report the results in tables of biomass (tonnes) and productivity (tonnes per year) as provided in Tables 3.2 and 3.3 in Appendix 10-C.

VFPA Response

The Roberts Bank ecosystem model (RB model) was re-run incorporating the predominant source of fishing mortality at Roberts Bank: Dungeness crab fishing. The rationale for selection to include this type of fishing pressure in the RB model is provided below. The new results are presented in this response and confirm that the inclusion of the predominant source of fishing mortality in the RB model does not alter the conclusion that productivity changes from terminal and causeway footprints are relatively small.

Methodology

Dungeness crab was selected as the predominant fishing pressure to include in the RB model re-run. Rationale for this selection was based on the following (see EIS Section 21.5.1 for details on commercial, recreational, and Aboriginal fish and seafood harvesting at Roberts Bank):

- Dungeness crab is the focus of commercial harvesting at Roberts Bank;
- Salmon harvesting occurs over large geographic areas (i.e., Gillnet Salmon Area E, Seine Net Salmon Area B, Troll Salmon Area H), and is considered limited at Roberts Bank, with only a small proportion of the salmon catch coming from areas in the periphery of or adjacent to Roberts Bank. As such, inclusion of salmon fishing mortality in the RB model is considered unlikely to influence RB model outputs. Specifically:
    - Salmon gillnet harvesting (including Aboriginal salmon harvesting) is concentrated in the lower Fraser River and its mouth, particularly in Canoe Passage (i.e., outside of Roberts Bank);
    - Salmon seining occurs in deeper waters seaward of the Westshore Terminals (limited overlap with the RB model study area) and near the U.S. border, outside of Roberts Bank;
    - Salmon troll harvesting occurs in deeper waters outside of Roberts Bank; and
    - Guided sport fisheries occur at the Fraser River mouth, outside of Roberts Bank;
- Salmon logbook harvest data are reported by large fisheries management areas (e.g., Pacific Fisheries Management Area 29), but are not available by sub-area (e.g., 29-6, 29-7 that cover Roberts Bank). In contrast, crab catch data exists to reliably estimate crab fishing mortality in the RB model study area;
- Salmon adult biomass inputs to the RB model were calculated based on local field survey information on juvenile salmon biomass, combined with juvenile-to-adult return (survival) rates and salmon adult return biomass estimates (see Section 4.0 of EIS Appendix 10-B). Return (survival) rates were derived by considering number of salmon that escape fisheries along their migration route (outside of the RB model study area) and ultimately reach spawning grounds; hence, salmon extraction by fisheries beyond the Roberts Bank boundaries was indirectly accounted for during biomass input calculations to the RB model; and
- No commercial groundfish fisheries occur at Roberts Bank.

Fishing mortality was included in this re-run of the RB model using a 95% harvest rate for legal sized male Dungeness crabs, assuming a 50:50 sex ratio at Roberts Bank. This level of harvesting is considered conservative for a male-retention-only fishery, but realistic for

Roberts Bank (see TDR MI-4 in Appendix AIR10-C of Additional Information Request #10 (AIR-12.04.15-10 in CEAR Document #388[1])). The RB model was then re-run using the same other basic input parameters and assumptions as used in the key run described in the EIS.

Results

Results from the RB model re-run with Dungeness crab fishing mortality include net changes in biomass (tonnes per square kilometre (t/km^2)) and production (tonnes per square kilometre per year (t/km^2/year)) of functional groups at Roberts Bank with the Project in **Tables IR3-09-1** and **IR3-09-2**, respectively.

Table IR3-09-1 Biomass Estimates from the Roberts Bank Ecosystem Model Run Including Fishing Mortality for Dungeness Crab, Without and With the Project (numbers in bold font identify results differences and are discussed below)

No.	Functional Group	Biomass (without Project, including fishing mortality, t/km^2)	Biomass (with Project, including fishing mortality, t/km^2)	Difference (with – without Project, including fishing mortality, t/km^2)	Biomass Ratio (with/without Project, including fishing mortality)	Biomass Ratio (with/without Project, not including fishing mortality/ EIS Key Run)
1	Baleen whales	0.273	0.250	-0.023	**0.91**	0.92
2	Dolphins and porpoises	0.273	0.264	-0.008	0.97	0.97
3	Pinnipeds	21.832	21.239	-0.592	0.97	0.97
4	Southern resident killer whales	0.546	0.531	-0.015	0.97	0.97
5	Transient killer whales	0.284	0.252	-0.031	0.89	0.89
6	American wigeon	4.765	4.365	-0.400	0.92	0.92
7	Bald eagle	0.120	0.112	-0.008	0.93	0.93
8	Brant goose	1.088	1.031	-0.058	0.95	0.95
9	Diving waterbirds	1.506	1.412	-0.095	0.94	0.94
10	Dunlin	0.471	0.531	0.060	1.13	1.13
11	Great blue heron	0.671	0.669	-0.002	1.00	1.00
12	Gulls and terns	2.639	2.601	-0.038	0.99	0.99
13	Raptors	0.008	0.011	0.003	1.31	1.31
14	Shorebirds	0.045	0.044	-0.001	0.98	0.98

[1] CEAR Document #388 From Port Metro Vancouver to the Canadian Environmental Assessment Agency re: Completeness Review - Responses to Additional Information Requirements Follow-Up (See Reference Document #345) including 22 Technical Data Reports.

No.	Functional Group	Biomass (without Project, including fishing mortality, t/km^2)	Biomass (with Project, including fishing mortality, t/km^2)	Difference (with – without Project, including fishing mortality, t/km^2)	Biomass Ratio (with/without Project, including fishing mortality)	Biomass Ratio (with/without Project, not including fishing mortality/ EIS Key Run)
15	Waterfowl	16.559	17.904	1.344	1.08	1.08
16	Western sandpiper	0.058	0.066	0.008	1.13	1.13
17	Chinook salmon adult	187.099	177.545	-9.554	0.95	0.95
18	Chinook salmon juvenile	0.655	0.759	0.104	1.16	1.16
19	Chum salmon adult	111.643	106.505	-5.138	0.95	0.95
20	Chum salmon juvenile	0.491	0.561	0.070	1.14	1.14
21	Dogfish	35.953	35.126	-0.827	0.98	0.98
22	Flatfish	20.441	20.180	-0.261	**0.99**	0.98
23	Forage fish	573.086	565.001	-8.085	0.99	0.99
24	Herring	242.712	238.081	-4.631	0.98	0.98
25	Large demersal fish	8.386	8.283	-0.103	0.99	0.99
26	Lingcod	32.031	30.959	-1.072	0.97	0.97
27	Rockfish	18.475	16.824	-1.651	0.91	0.91
28	Salmon adult	55.454	53.160	-2.295	0.96	0.96
29	Salmon juvenile	0.092	0.090	-0.003	0.97	0.97
30	Sandlance	11.323	12.031	0.708	1.06	1.06
31	Shiner perch	8.921	10.551	1.630	1.18	1.18
32	Skate	12.584	11.547	-1.037	0.92	0.92
33	Small demersal fish	3.945	3.733	-0.212	0.95	0.95
34	Starry flounder	11.453	12.142	0.689	1.06	1.06
35	Carnivorous zooplankton	1,623.743	1,449.829	-173.914	0.89	0.89
36	Dungeness crab	252.769	241.660	-11.109	**0.96**	0.97
37	Epifaunal grazer	835.674	769.359	-66.314	0.92	0.92
38	Epifaunal omnivore	105.284	102.867	-2.417	0.98	0.98
39	Epifaunal sessile suspension feeder	48.876	58.177	9.302	1.19	1.19
40	Infaunal bivalve	6,590.176	6,073.503	-516.673	0.92	0.92
41	Jellyfish	599.746	550.613	-49.133	0.92	0.92

No.	Functional Group	Biomass (without Project, including fishing mortality, t/km^2)	Biomass (with Project, including fishing mortality, t/km^2)	Difference (with – without Project, including fishing mortality, t/km^2)	Biomass Ratio (with/without Project, including fishing mortality)	Biomass Ratio (with/without Project, not including fishing mortality/ EIS Key Run)
42	Macrofaunal	2,743.430	3,476.504	733.073	1.27	1.27
43	Meiofauna	1,588.644	1,763.854	175.211	1.11	1.11
44	Omnivorous and herbivorous zooplankton	2,970.768	2,761.798	-208.970	0.93	0.93
45	Polychaetes	1,099.779	979.595	-120.184	0.89	0.89
46	Orange sea pen	7.692	3.463	-4.229	0.45	0.45
47	Shrimp	27.290	23.806	-3.484	0.87	0.87
48	Biofilm freshwater	1,642.846	3,111.264	1,468.419	1.89	1.89
49	Biofilm marine	1,819.684	1,399.847	-419.837	0.77	0.77
50	Brown algae	448.060	394.910	-53.150	0.88	0.88
51	Eelgrass (native)	304.576	316.064	11.488	1.04	1.04
52	Green algae	6,894.604	6,311.667	-582.938	0.92	0.92
53	Japanese eelgrass (non-native)	6.855	6.807	-0.048	0.99	0.99
54	Red algae	15.168	13.597	-1.571	0.90	0.90
55	Phytoplankton	2,183.184	2,251.999	68.815	1.03	1.03
56	Tidal marsh	1,329.832	1,664.891	335.059	1.25	1.25
57	Biomat	1,217.125	861.009	-356.116	0.71	0.71
58	Detritus	545.796	550.558	4.762	1.01	1.01

Note:

- Estimates are rounded. Biomass information is at a point in time after equilibrium at Roberts Bank has been reached.
- Ratio (with/without Project) outputs from the RB model run with Dungeness crab fishing mortality that differ from ratio (with/without Project) outputs from the EIS key run are shown in bold.
- Marine mammals are included in the RB model for their important role as top predators, but the RB model has not been used to assess effects to marine mammals.

Table IR3-09-2 Production Estimates from the Roberts Bank Ecosystem Model Run Including Fishing Mortality for Dungeness Crab, Without and With the Project (numbers in bold font identify results differences and are discussed below). Production ratios in this table are the same as biomass ratios in Table IR3-09-1 (see notes).

No.	Functional Group	Production (without Project, including fishing mortality, t/km^2/year)	Production (with Project, including fishing mortality, t/km^2/year)	Difference (with – without Project, including fishing mortality, t/km^2/year)	Production Ratio (with/ without Project; including fishing mortality)	Production Ratio (with/ without Project; not including fishing mortality/ EIS Key Run)
1	Baleen whales	0.008	0.007	-0.001	**0.91**	0.92
2	Dolphins and porpoises	0.044	0.042	-0.001	0.97	0.97
3	Pinnipeds	3.056	2.974	-0.083	0.97	0.97
4	Southern resident killer whales	0.022	0.021	-0.001	0.97	0.97
5	Transient killer whales	0.011	0.010	-0.001	0.89	0.89
6	American wigeon	0.953	0.873	-0.080	0.92	0.92
7	Bald eagle	0.030	0.028	-0.002	0.93	0.93
8	Brant goose	0.218	0.206	-0.012	0.95	0.95
9	Diving waterbirds	0.362	0.339	-0.023	0.94	0.94
10	Dunlin	0.240	0.271	0.031	1.13	1.13
11	Great blue heron	0.329	0.328	-0.001	1.00	1.00
12	Gulls and terns	0.607	0.598	-0.009	0.99	0.99
13	Raptors	0.003	0.004	0.001	1.31	1.31
14	Shorebirds	0.023	0.023	0.000	0.98	0.98
15	Waterfowl	3.312	3.581	0.269	1.08	1.08
16	Western sandpiper	0.030	0.033	0.004	1.13	1.13
17	Chinook salmon adult	58.001	55.039	-2.962	0.95	0.95
18	Chinook salmon juvenile	0.524	0.607	0.083	1.16	1.16
19	Chum salmon adult	48.006	45.797	-2.209	0.95	0.95
20	Chum salmon juvenile	0.442	0.505	0.063	1.14	1.14
21	Dogfish	4.314	4.215	-0.099	0.98	0.98
22	Flatfish	7.563	7.467	-0.096	**0.99**	0.98

No.	Functional Group	Production (without Project, including fishing mortality, t/km^2/year)	Production (with Project, including fishing mortality, t/km^2/year)	Difference (with – without Project, including fishing mortality, t/km^2/year)	Production Ratio (with/ without Project; including fishing mortality)	Production Ratio (with/ without Project; not including fishing mortality/ EIS Key Run)
23	Forage fish	544.432	536.751	-7.680	0.99	0.99
24	Herring	194.170	190.465	-3.705	0.98	0.98
25	Large demersal fish	4.277	4.224	-0.053	0.99	0.99
26	Lingcod	9.929	9.597	-0.332	0.97	0.97
27	Rockfish	4.065	3.701	-0.363	0.91	0.91
28	Salmon adult	23.845	22.859	-0.987	0.96	0.96
29	Salmon juvenile	0.079	0.076	-0.002	0.97	0.97
30	Sandlance	5.322	5.655	0.333	1.06	1.06
31	Shiner perch	11.330	13.400	2.070	1.18	1.18
32	Skate	1.133	1.039	-0.093	0.92	0.92
33	Small demersal fish	3.945	3.733	-0.212	0.95	0.95
34	Starry flounder	4.581	4.857	0.276	1.06	1.06
35	Carnivorous zooplankton	11,366.200	10,148.800	-1,217.397	0.89	0.89
36	Dungeness crab	631.920	604.150	-27.773	**0.96**	0.97
37	Epifaunal grazer	1,210.060	1,114.030	-96.023	0.92	0.92
38	Epifaunal omnivore	368.490	360.030	-8.461	0.98	0.98
39	Epifaunal sessile suspension feeder	83.350	99.210	15.862	1.19	1.19
40	Infaunal bivalve	13,569.170	12,505.340	-1,063.830	0.92	0.92
41	Jellyfish	5,757.560	5,285.880	-471.679	0.92	0.92
42	Macrofaunal	10,973.720	13,906.010	2,932.293	1.27	1.27
43	Meiofauna	12,709.150	14,110.830	1,401.684	1.11	1.11
44	Omnivorous and herbivorous zooplankton	71,298.420	66,283.160	-5,015.268	0.93	0.93
45	Polychaetes	5,498.890	4,897.980	-600.918	0.89	0.89
46	Orange sea pen	9.230	4.160	-5.075	0.45	0.45
47	Shrimp	65.500	57.130	-8.361	0.87	0.87
48	Biofilm freshwater	59,142.450	112,005.520	52,863.066	1.89	1.89
49	Biofilm marine	65,508.620	50,394.490	-15,114.133	0.77	0.77

No.	Functional Group	Production (without Project, including fishing mortality, t/km^2/year)	Production (with Project, including fishing mortality, t/km^2/year)	Difference (with – without Project, including fishing mortality, t/km^2/year)	Production Ratio (with/ without Project; including fishing mortality)	Production Ratio (with/ without Project; not including fishing mortality/ EIS Key Run)
50	Brown algae	4,032.540	3,554.190	-478.352	0.88	0.88
51	Eelgrass (native)	5,482.370	5,689.160	206.793	1.04	1.04
52	Green algae	89,629.860	82,051.660	-7,578.190	0.92	0.92
53	Japanese eelgrass (non-native)	68.550	68.070	-0.480	0.99	0.99
54	Red algae	303.350	271.940	-31.411	0.90	0.90
55	Phytoplankton	283,813.920	292,759.810	8,945.895	1.03	1.03
56	Tidal marsh	19,947.480	24,973.370	5,025.889	1.25	1.25
57	Biomat	101,021.380	71,463.770	-29,557.613	0.71	0.71

Note:

- Ratio (with/without Project) outputs from the RB model run with Dungeness crab fishing mortality that differ from ratio (with/without Project) outputs from the EIS key run are shown in bold.
- Production is not defined for detritus (functional group #58) as this is a non-living group.
- Estimates are rounded. Production information is at a point in time after equilibrium at Roberts Bank has been reached.
- Marine mammals are included in the RB model for their important role as top predators, but the RB model has not been used to assess effects to marine mammals.
- Biomass ratios (last two columns of **Table IR3-09-1**) and production ratios (last two columns of **Table IR3-09-2**) are always equal for a given functional group. Production = Biomass * (P/B). P/B is fixed, so the ratio of $P_{with\ project}$ / $P_{without\ project}$ = $B_{with\ project}$ * (P/B) / $B_{without\ project}$ * (P/B) = $B_{with\ project}$ / $B_{without\ project}$.

As demonstrated in the above tables, the biomass and production ratios (with/without Project) from the RB model re-run, including Dungeness crab fishing mortality, are generally the same when compared to the ratios described in the EIS. Dungeness crab biomass is reduced in the system when fishing is added. Reduced biomass is the same for both with and without Project scenarios; however, Dungeness crab support few functional groups, resulting in negligible trophic effects for a few groups within the food web, as explained below.

When fishing mortality is incorporated into the RB model, three functional groups had a negligible change (~1%) in the biomass and production ratios (with/without Project) (i.e., Dungeness crab, flatfish, baleen whale; see numbers in bold font in **Tables IR3-09-1** and **IR3-09-2**). Albeit small, these changes are likely the result of trophic interactions established among functional groups in the RB model. For example, harvesting of Dungeness crab at Roberts Bank would reduce predatory pressure on their prey, such as epifaunal sessile and infaunal bivalve groups. These reductions would in turn increase predation on other prey such as macrofauna, which contribute to the diet of predatory groups, such as baleen whales. The negligible ratio changes shown in the above tables, including fishing mortality,

demonstrate that inclusion of fishing into the RB model does not change key run productivity estimates described in the EIS.

The RB model with Dungeness crab harvest was examined for sensitivity to input parameter variability in the same manner as the key run as described in the EIS (see EIS Appendix 10-D). Specifically, a Monte Carlo analysis was conducted with the same pedigree classifications and wider confidence intervals used in the supplemental sensitivity analyses (described in CEAR Document #547, question 2.7). Distributions of the forecast biomass ratio (with/without Project) of functional groups in the RB model were compiled for the key run (Appendix 10-D of the EIS), the supplemental sensitivity analyses (CEAR Document #547, question 2.7), and the Dungeness crab fishing mortality re-run, and are appended to this response as **Appendix IR3-09-A**.

In conclusion, results of sensitivity analyses demonstrate the RB model outputs are robust and show little change with parameter variability, even when fishing mortality is considered. The outputs of the RB model re-run with Dungeness crab fishing mortality demonstrates additional confidence in the forecasts of the RB model.

Appendices

Appendix IR3-09-A Monte Carlo Biomass Ratio Distributions of Functional Groups for the EIS Key Run, the Supplemental Sensitivity Analyses (Wider Confidence Intervals (C.I.)), and the Dungeness Crab Fishing Mortality Run (Wider C.I., Crab F)

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APPENDIX IR3-09-A

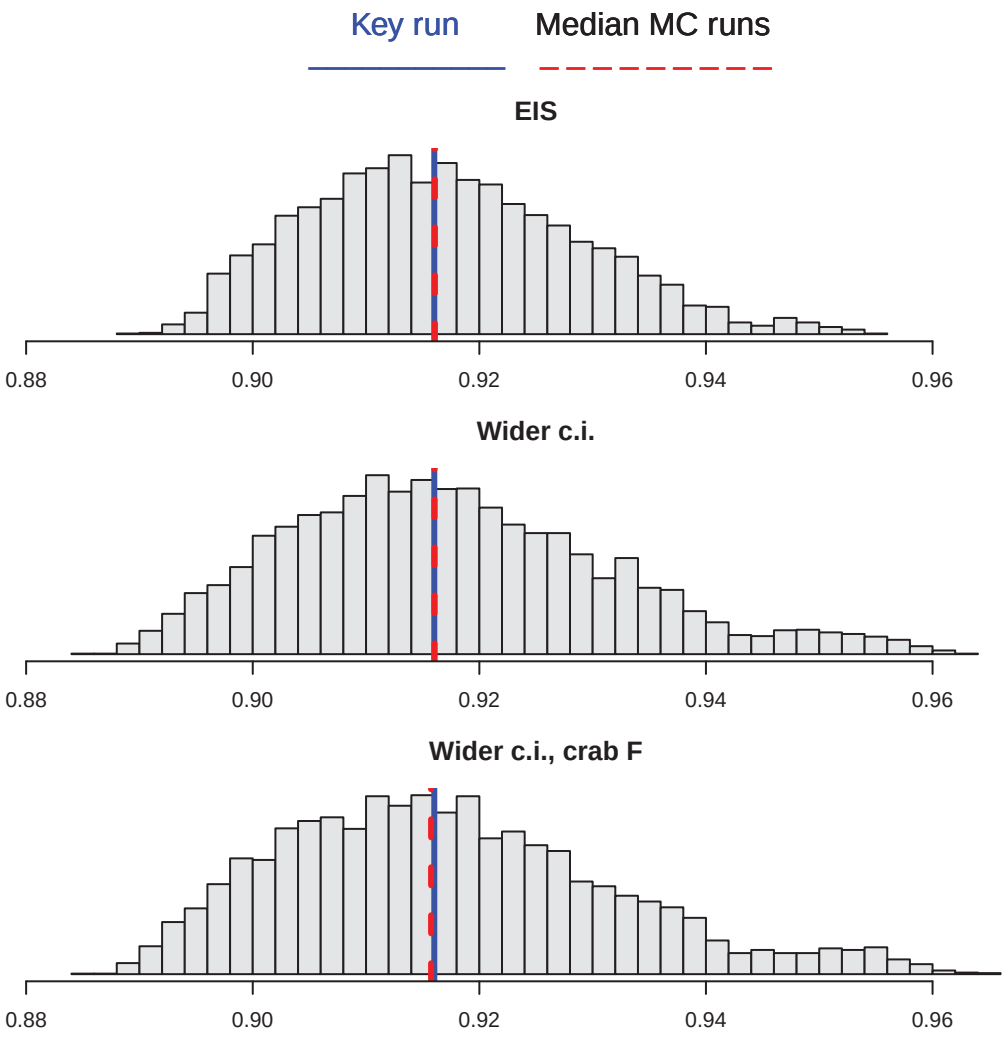
MONTE CARLO BIOMASS RATIO DISTRIBUTIONS OF FUNCTIONAL GROUPS FOR THE EIS KEY RUN, THE SUPPLEMENTAL SENSITIVITY ANALYSES (WIDER CONFIDENCE INTERVALS (C.I.)), AND THE DUNGENESS CRAB FISHING MORTALITY RUN (WIDER C.I., CRAB F)

Appendix IR3-09-A: Monte Carlo Biomass Ratio Distributions of Functional Groups for the EIS Key Run, the Supplemental Sensitivity Analyses (Wider Confidence Intervals (C.I.)), and the Dungeness Crab Fishing Mortality Run (Wider C.I., Crab F)

Notes:

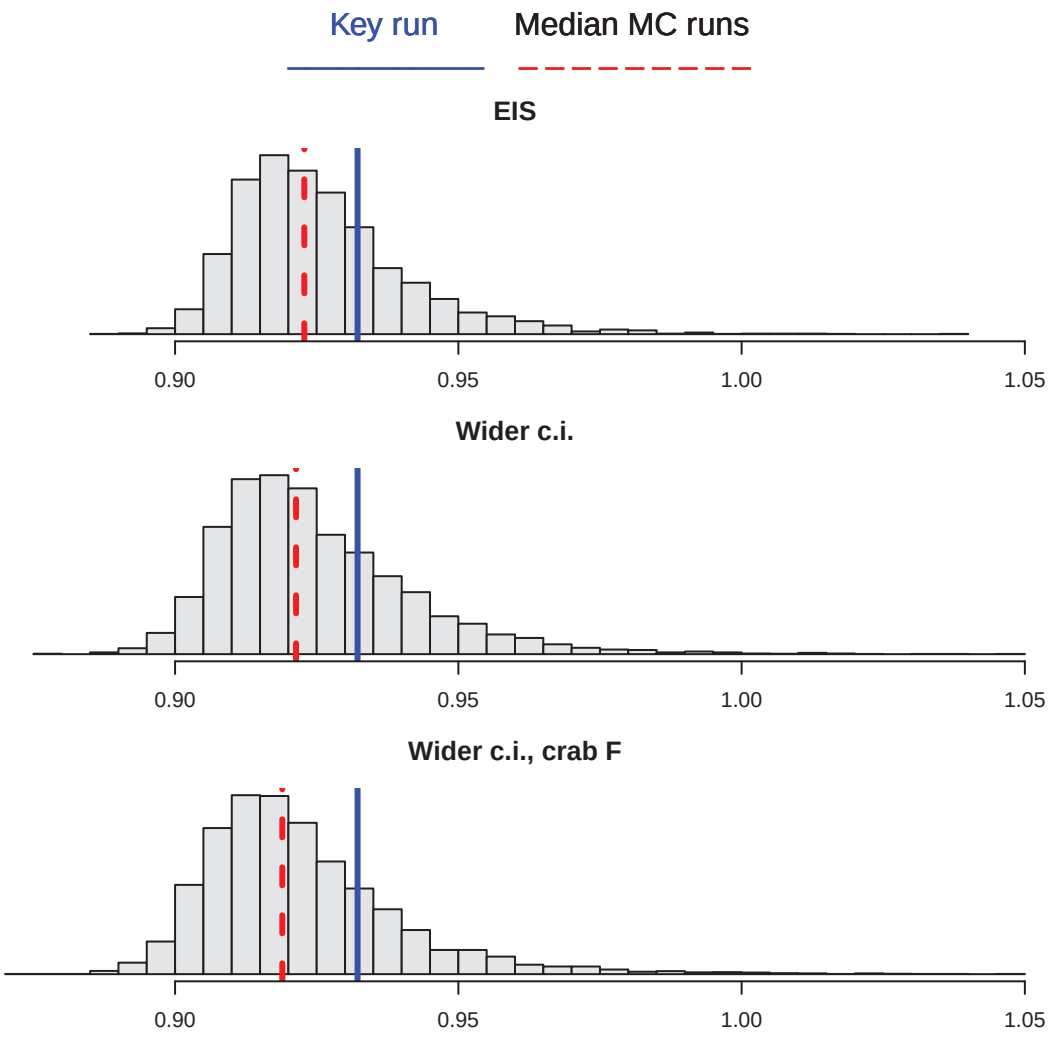
- Median MC runs: refers to the red dashed line that indicates the median of the Monte Carlo (MC) sensitivity analyses undertaken for the key run described in the EIS, the re-run using wider confidence intervals (wider C.I.) presented in CEAR Document #547, question 2.7, and the re-run using wider C.I. combined with fishing mortality for Dungeness crab (Crab F) presented in this information request.
- Wider C.I.: refers to the MC sensitivity analyses (presented in CEAR Document #547, question 2.7) that used wider C.I. of basic input parameters, established by reducing the C.I. by one pedigree category (for wider C.I. see Table 3 of CEAR Document #547, question 2.7).
- Crab F: refers to fishing mortality (F) for Dungeness crab incorporated into the RB model and re-run for this information request.

American wigeon



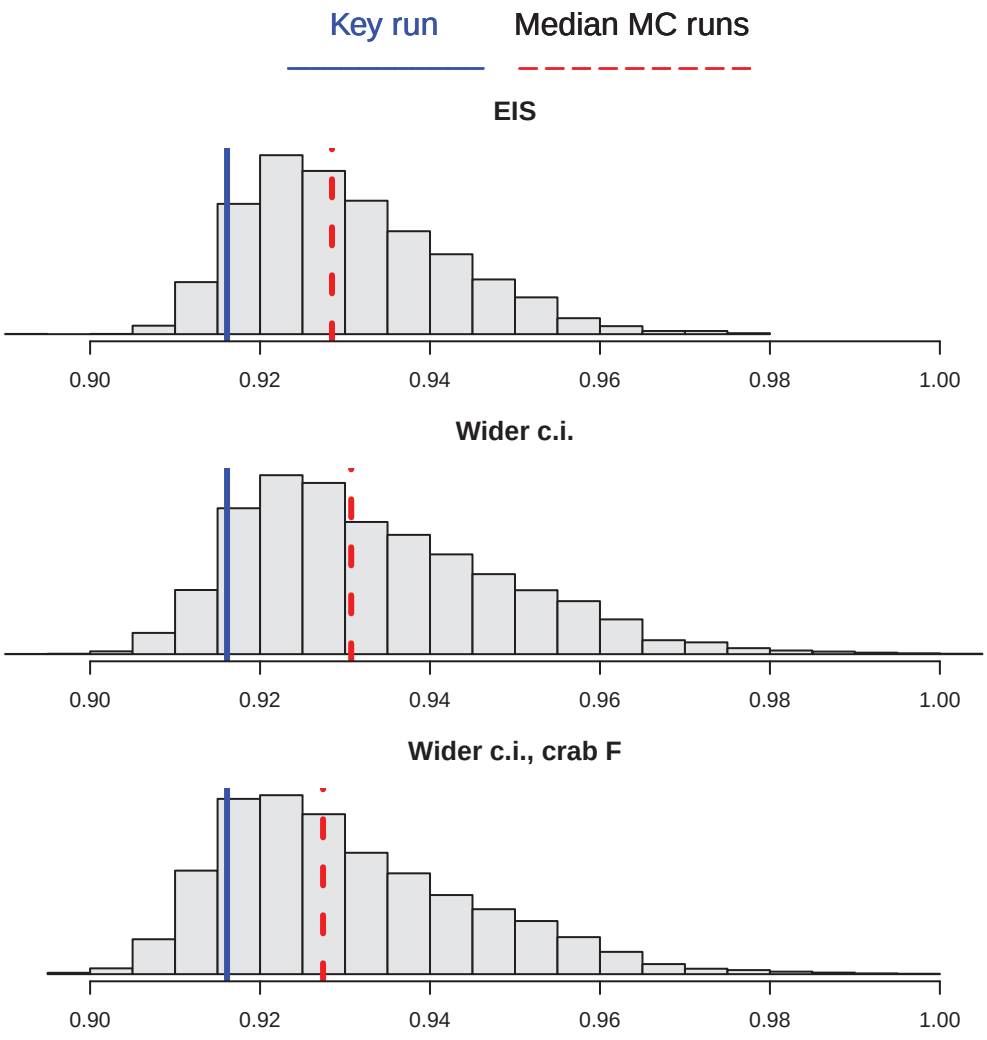
Biomass ratio (with/without project)

Bald eagle



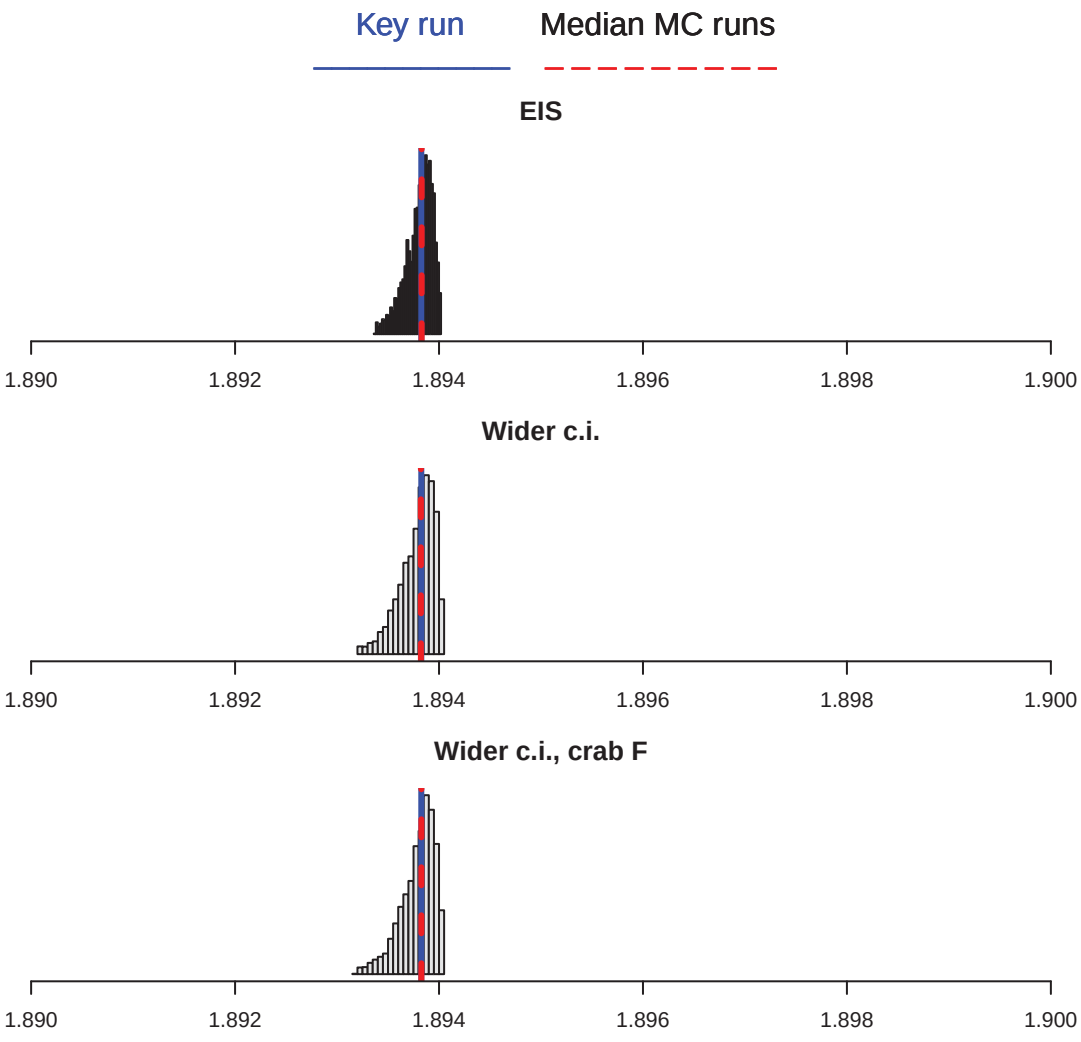
Biomass ratio (with/without project)

Baleen whales



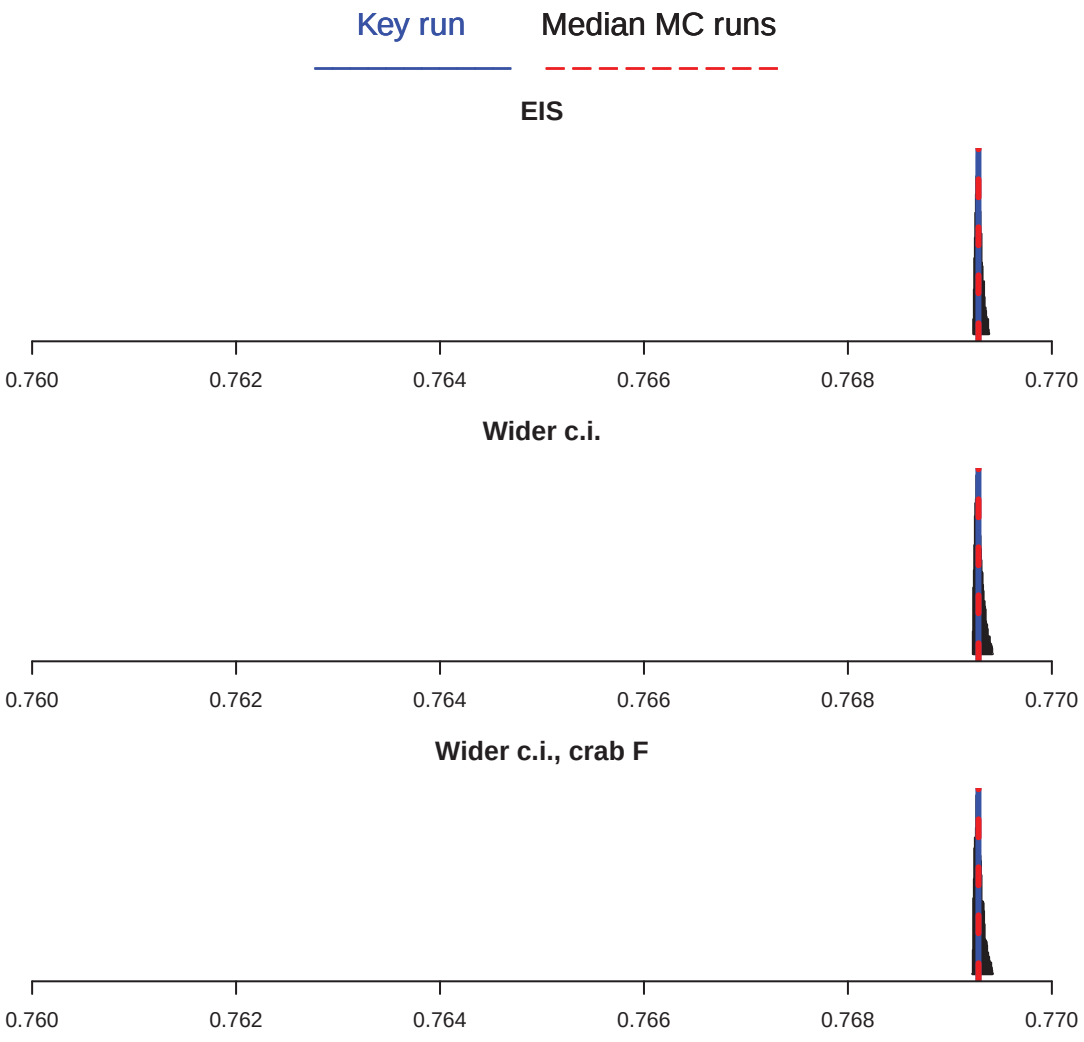
Biomass ratio (with/without project)

Biofilm fresh



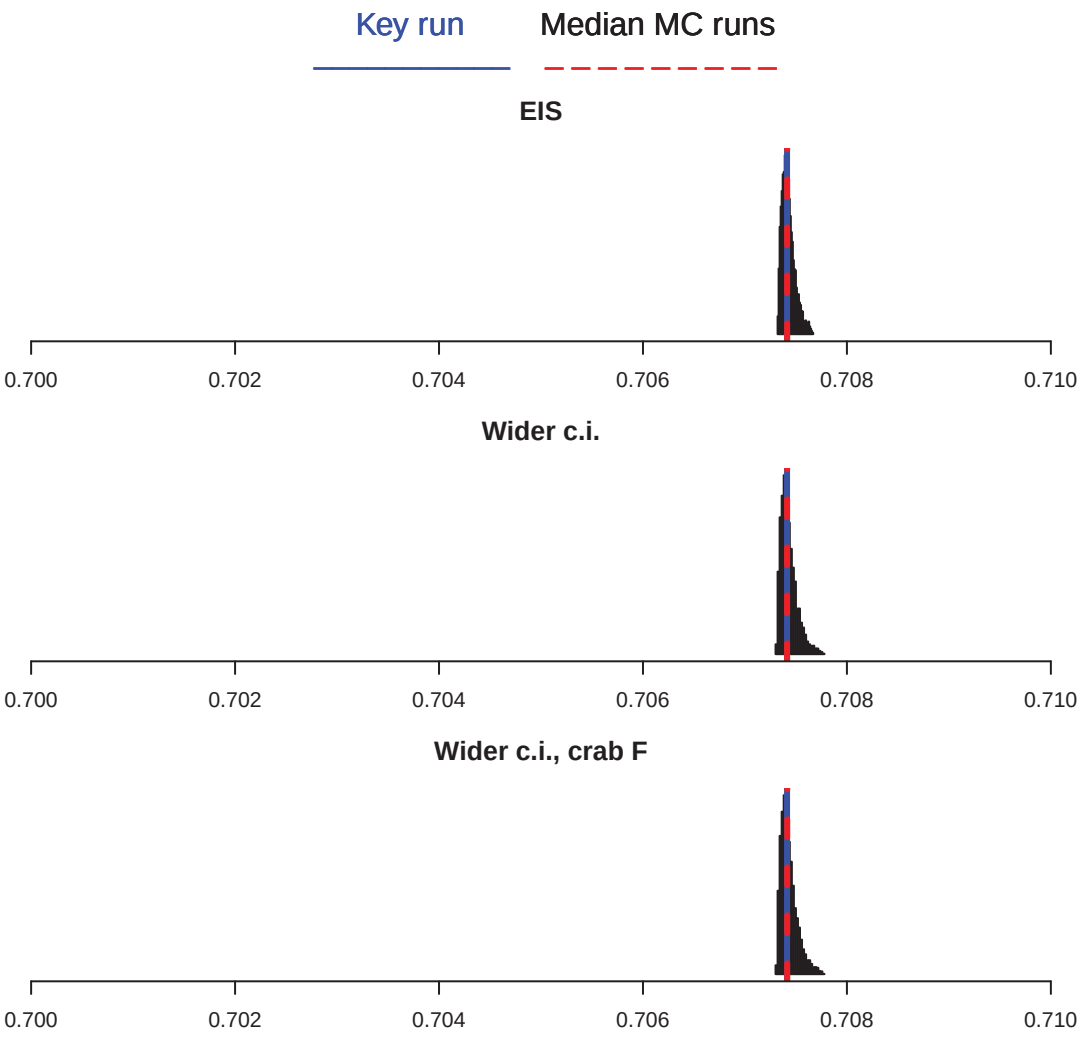
Biomass ratio (with/without project)

Biofilm marine



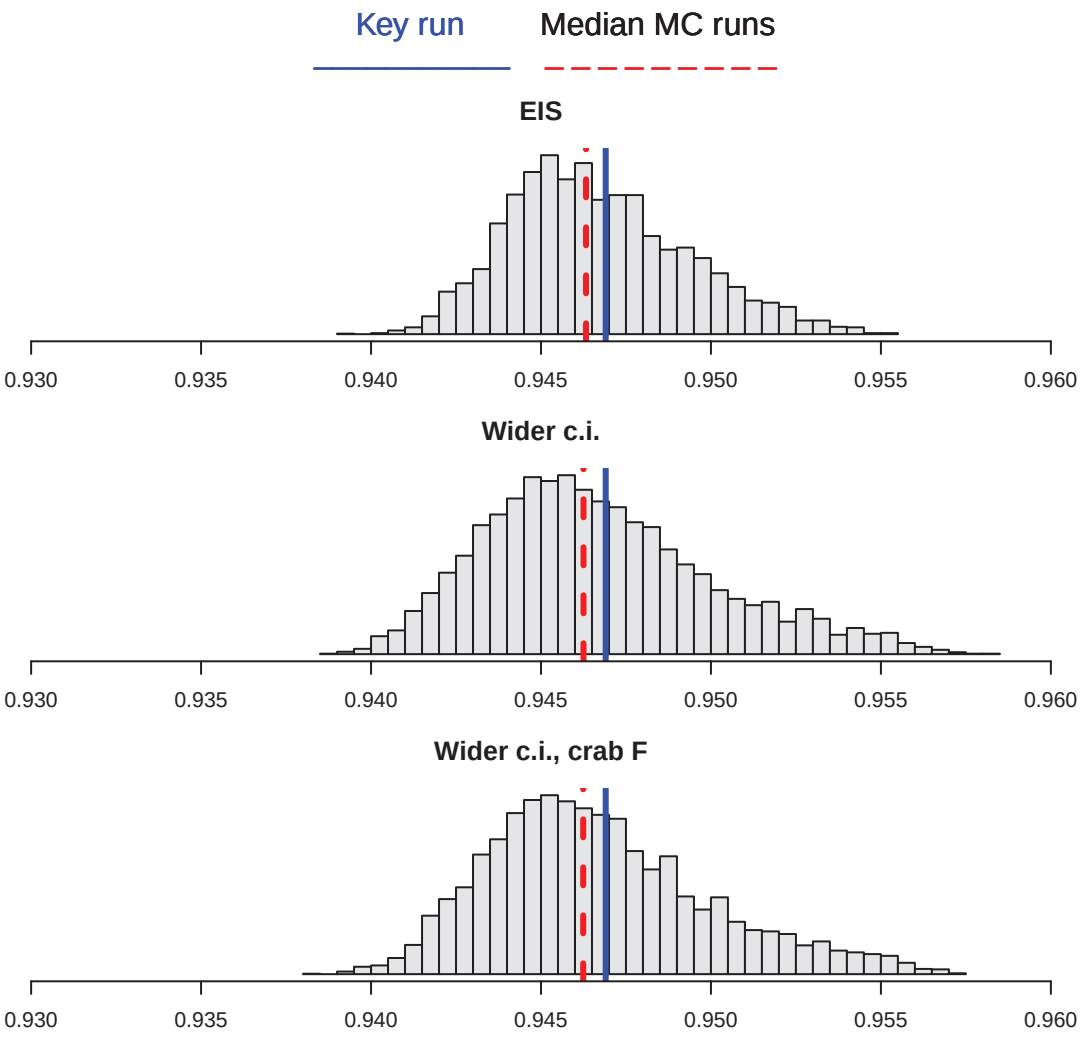
Biomass ratio (with/without project)

Biomat



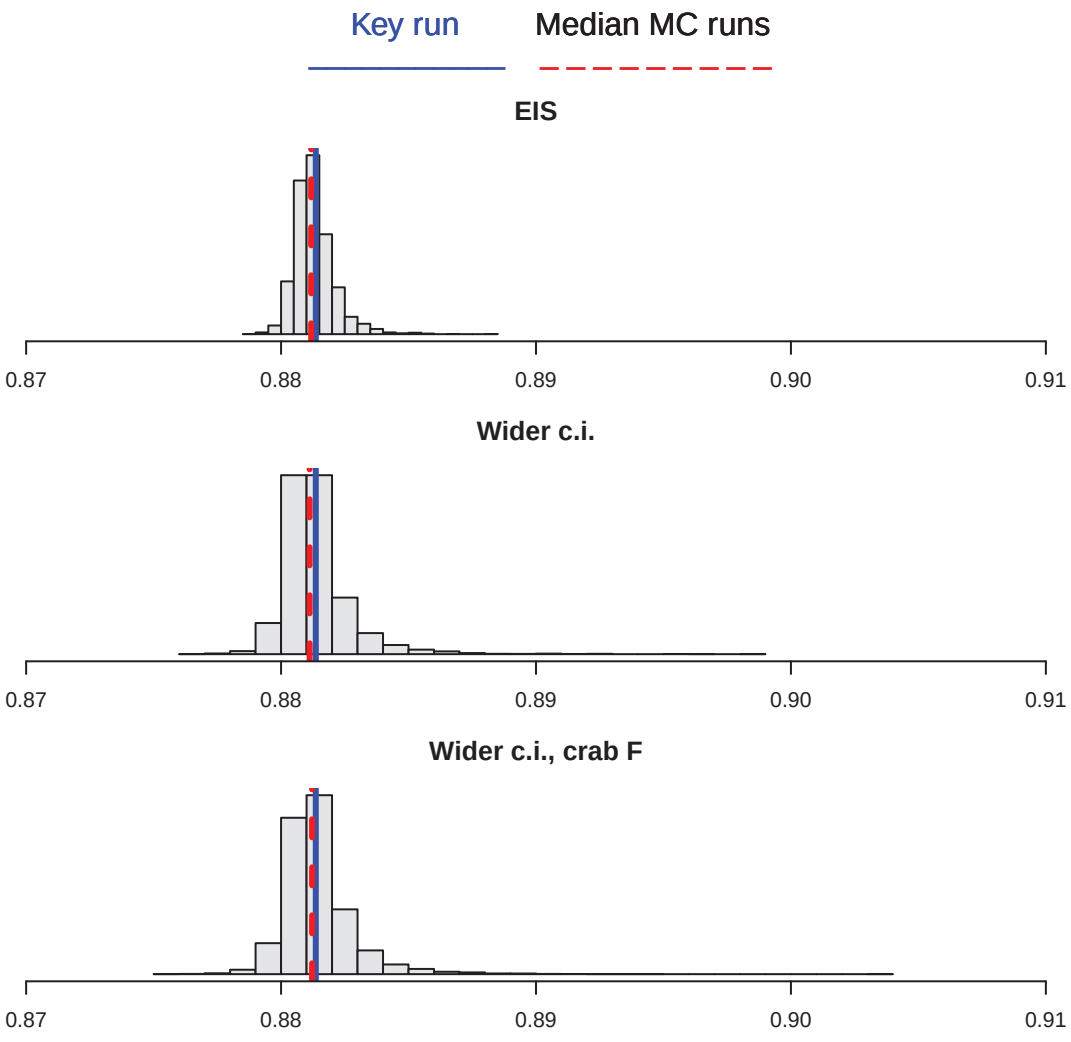
Biomass ratio (with/without project)

Brant goose



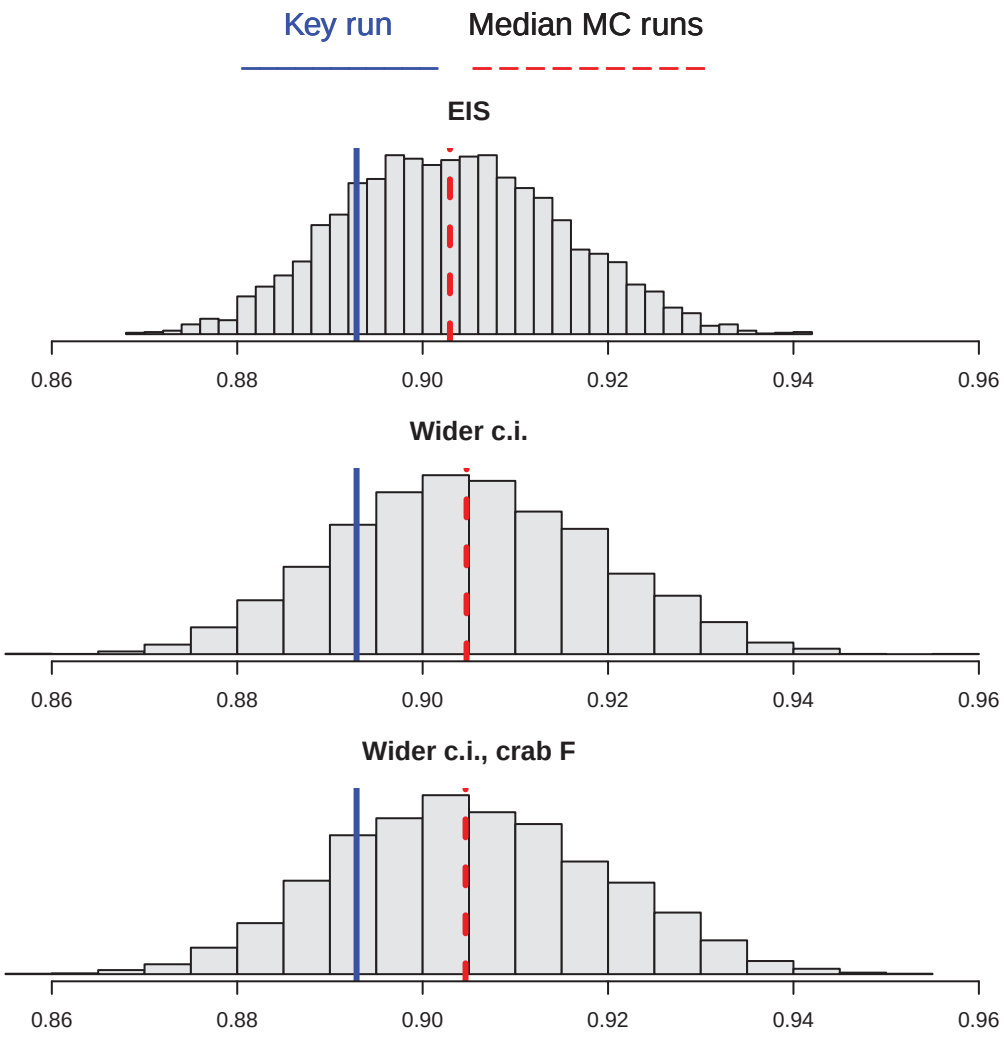
Biomass ratio (with/without project)

Brown algae



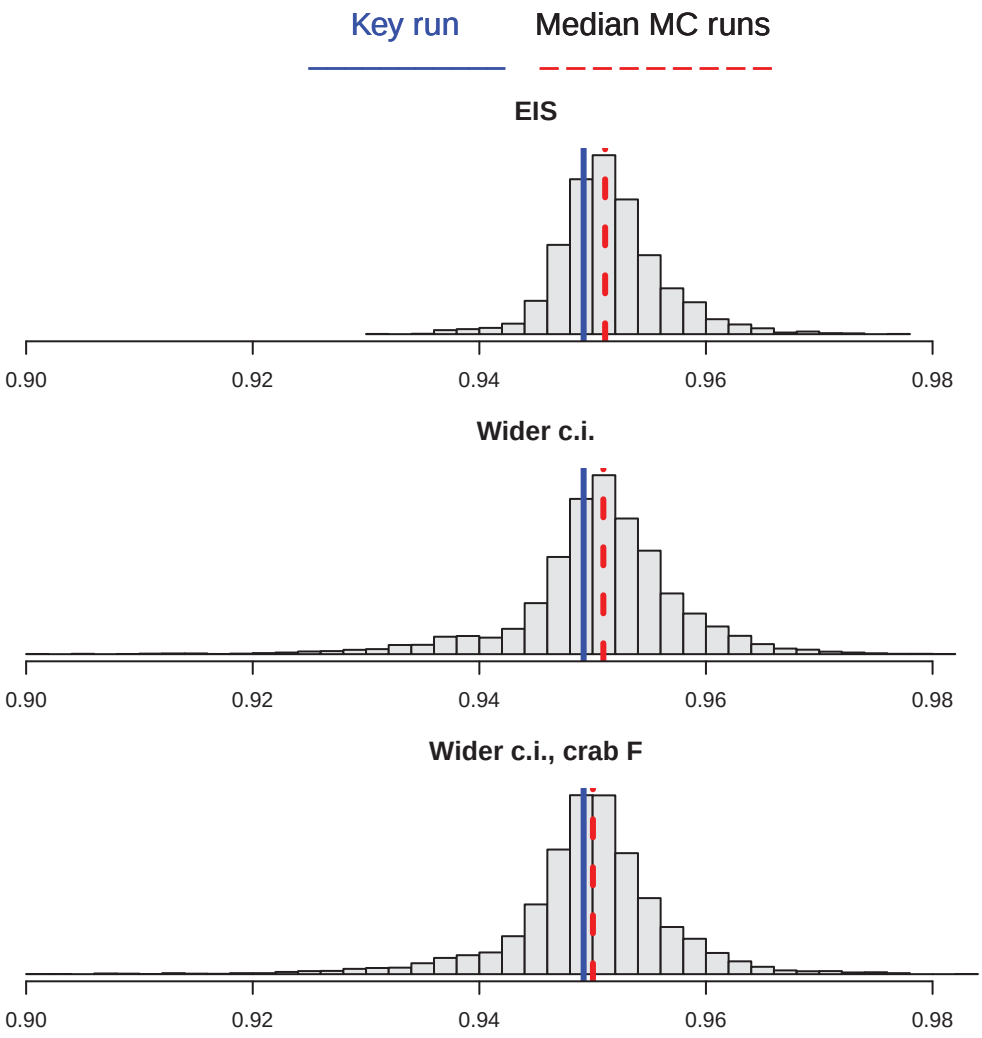
Biomass ratio (with/without project)

Carnivorous zooplankton



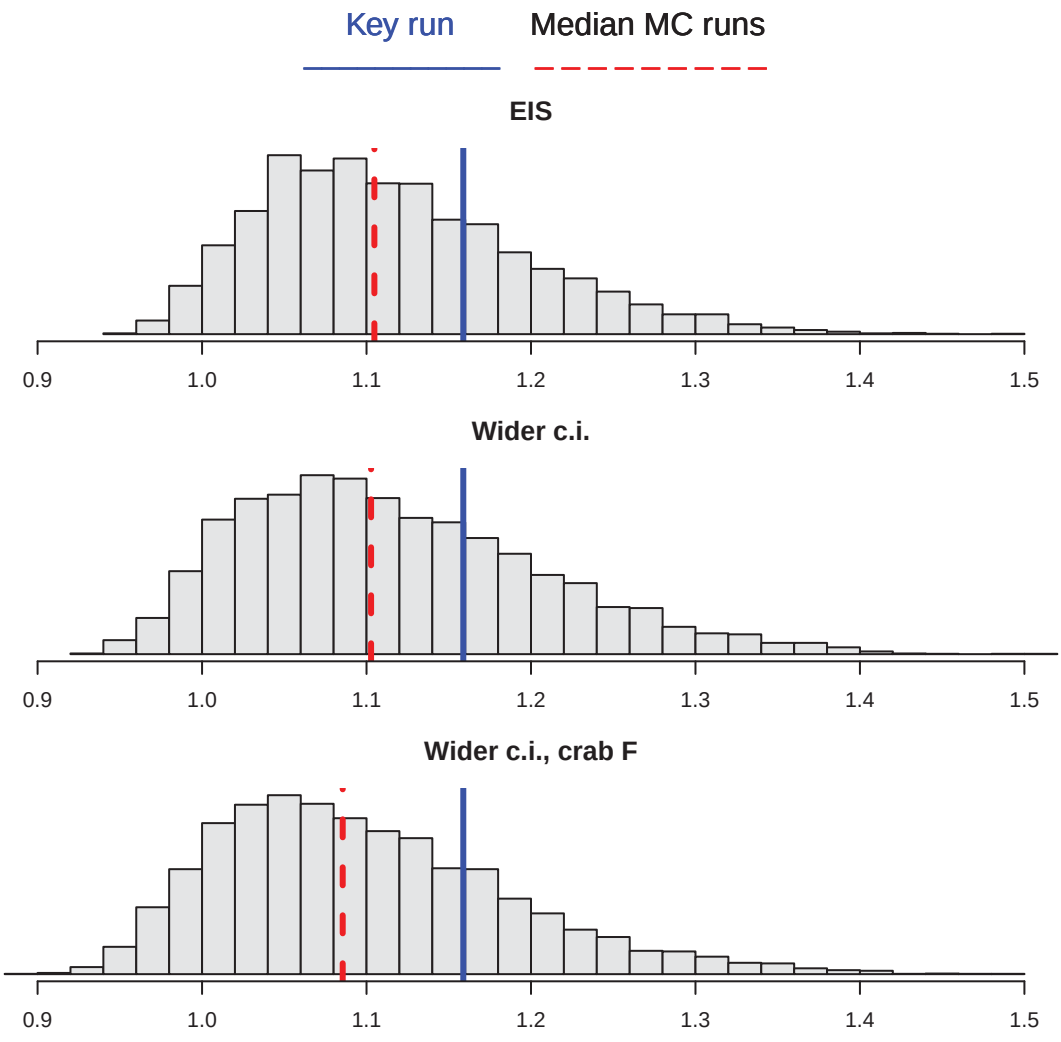
Biomass ratio (with/without project)

Chinook adult



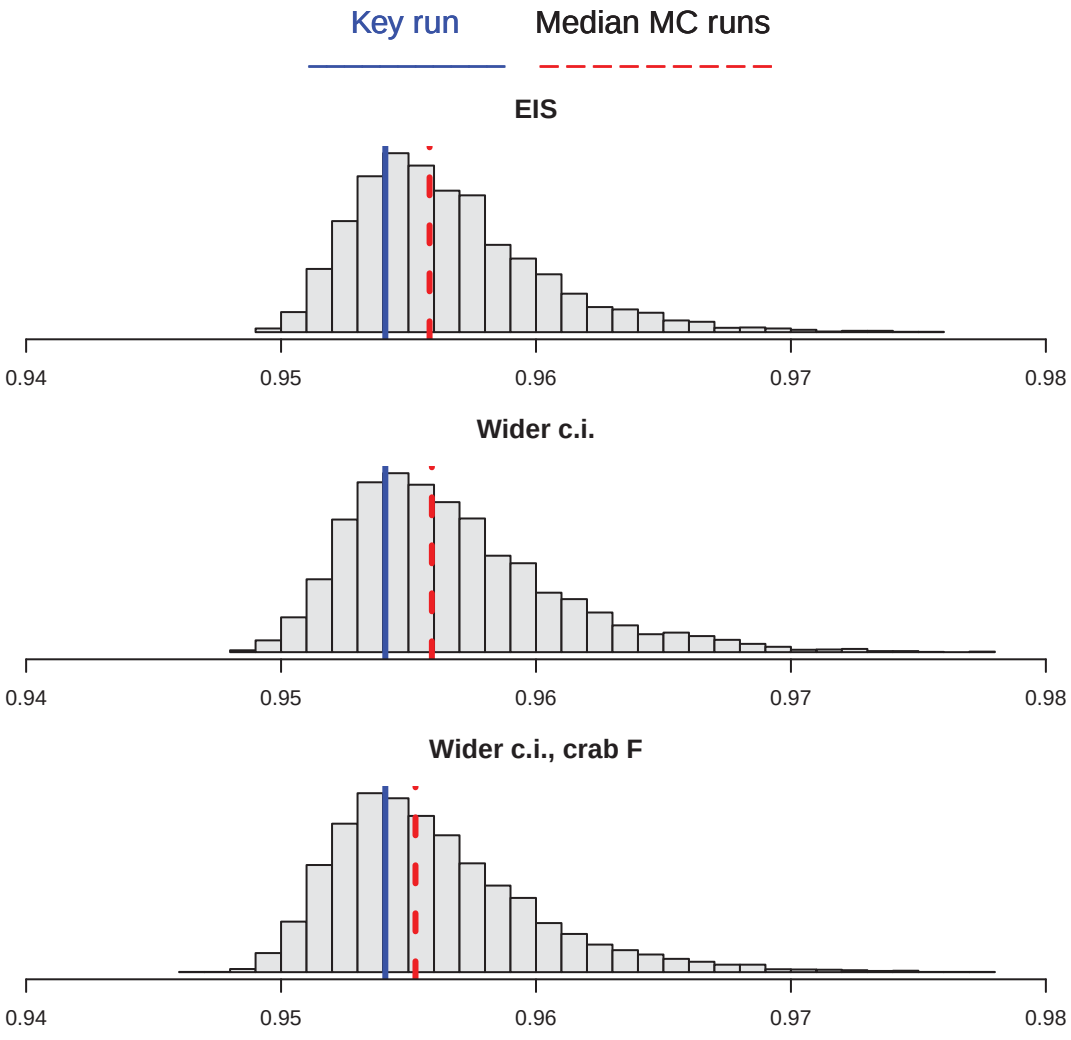
Biomass ratio (with/without project)

Chinook juv.



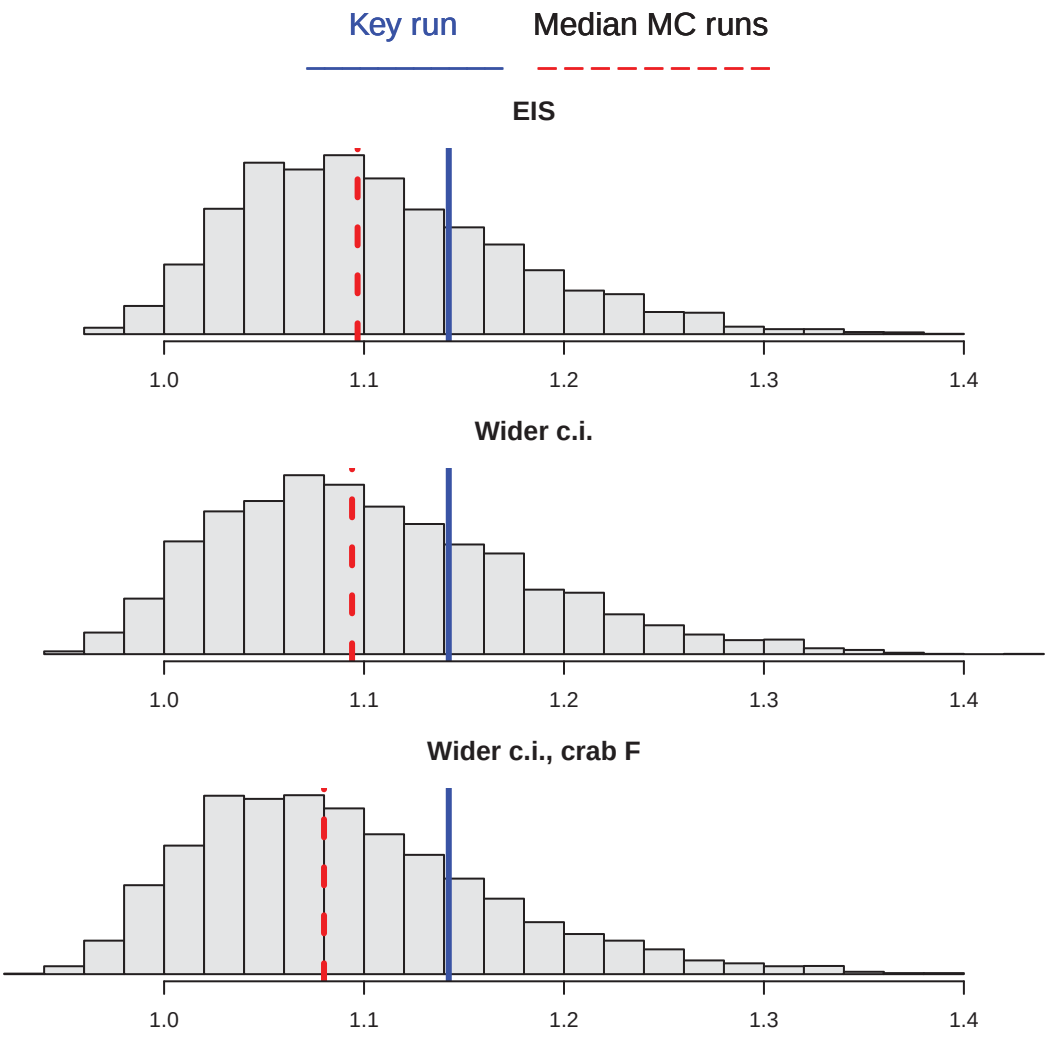
Biomass ratio (with/without project)

Chum adult



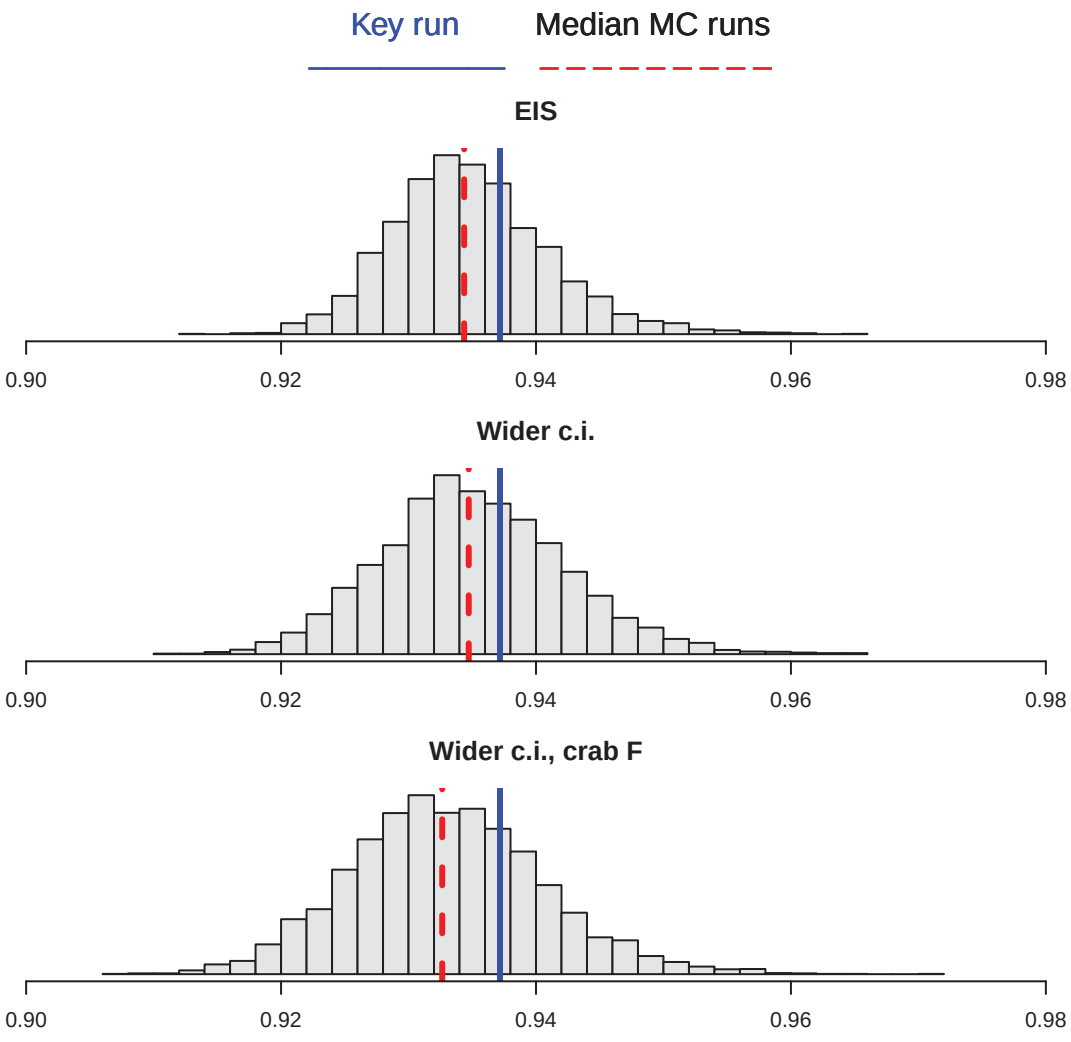
Biomass ratio (with/without project)

Chum juv.



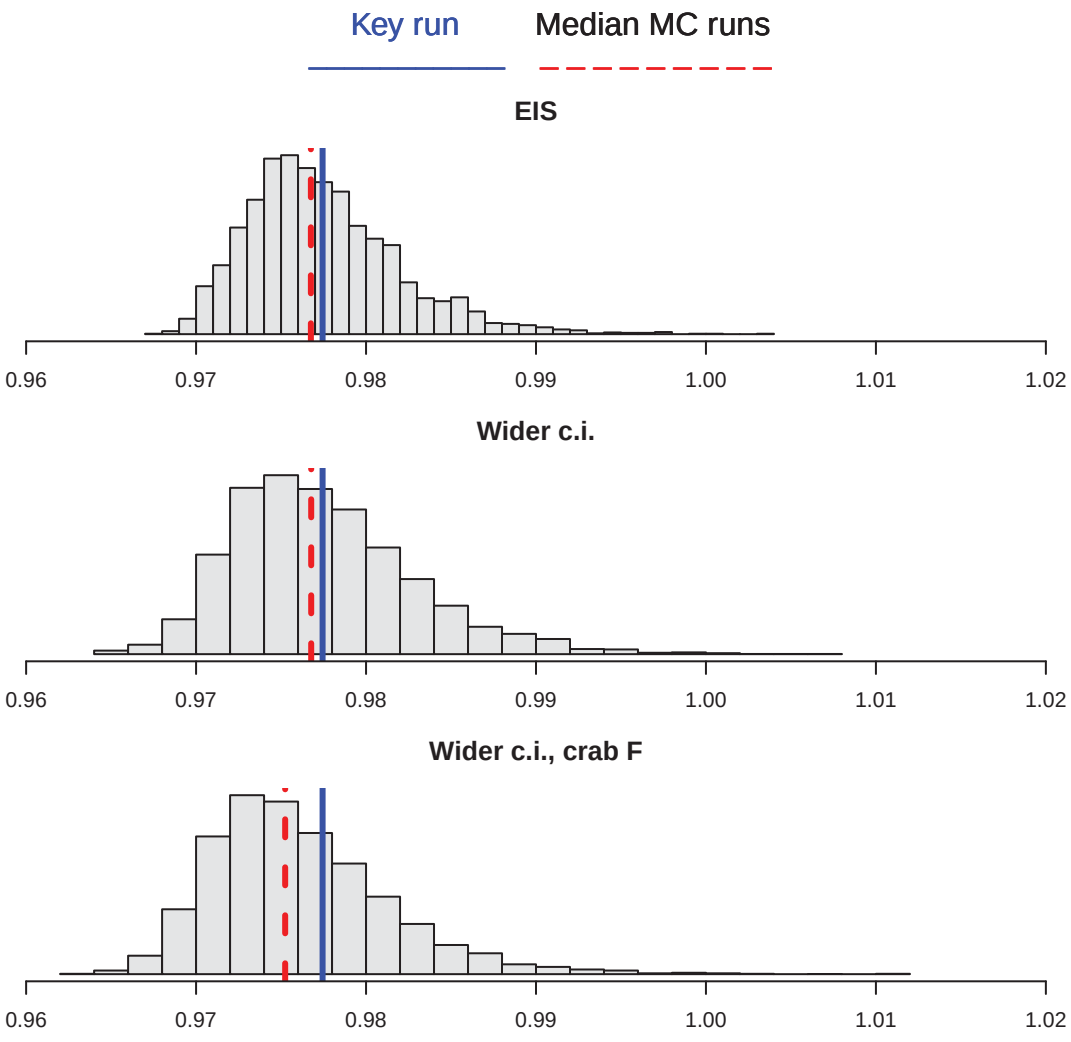
Biomass ratio (with/without project)

Diving waterbirds



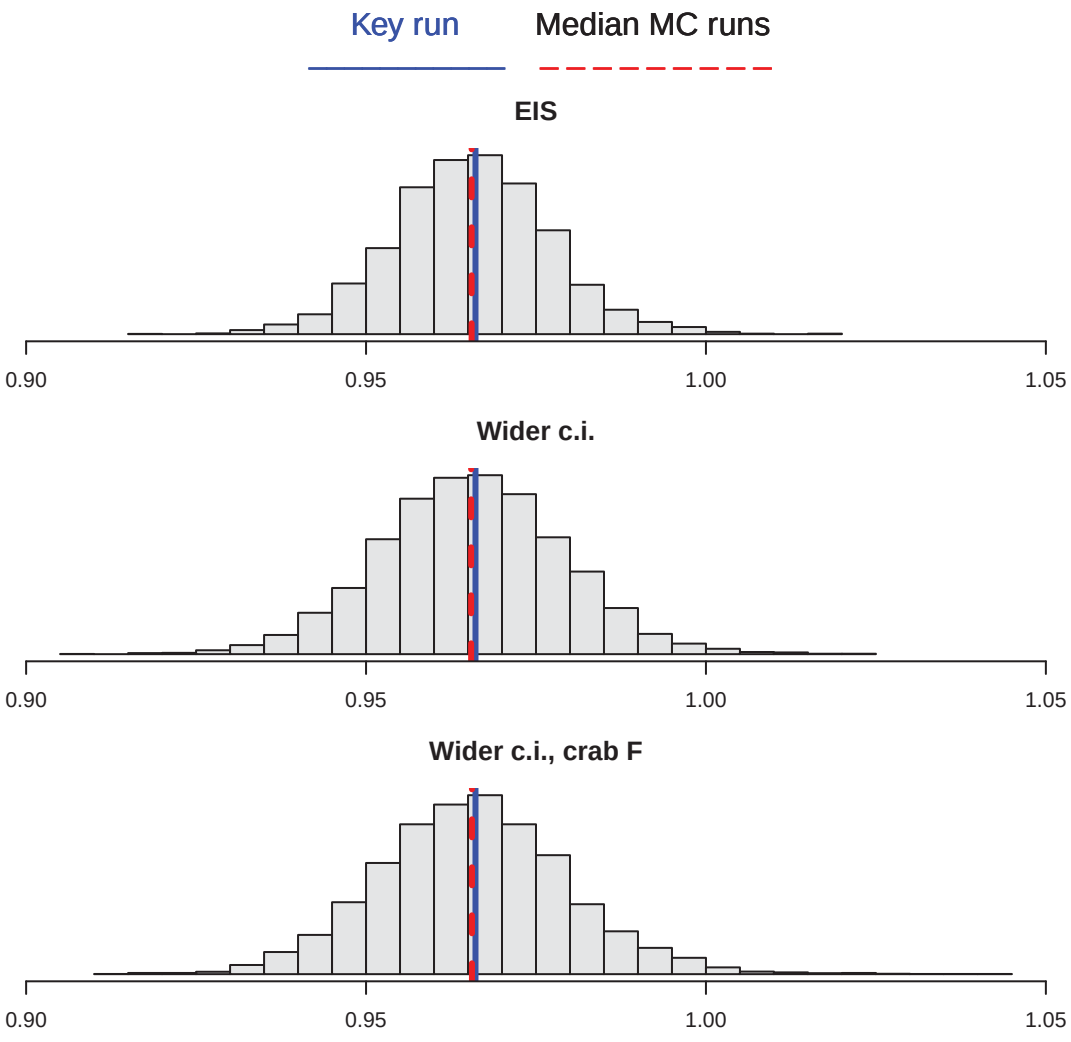
Biomass ratio (with/without project)

Dogfish



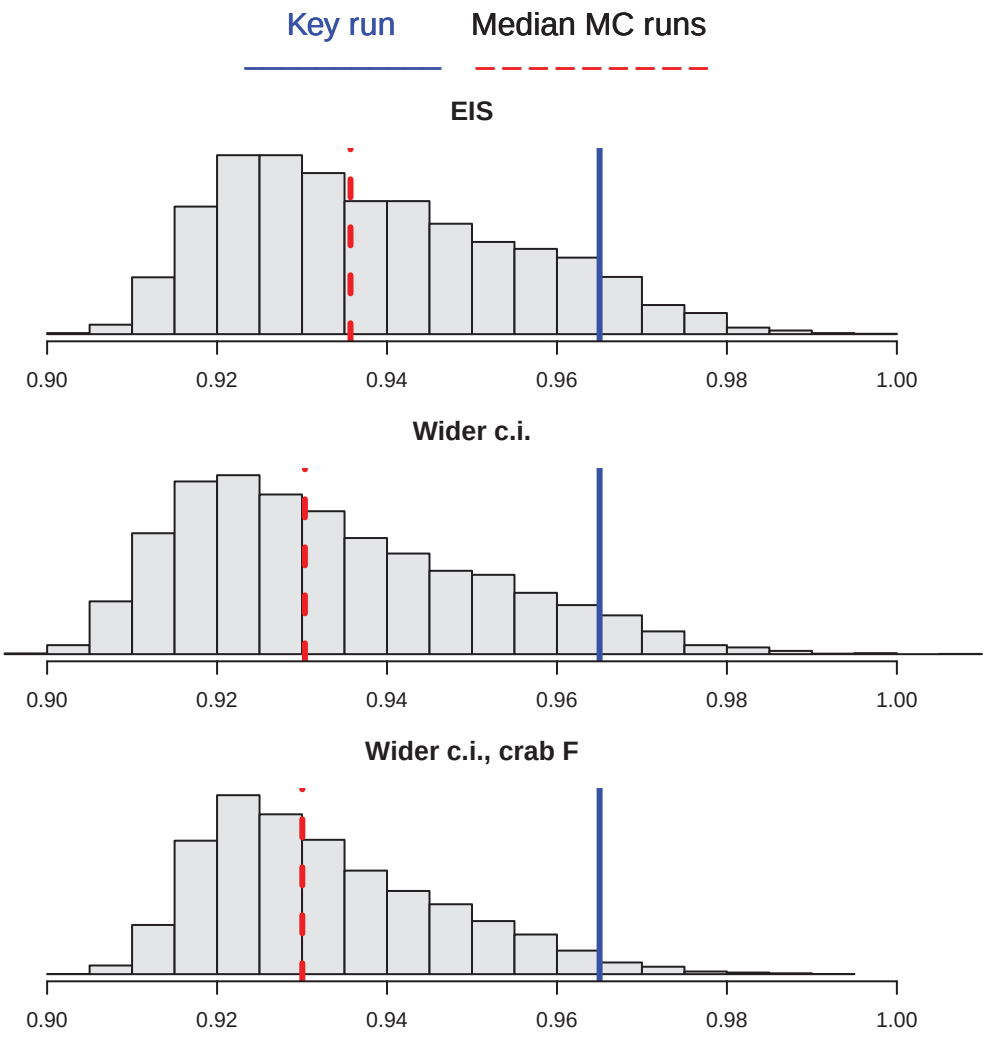
Biomass ratio (with/without project)

Dolphins and porpoises



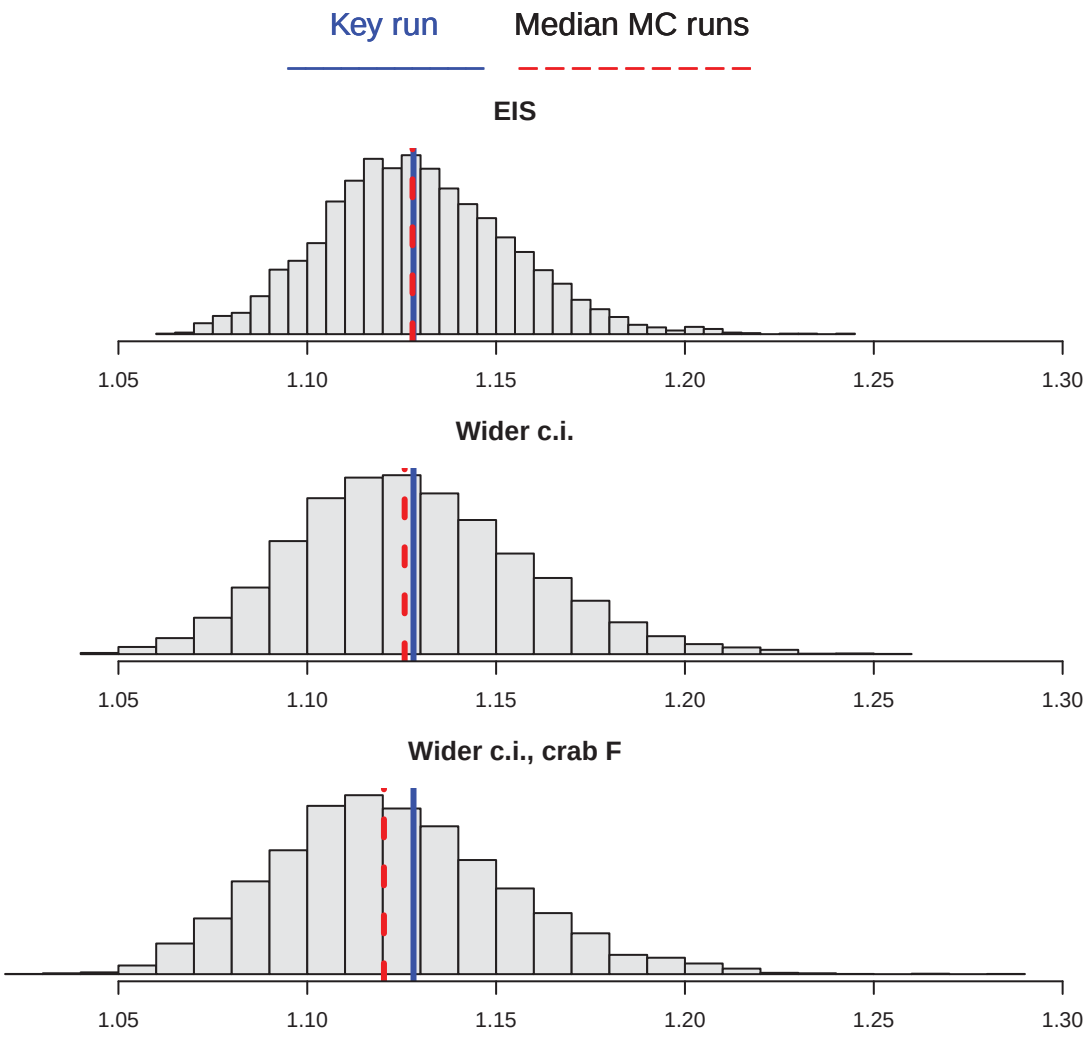
Biomass ratio (with/without project)

Dungeness crab



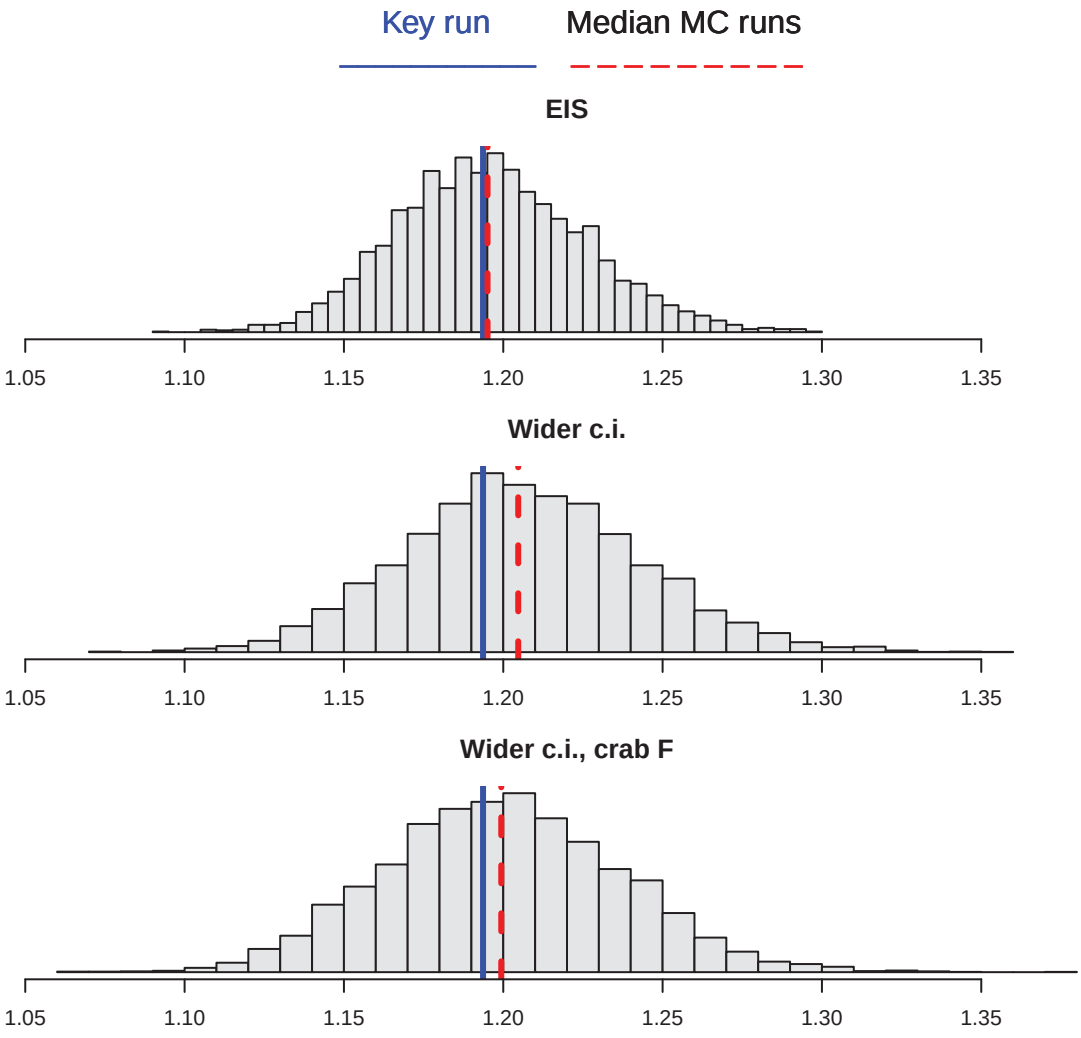
Biomass ratio (with/without project)

Dunlin



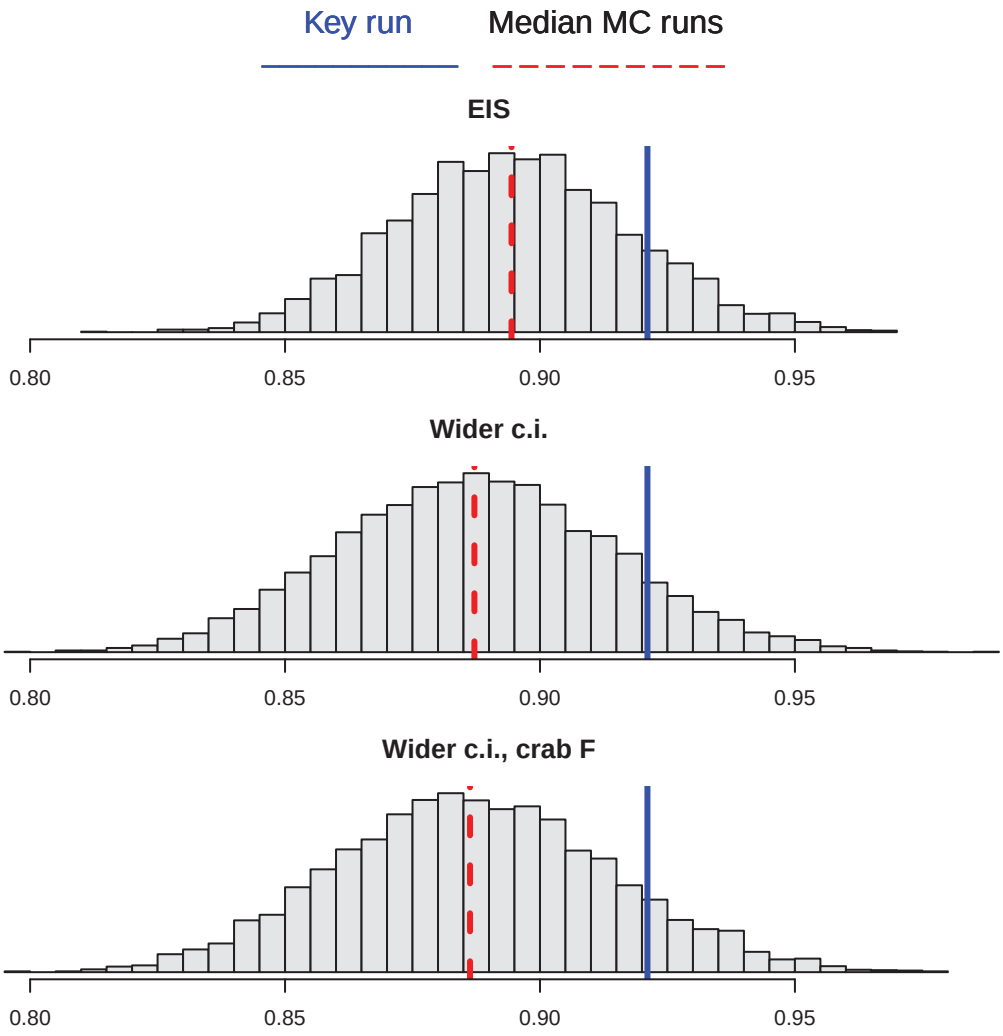
Biomass ratio (with/without project)

Epifauna sessile



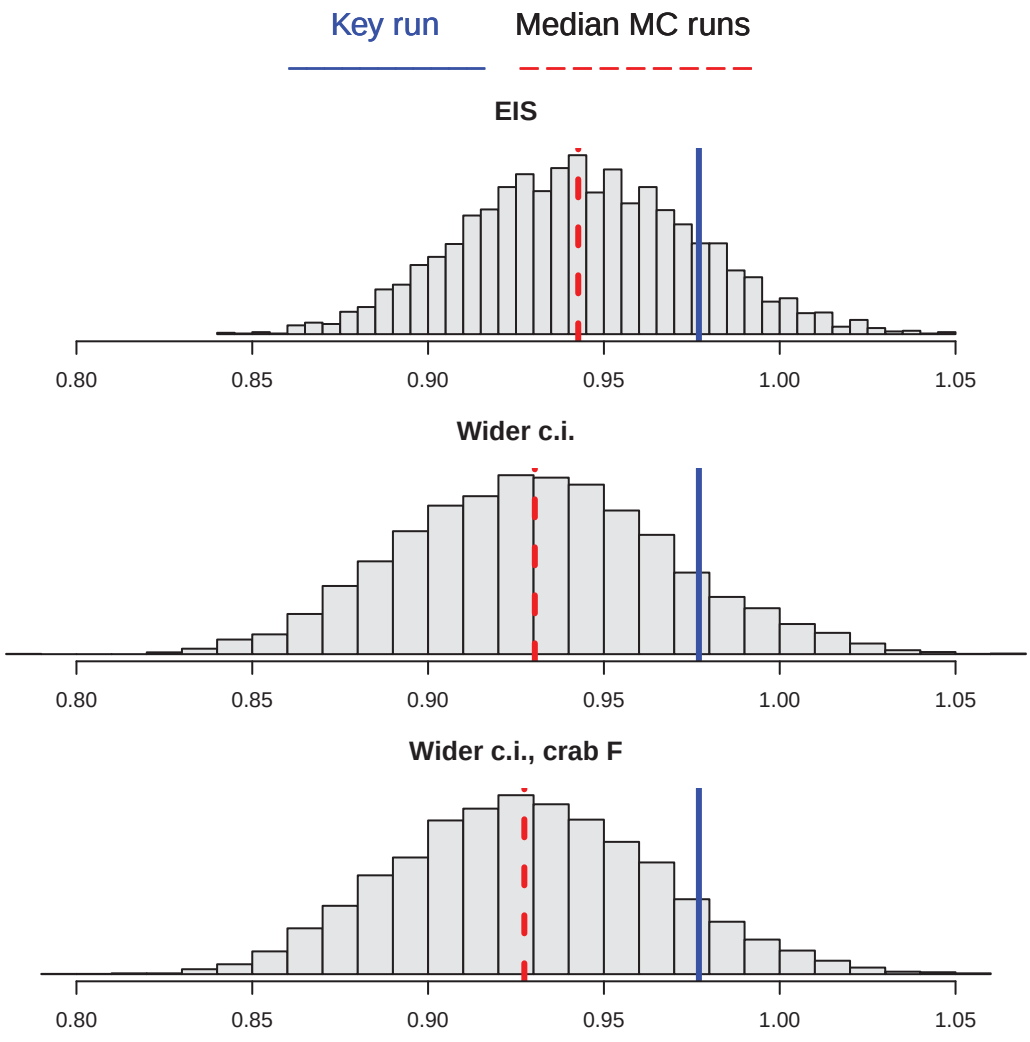
Biomass ratio (with/without project)

Epifaunal grazers



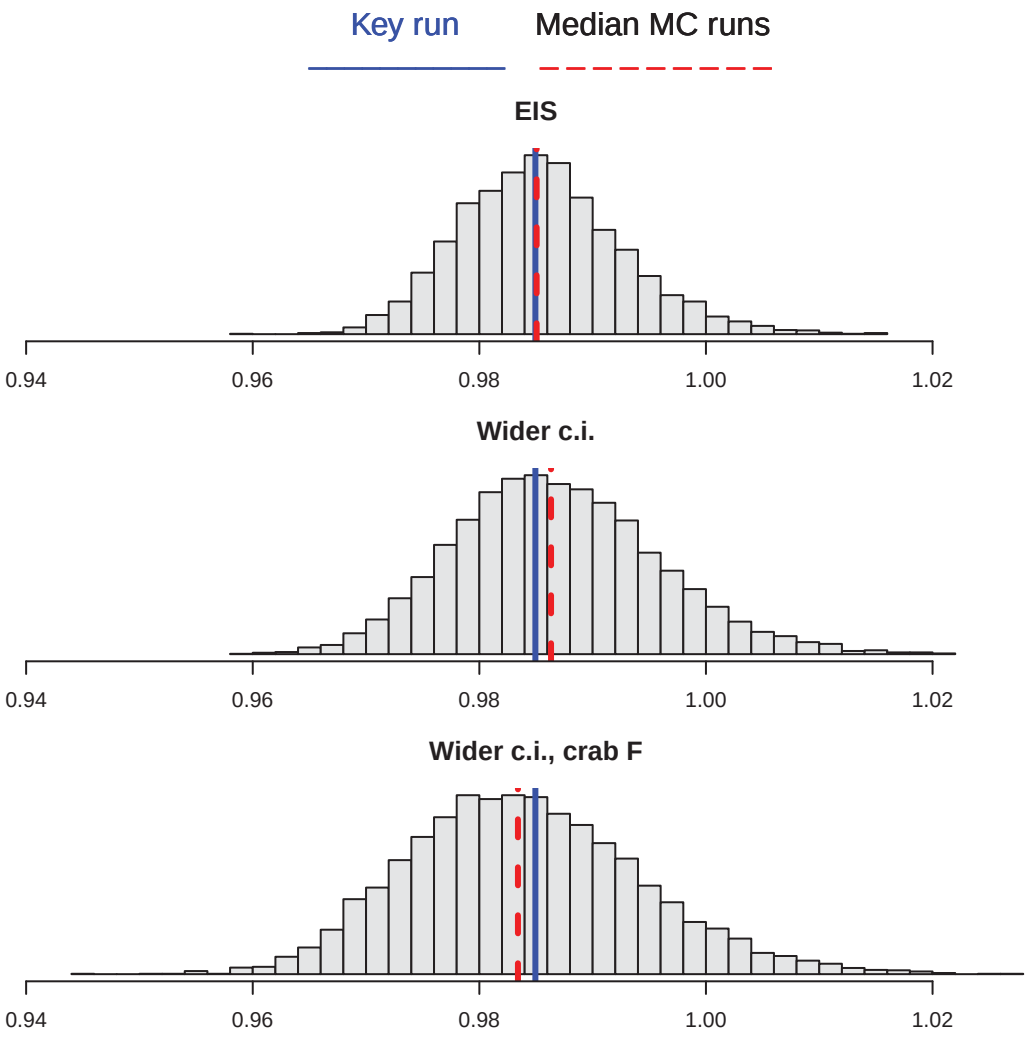
Biomass ratio (with/without project)

Epifaunal omnivore



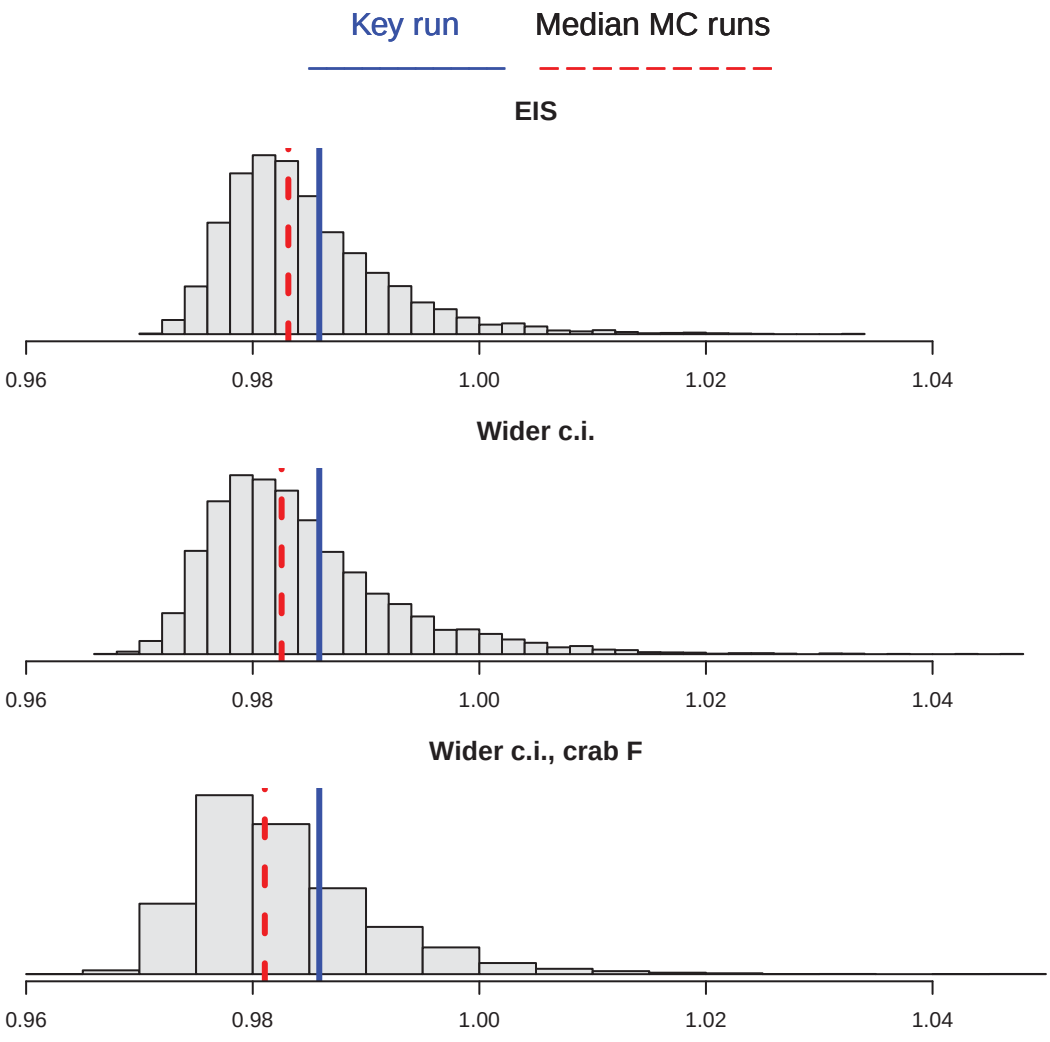
Biomass ratio (with/without project)

Flatfish



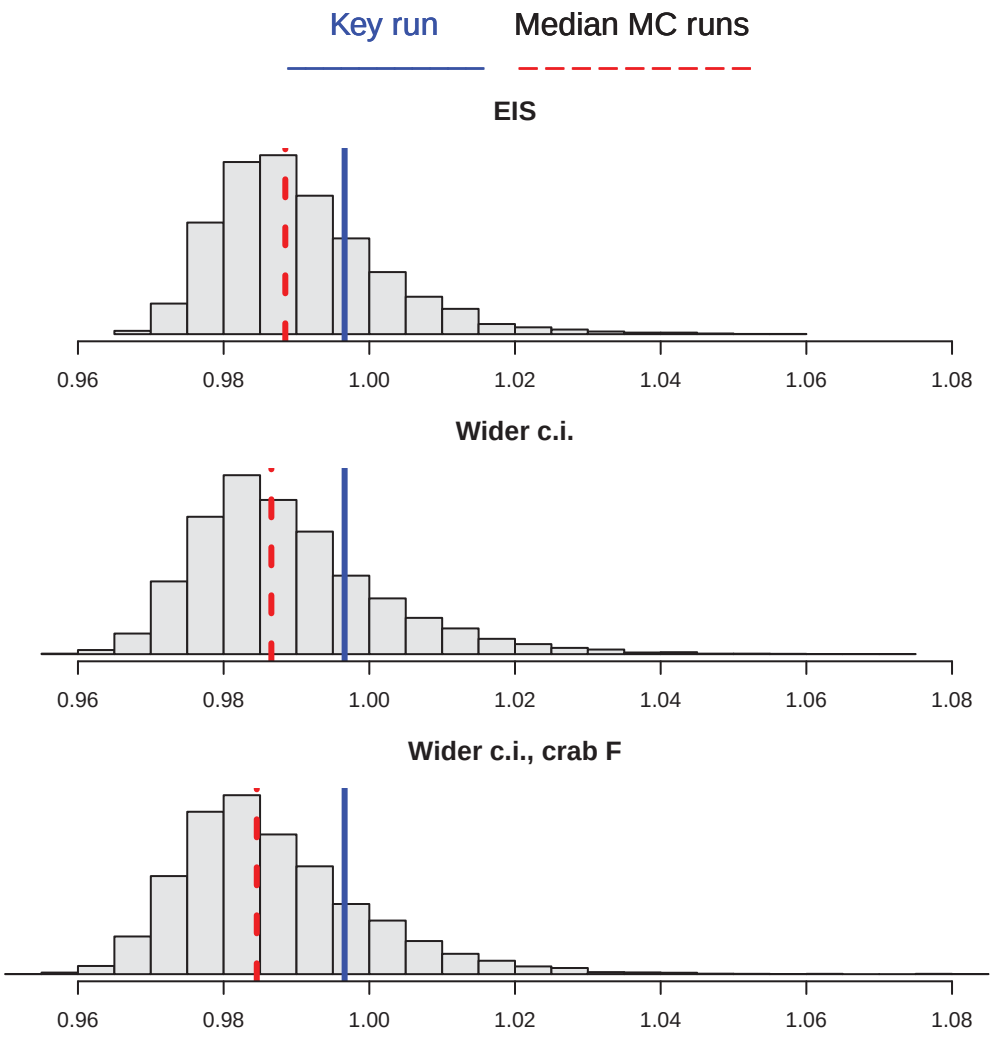
Biomass ratio (with/without project)

Forage fish



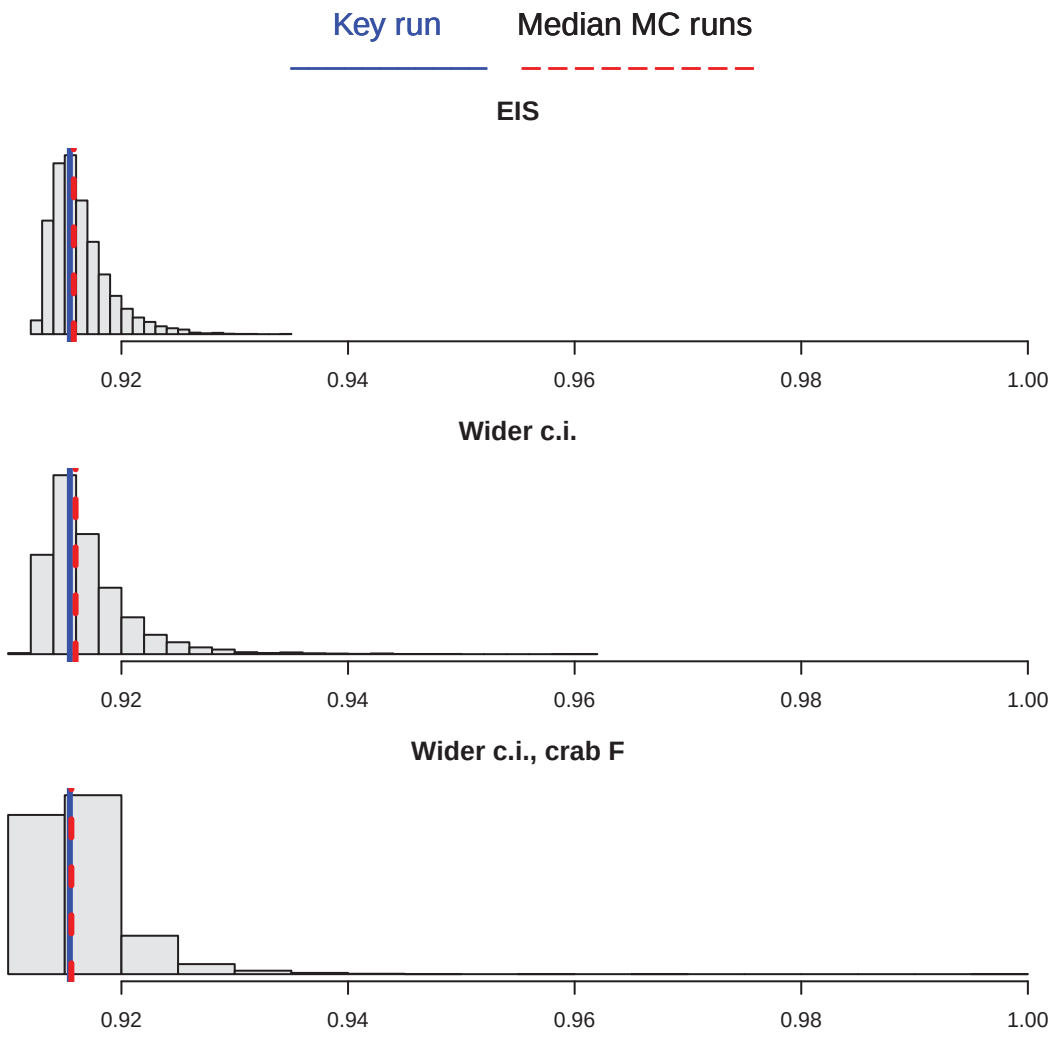
Biomass ratio (with/without project)

Great blue heron



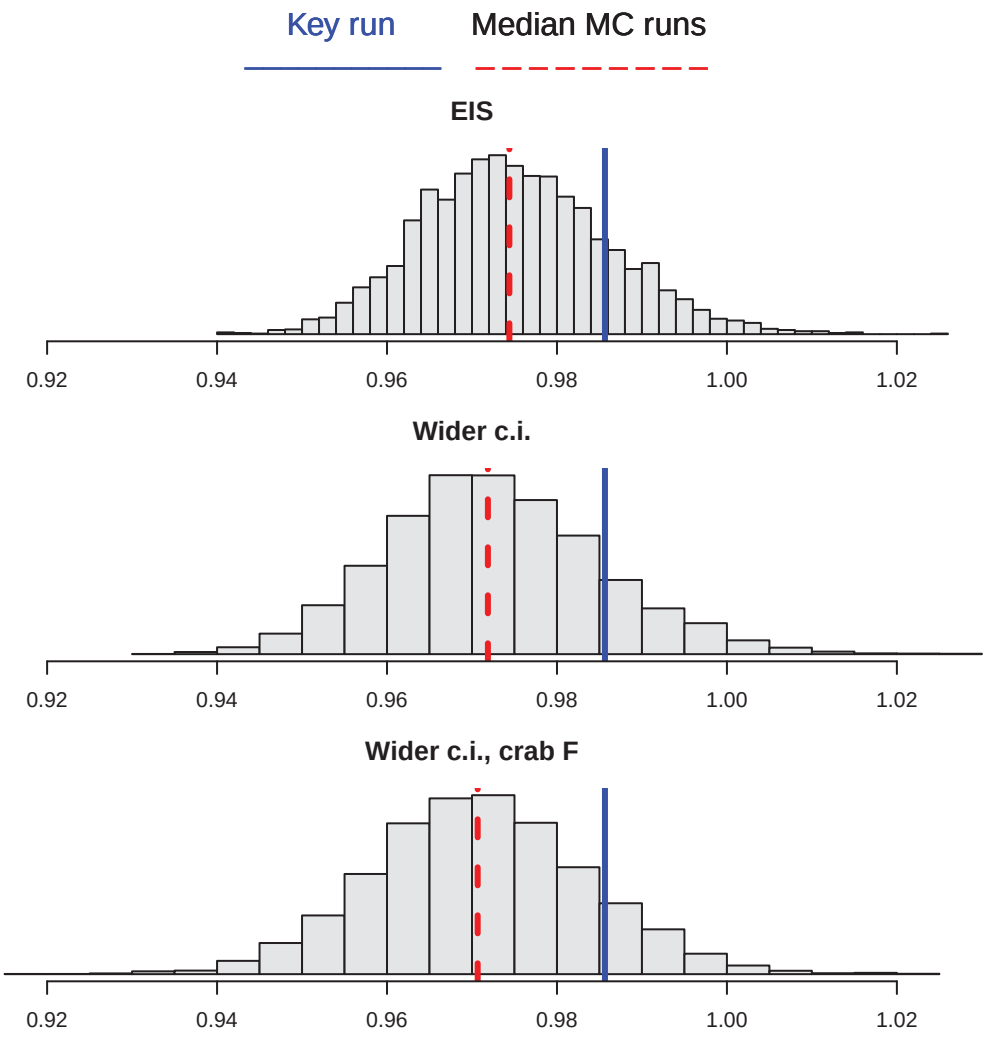
Biomass ratio (with/without project)

Green algae



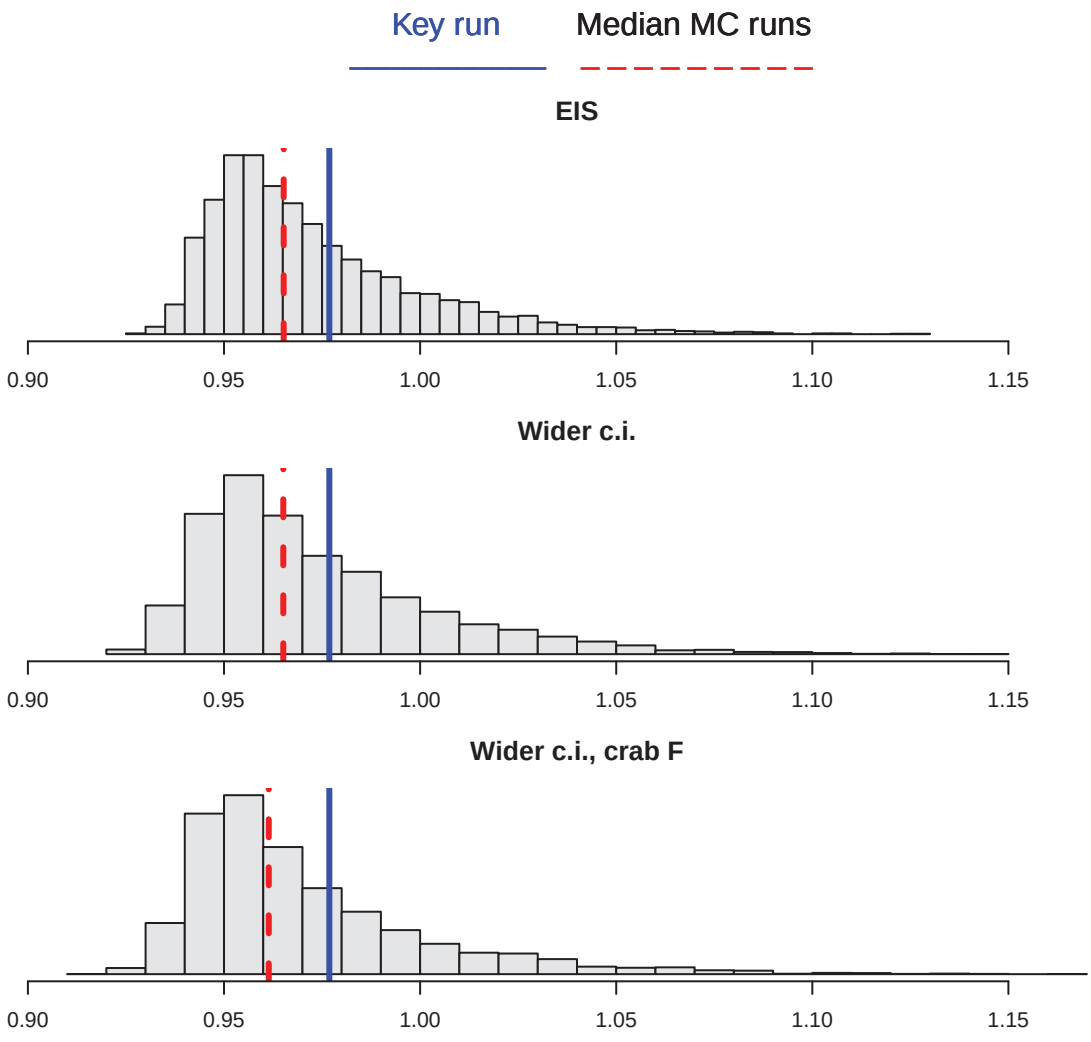
Biomass ratio (with/without project)

Gulls and terns



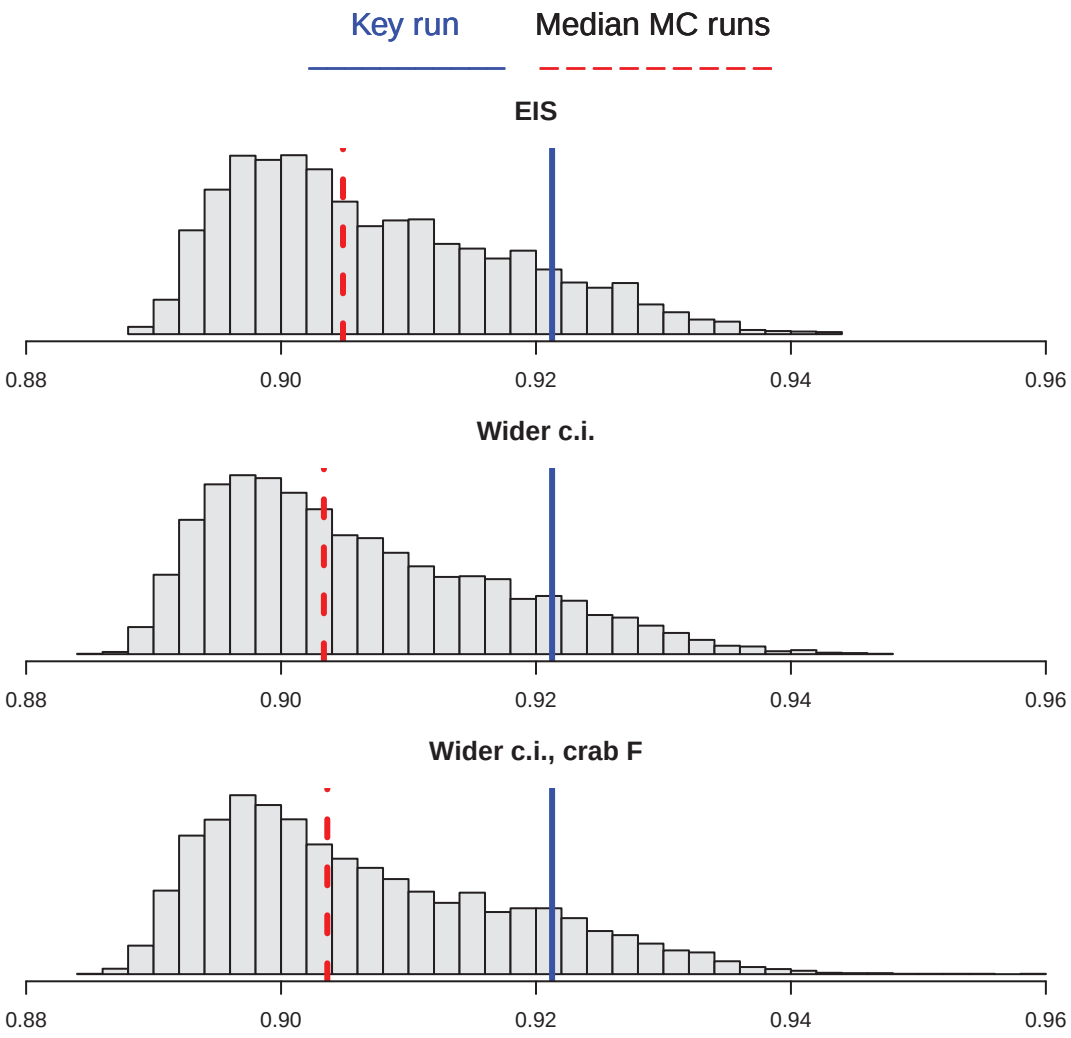
Biomass ratio (with/without project)

Herring



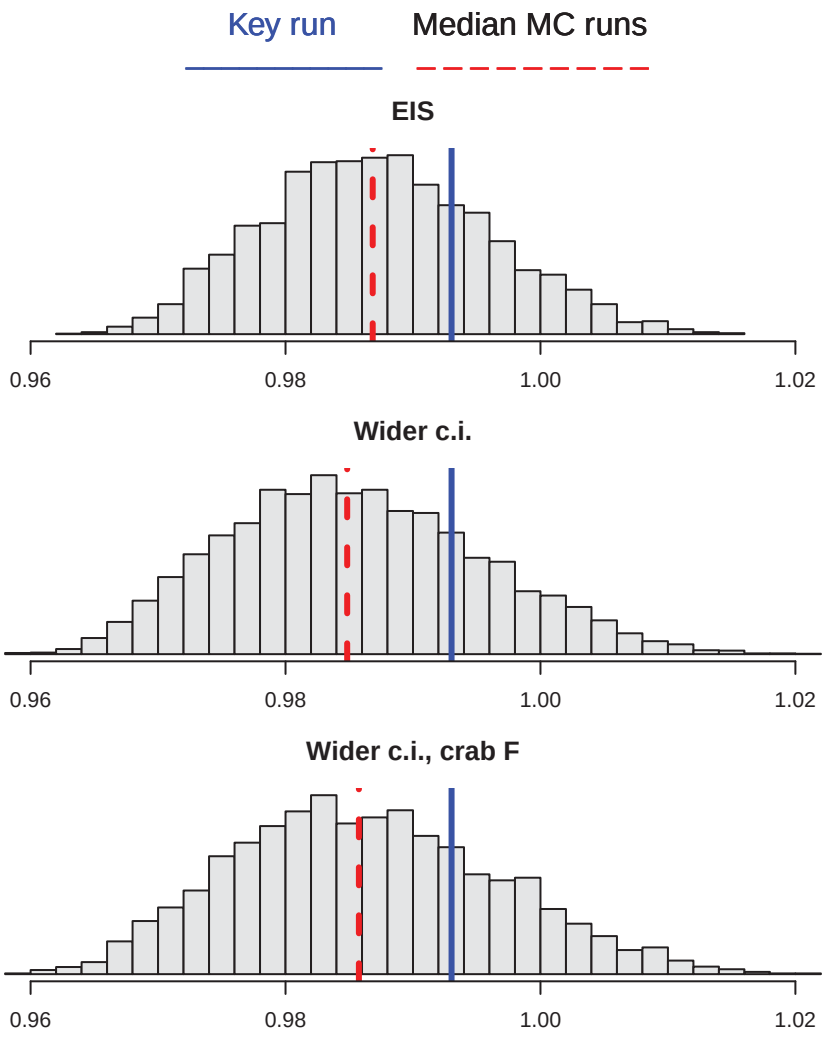
Biomass ratio (with/without project)

Infaunal bivalves



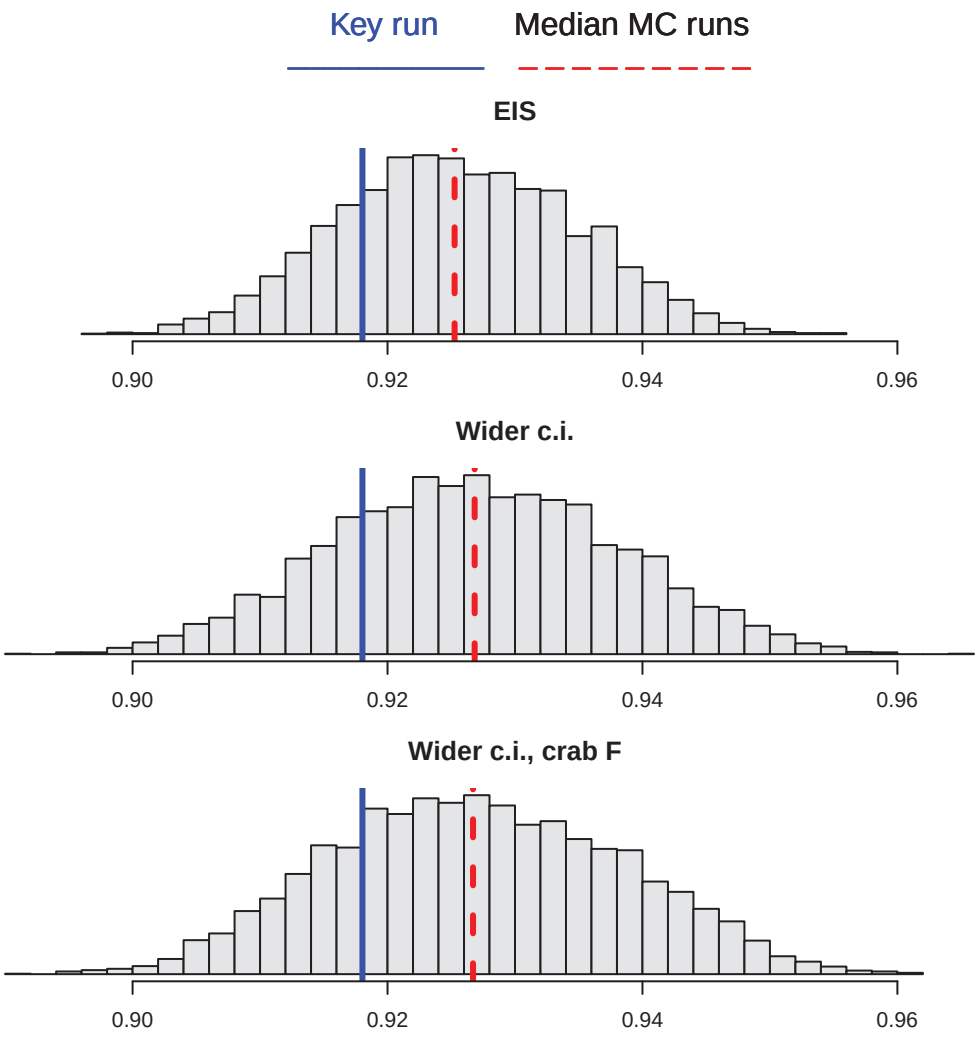
Biomass ratio (with/without project)

Japanese eelgrass



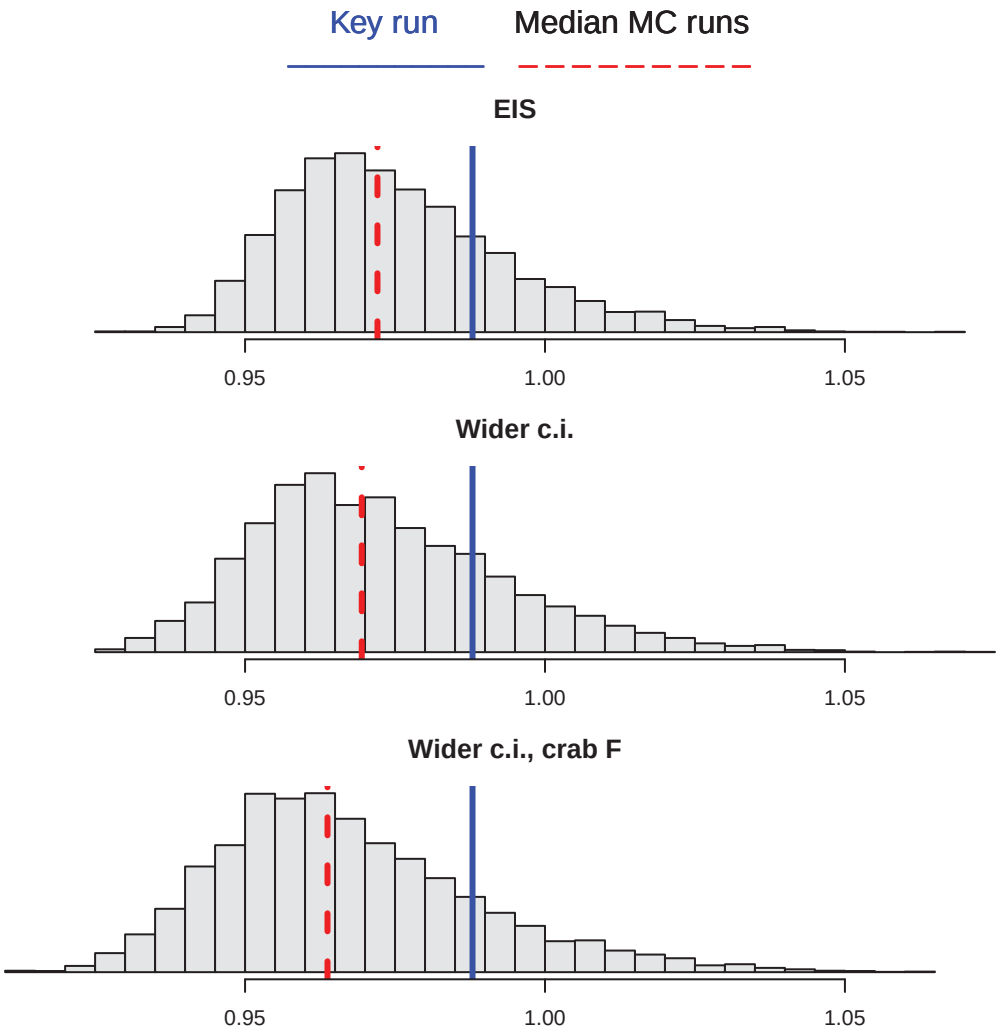
Biomass ratio (with/without project)

Jellyfish



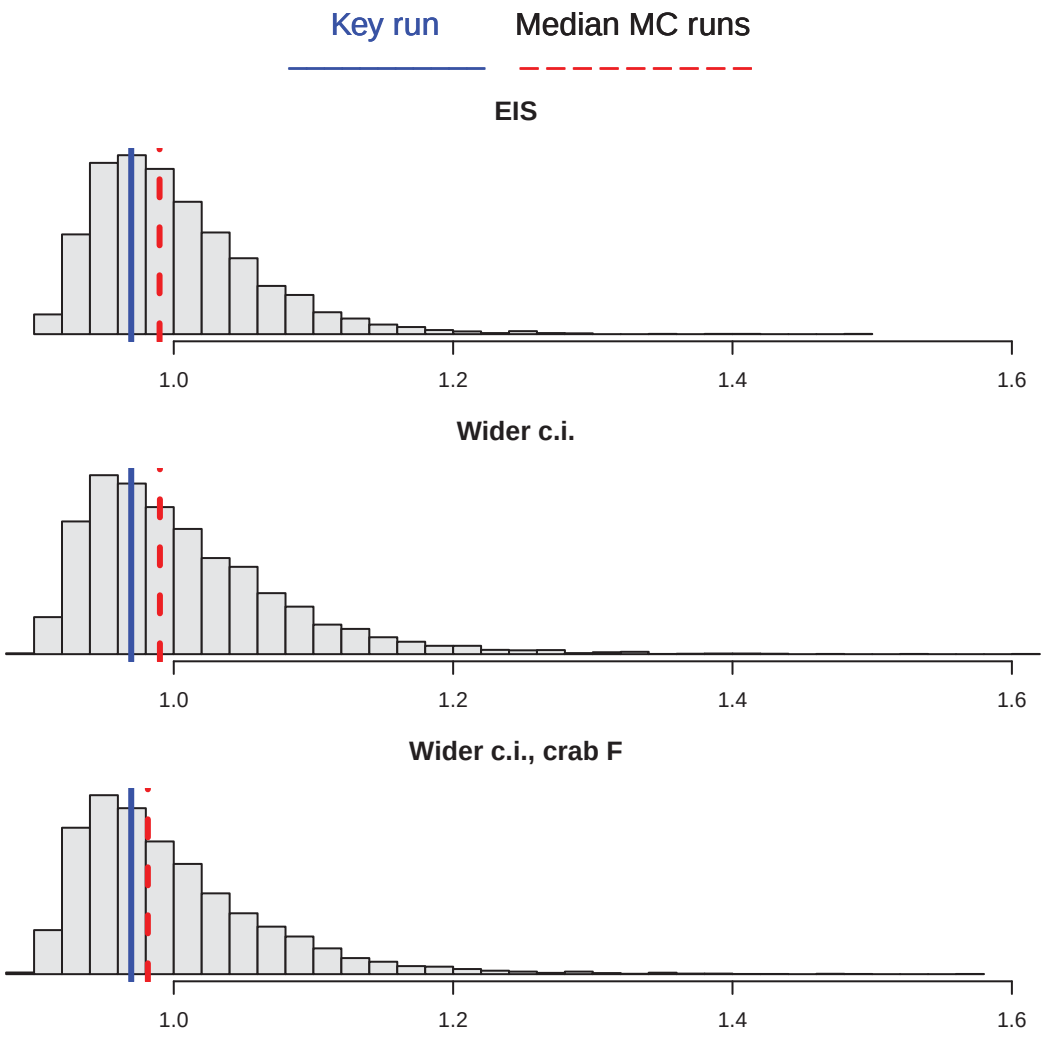
Biomass ratio (with/without project)

Large demersal fish



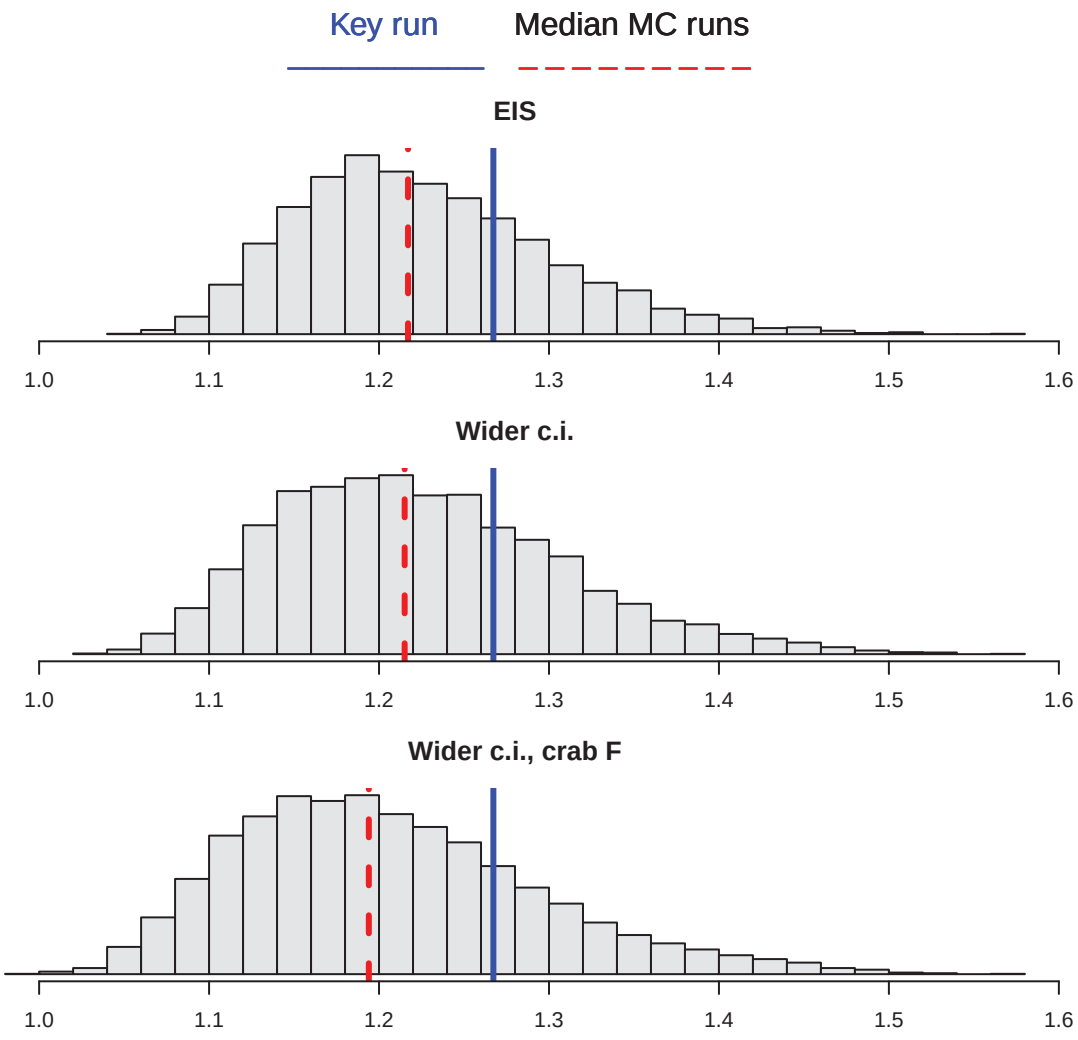
Biomass ratio (with/without project)

Lingcod



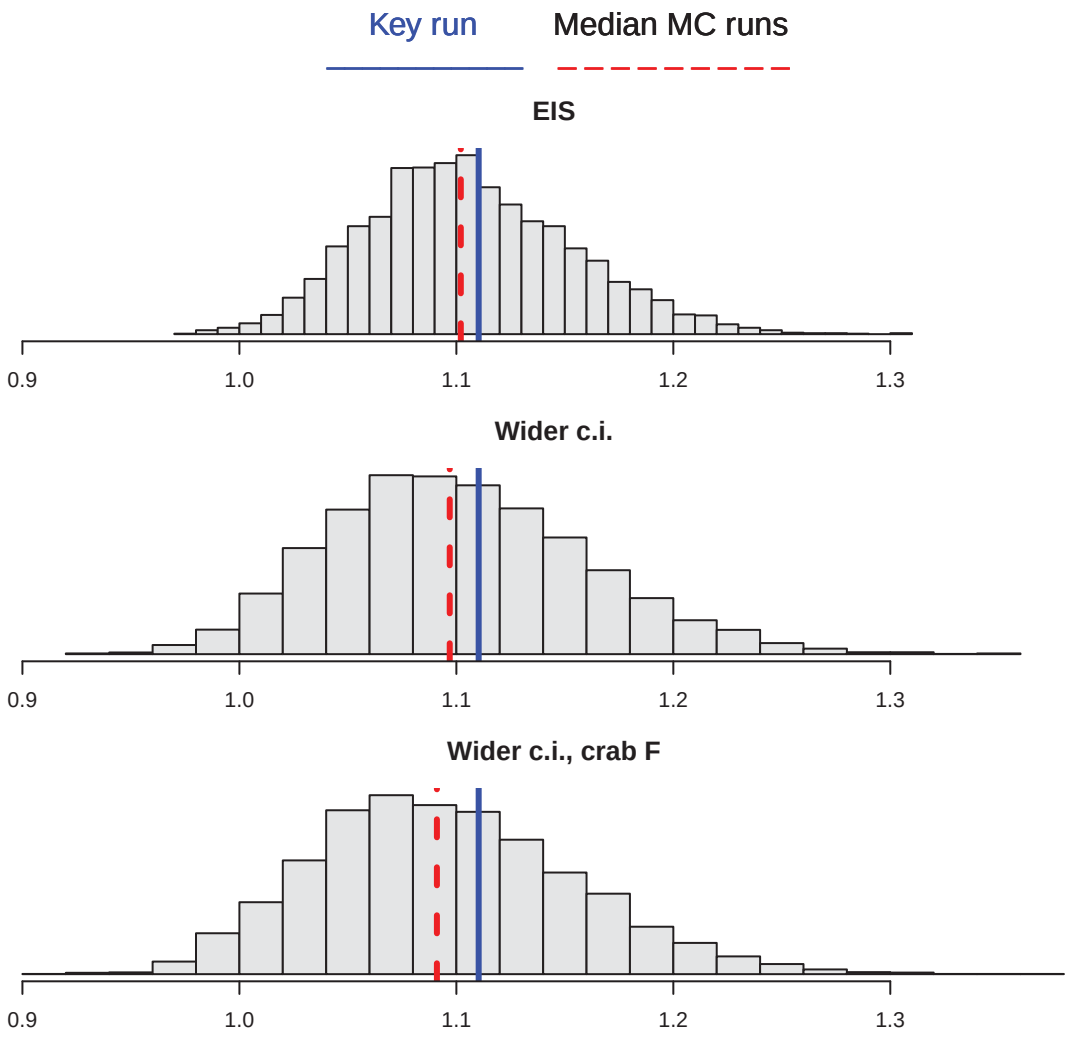
Biomass ratio (with/without project)

Macrofauna



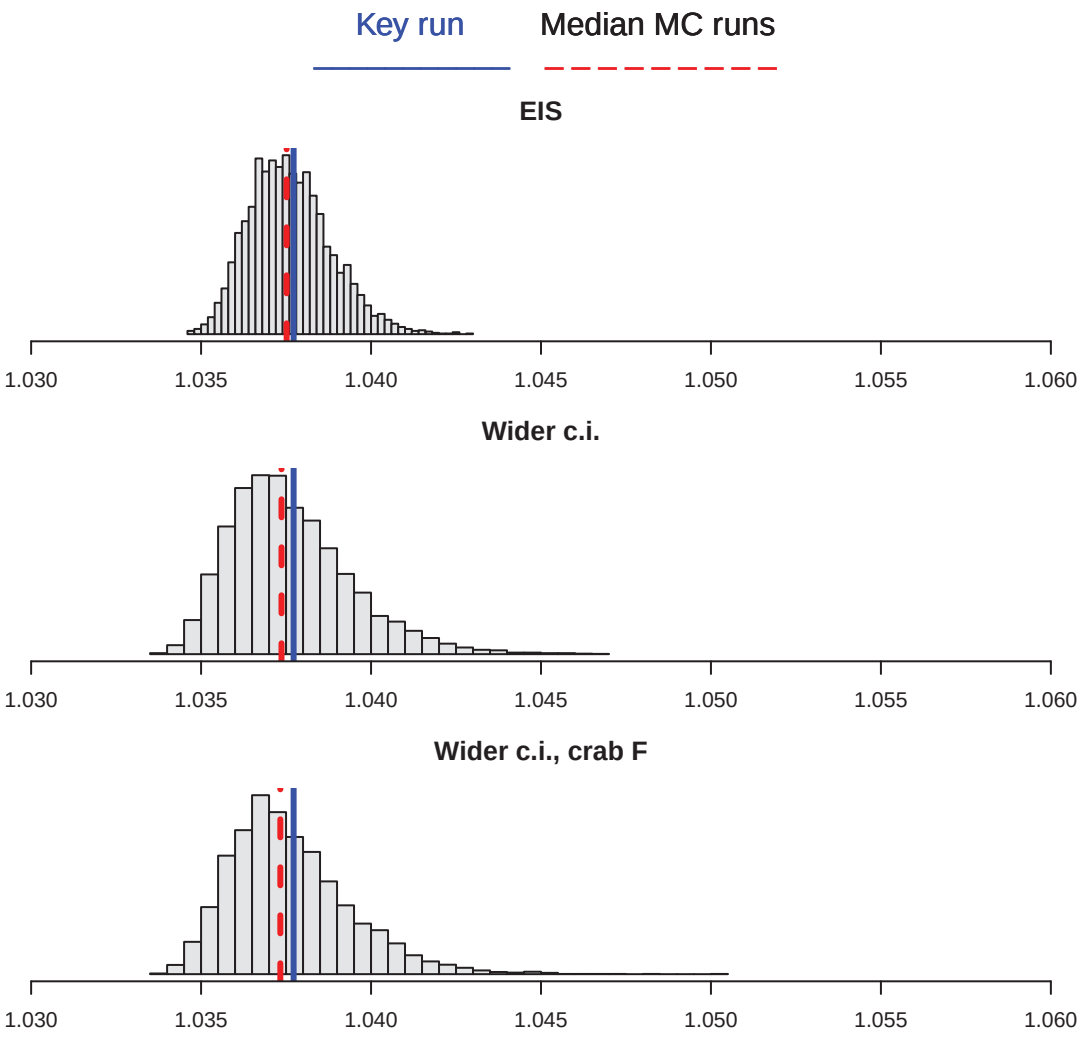
Biomass ratio (with/without project)

Meiofauna



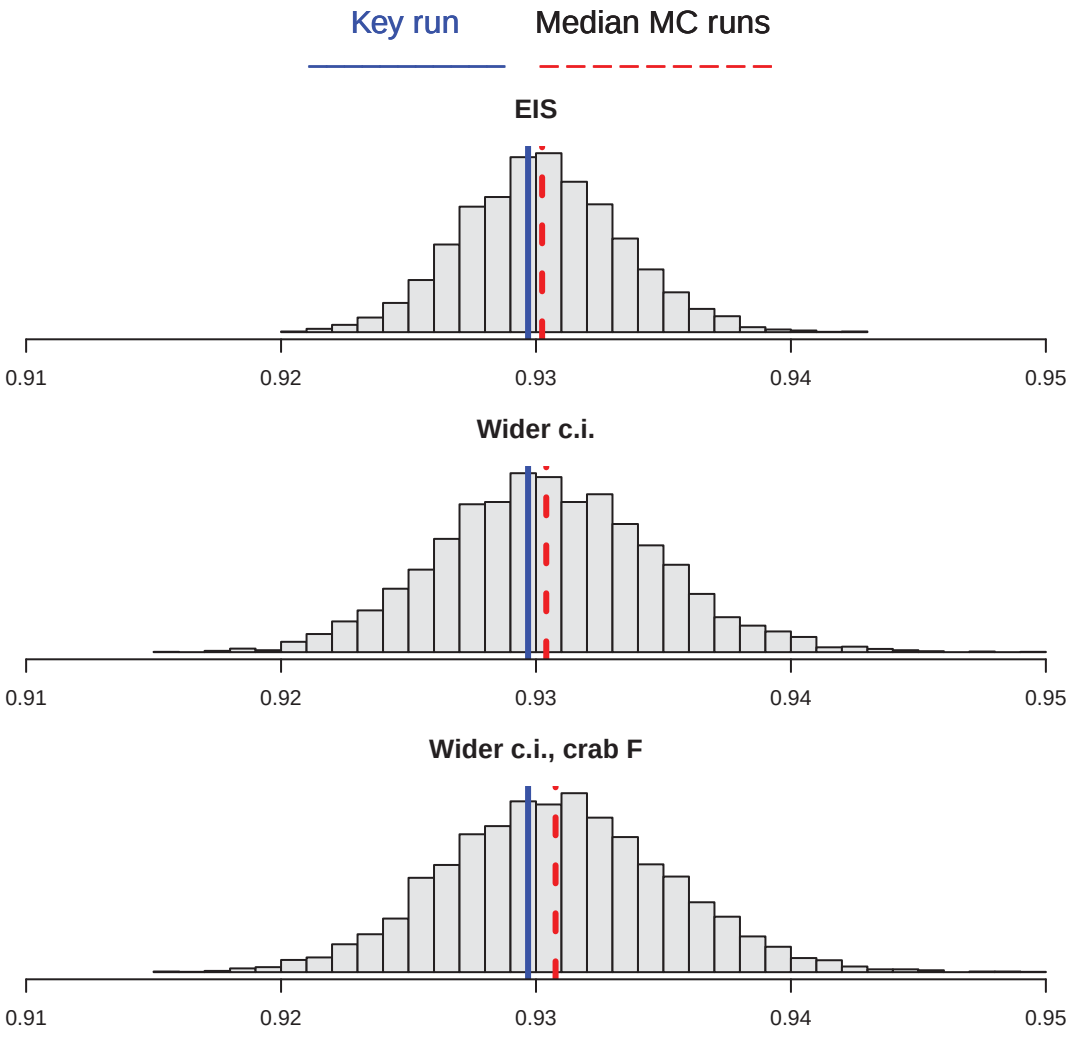
Biomass ratio (with/without project)

Native eelgrass



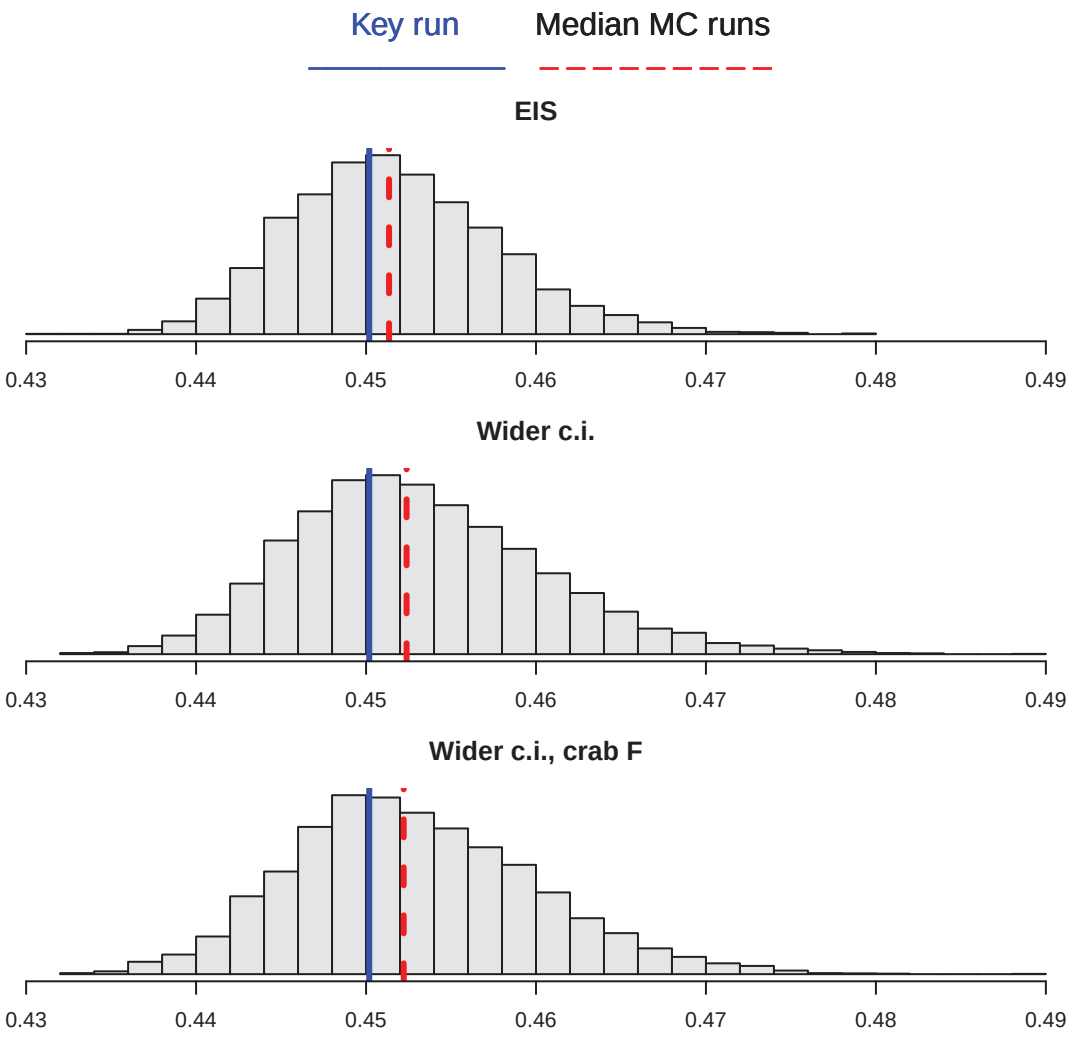
Biomass ratio (with/without project)

Omnivorous and herbivorous zooplanktor



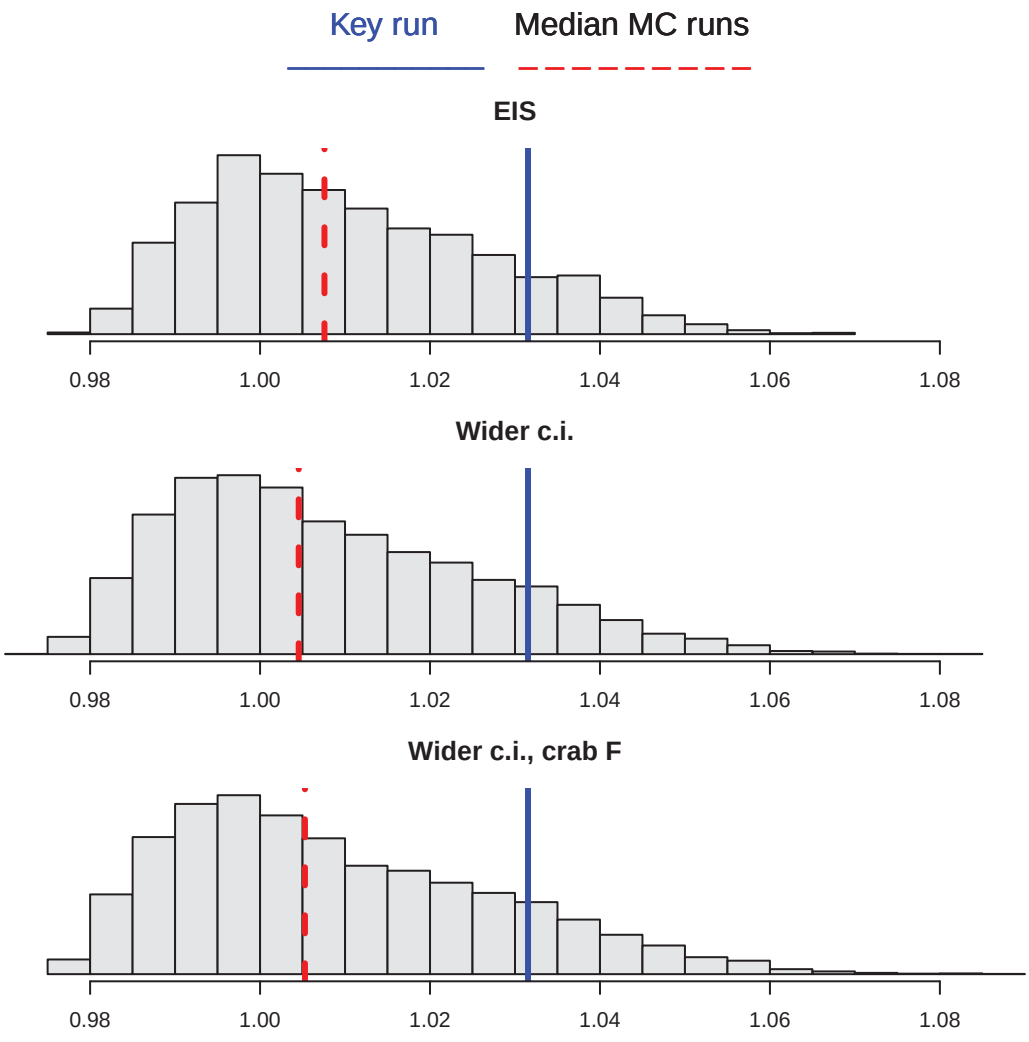
Biomass ratio (with/without project)

Orange sea pen



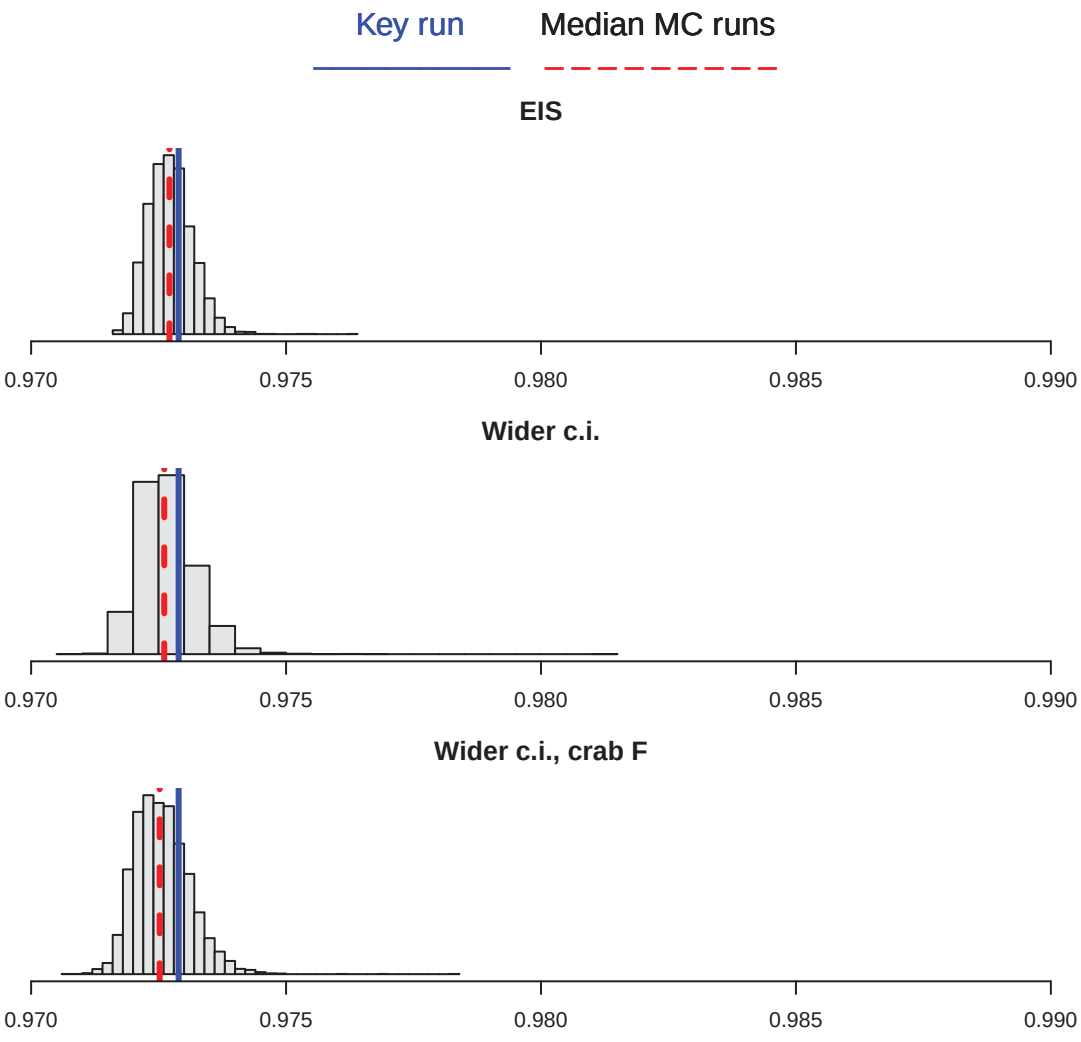
Biomass ratio (with/without project)

Phytoplankton



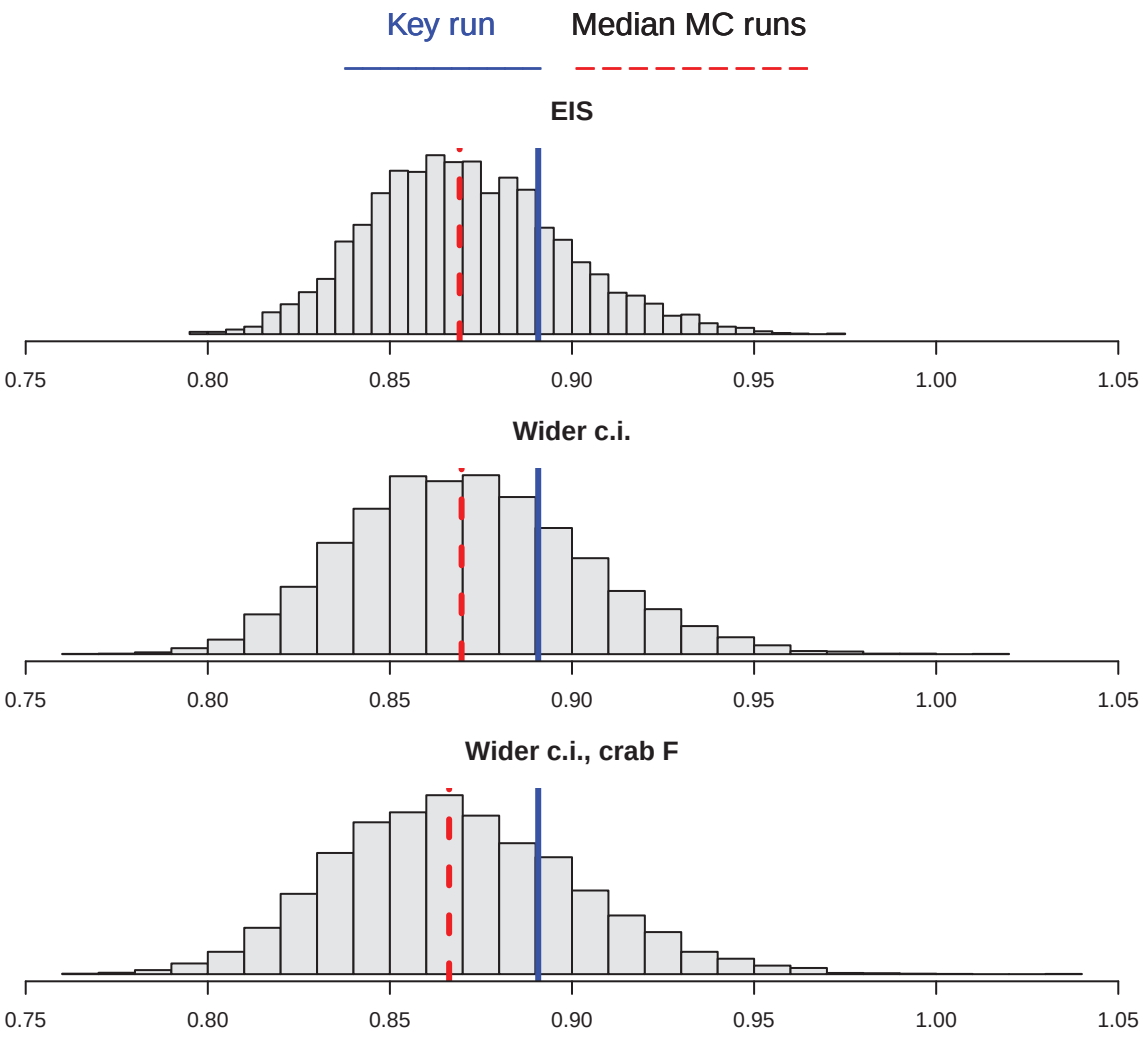
Biomass ratio (with/without project)

Pinnipeds



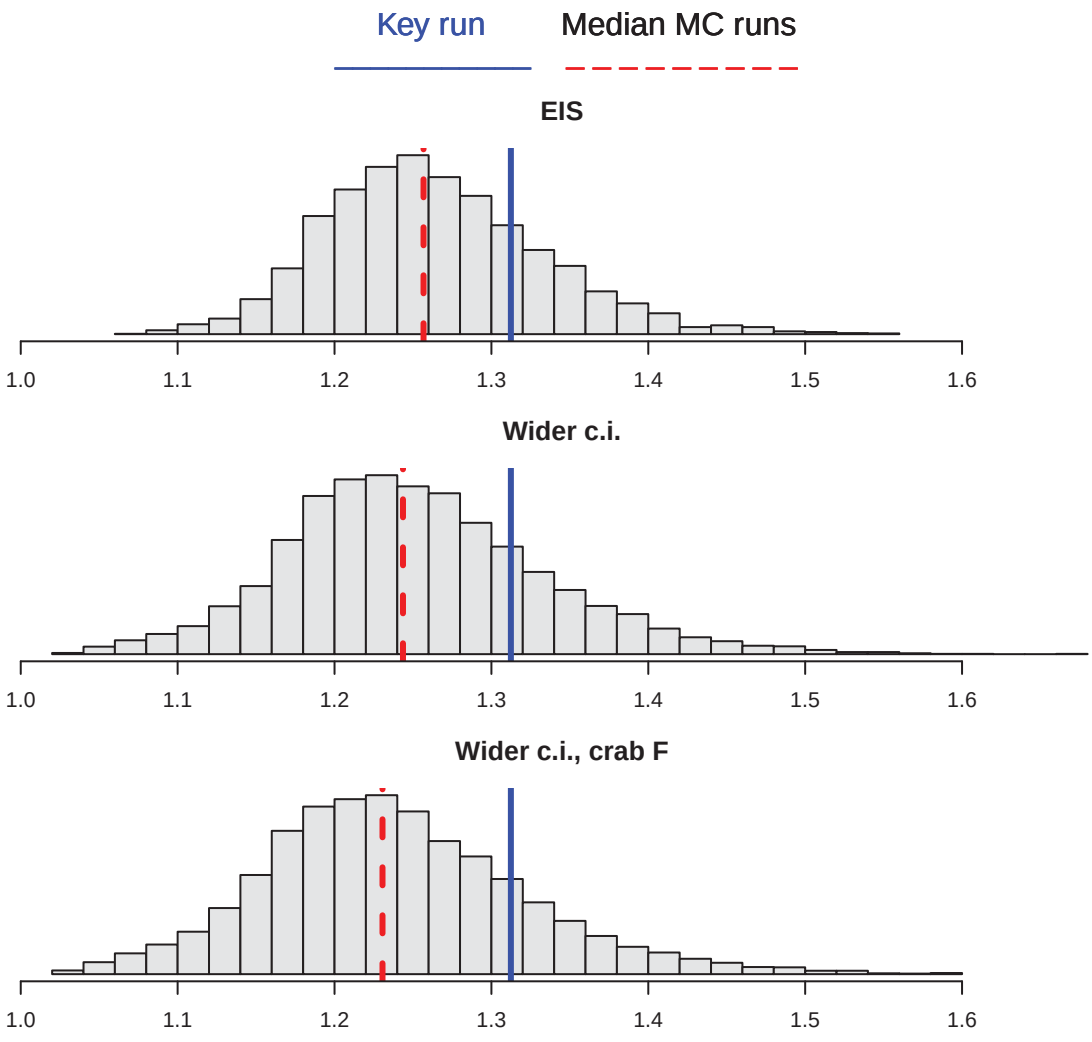
Biomass ratio (with/without project)

Polychaetes



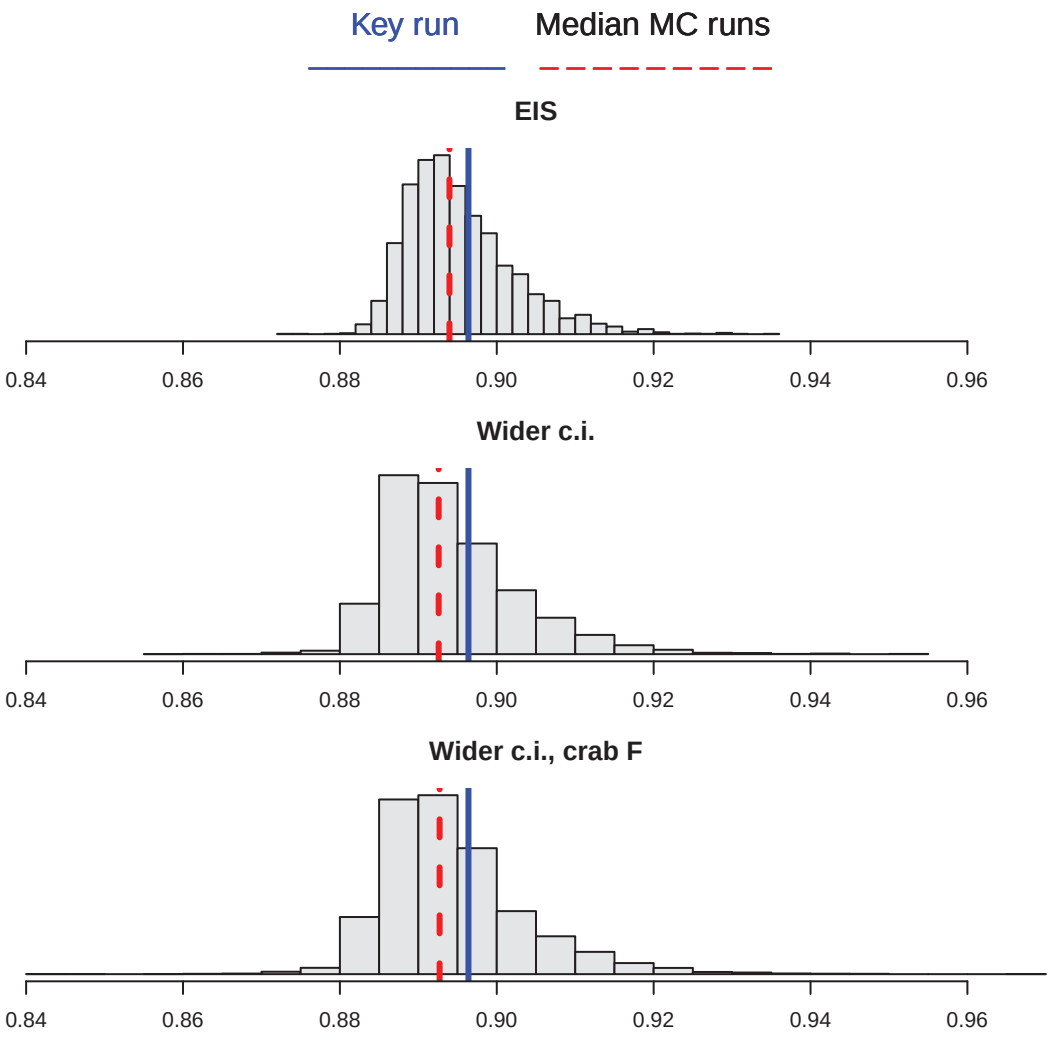
Biomass ratio (with/without project)

Raptors



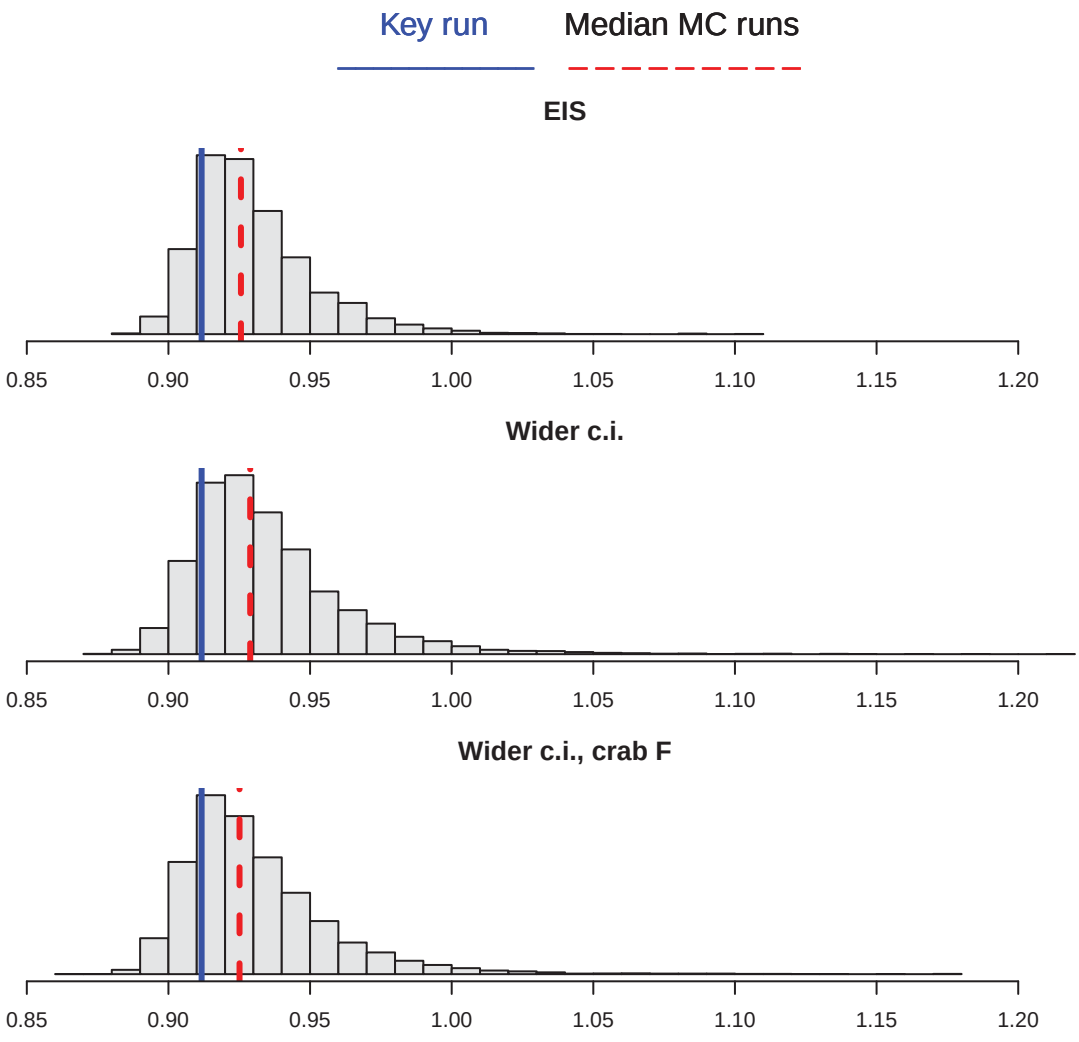
Biomass ratio (with/without project)

Red algae



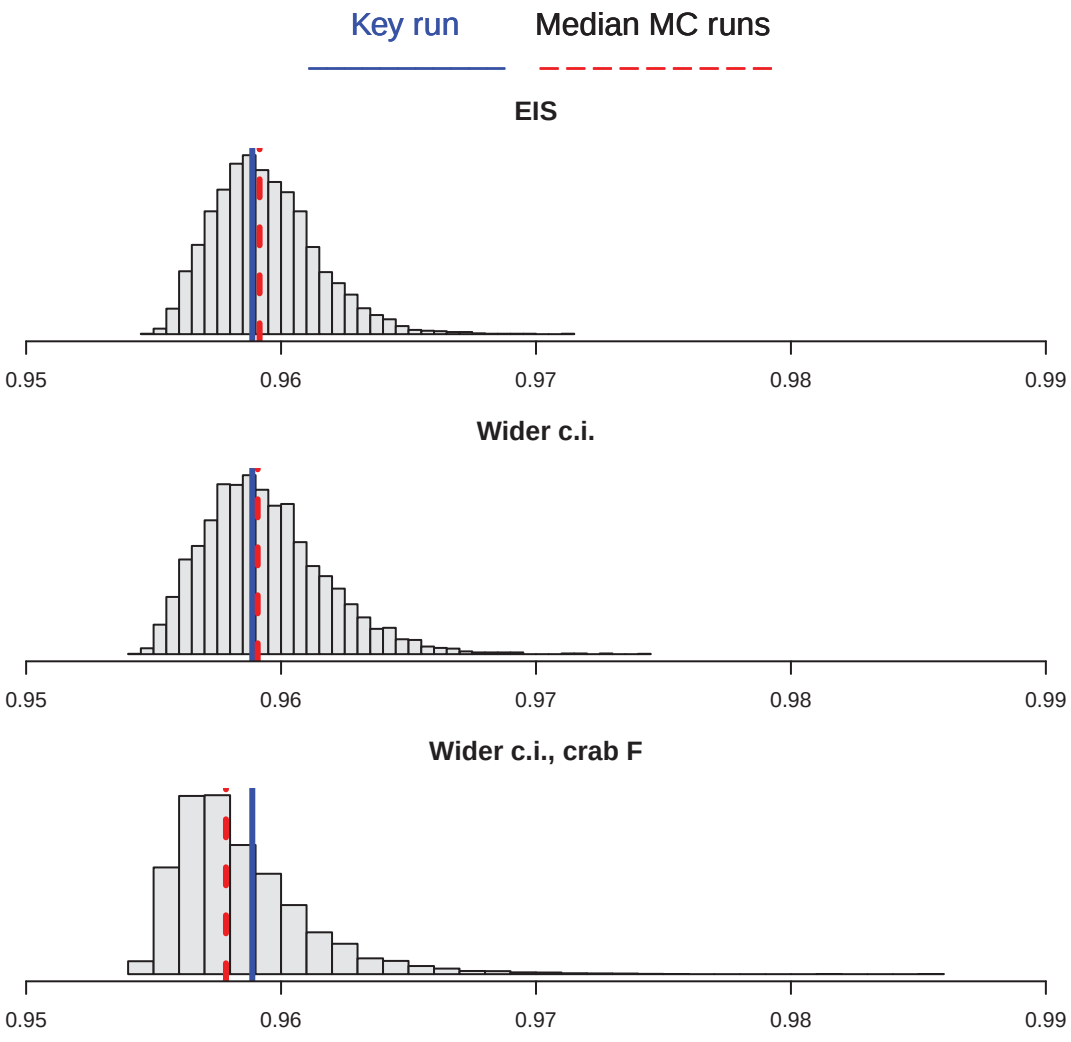
Biomass ratio (with/without project)

Rockfish



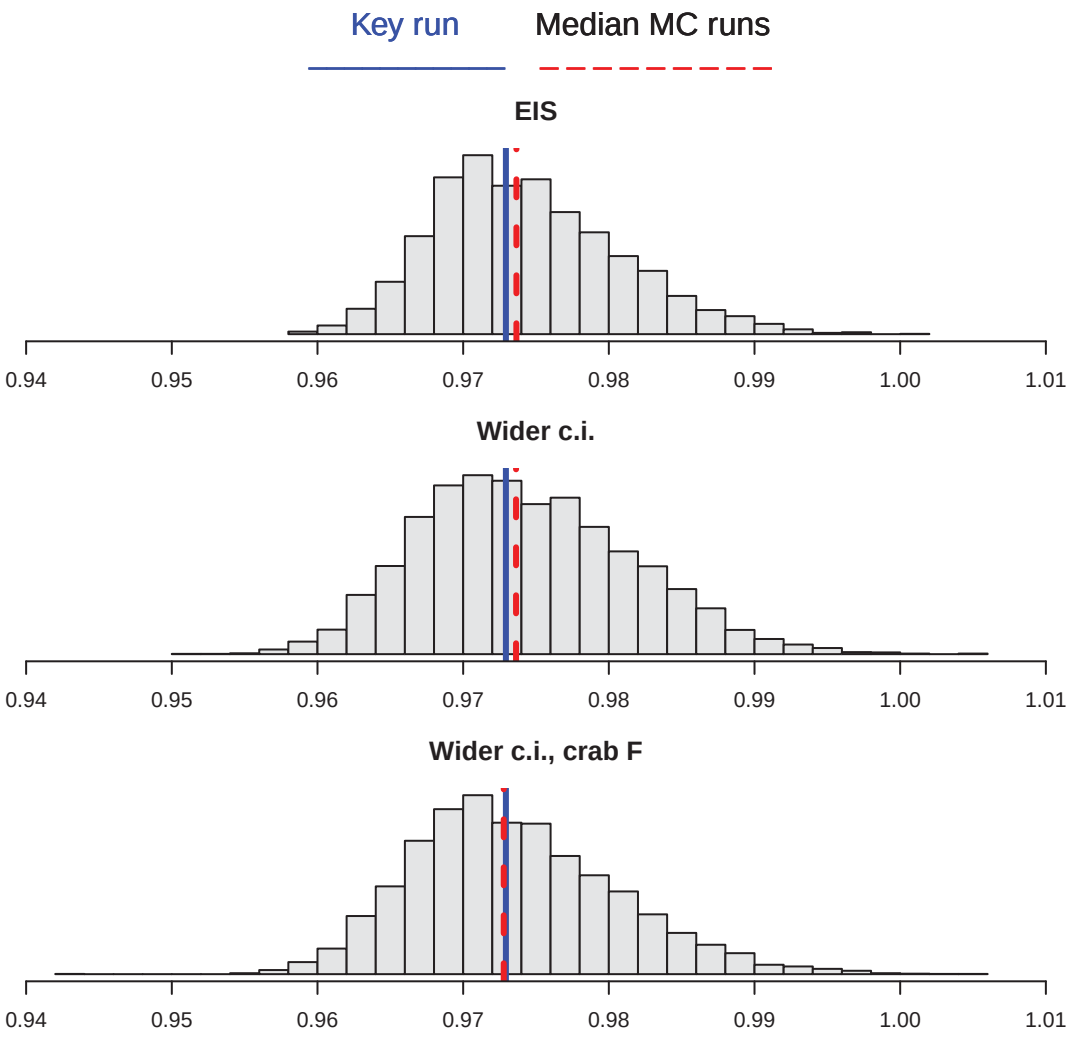
Biomass ratio (with/without project)

Salmon ad.



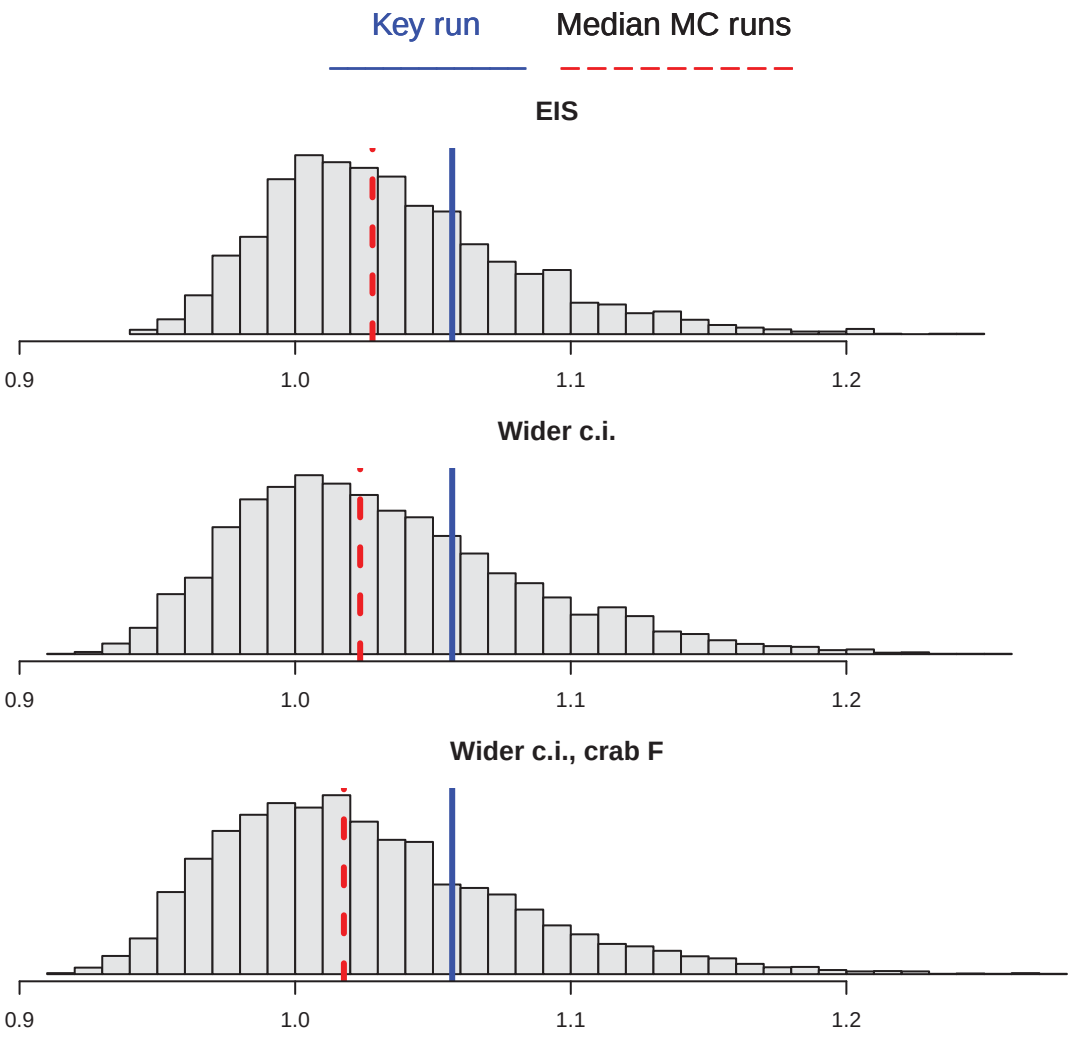
Biomass ratio (with/without project)

Salmon juv.



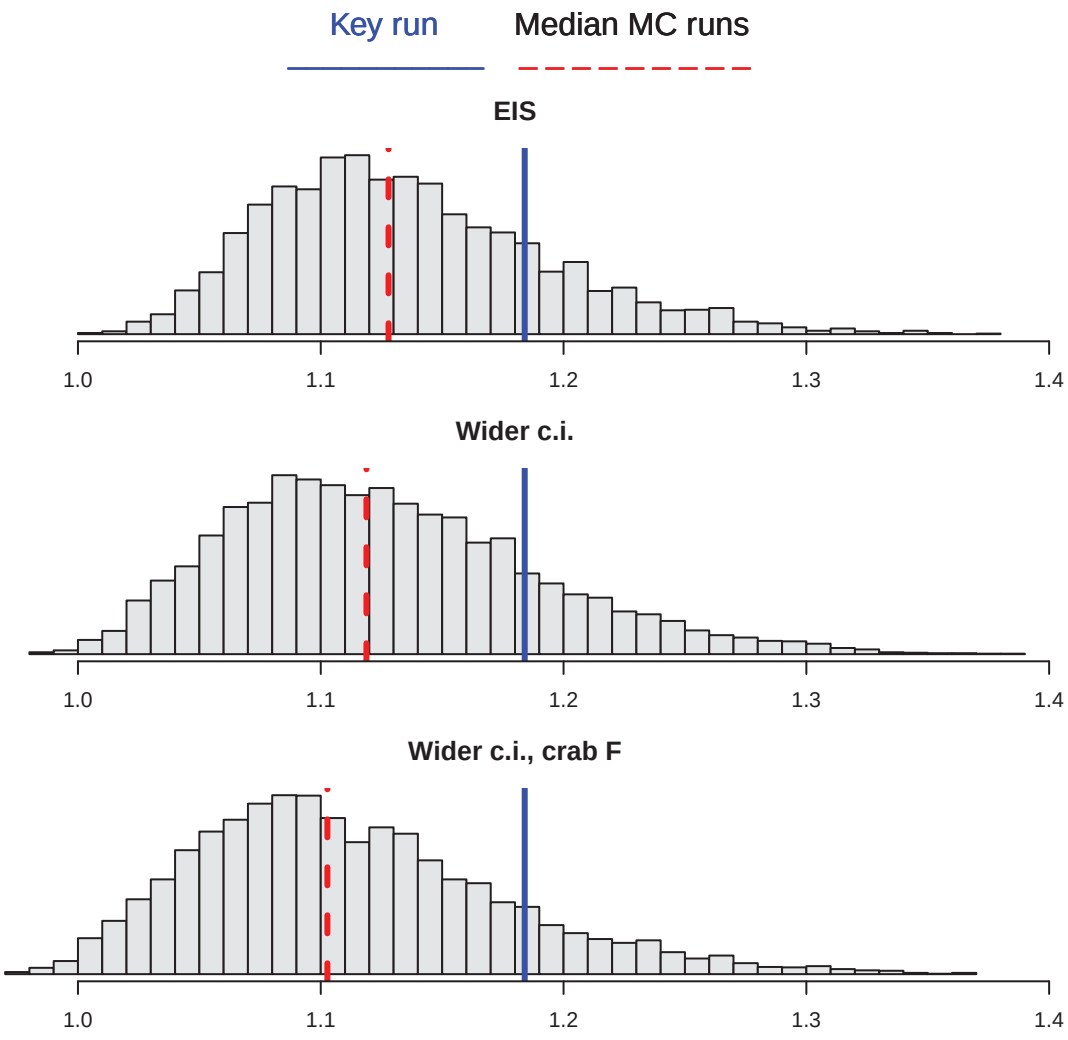
Biomass ratio (with/without project)

Sandlance



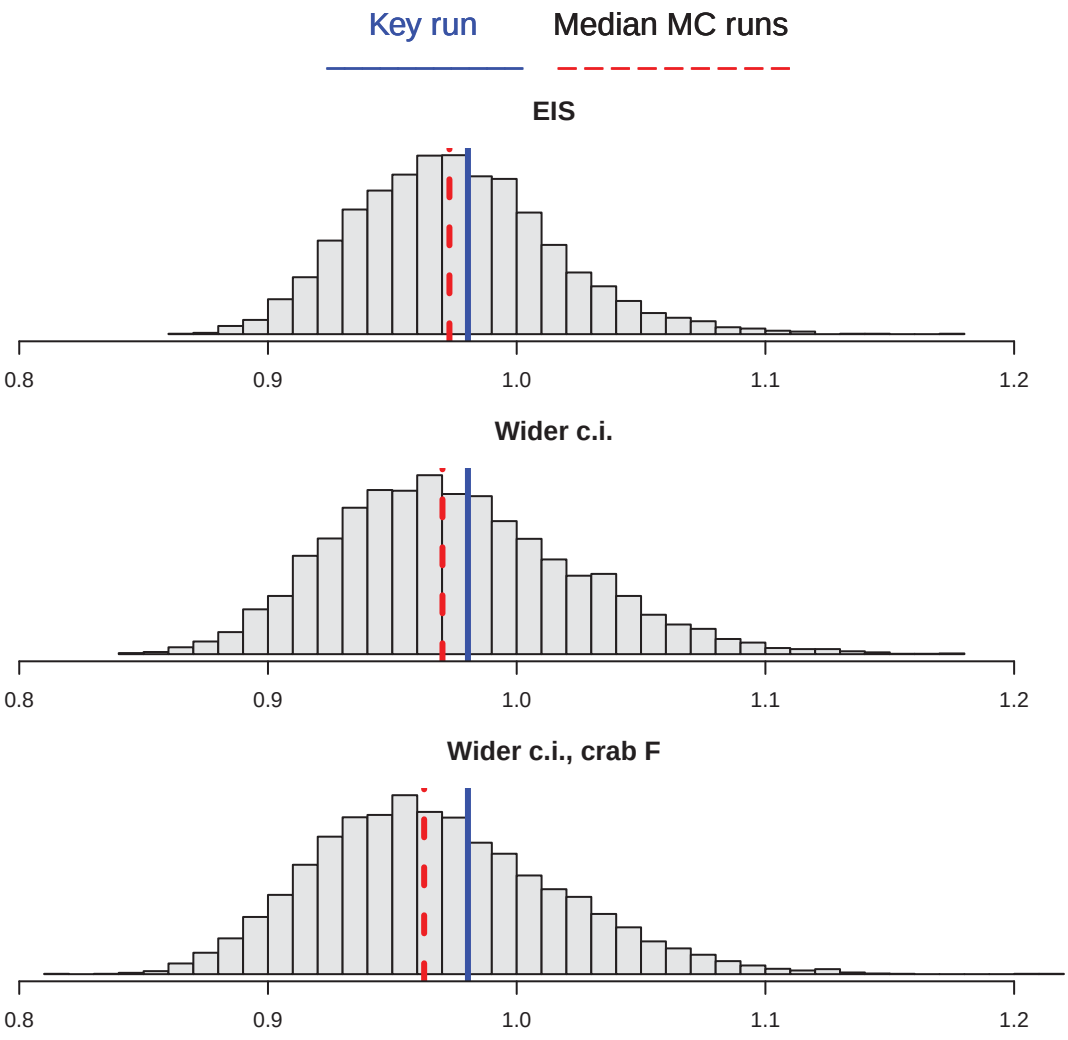
Biomass ratio (with/without project)

Shiner perch



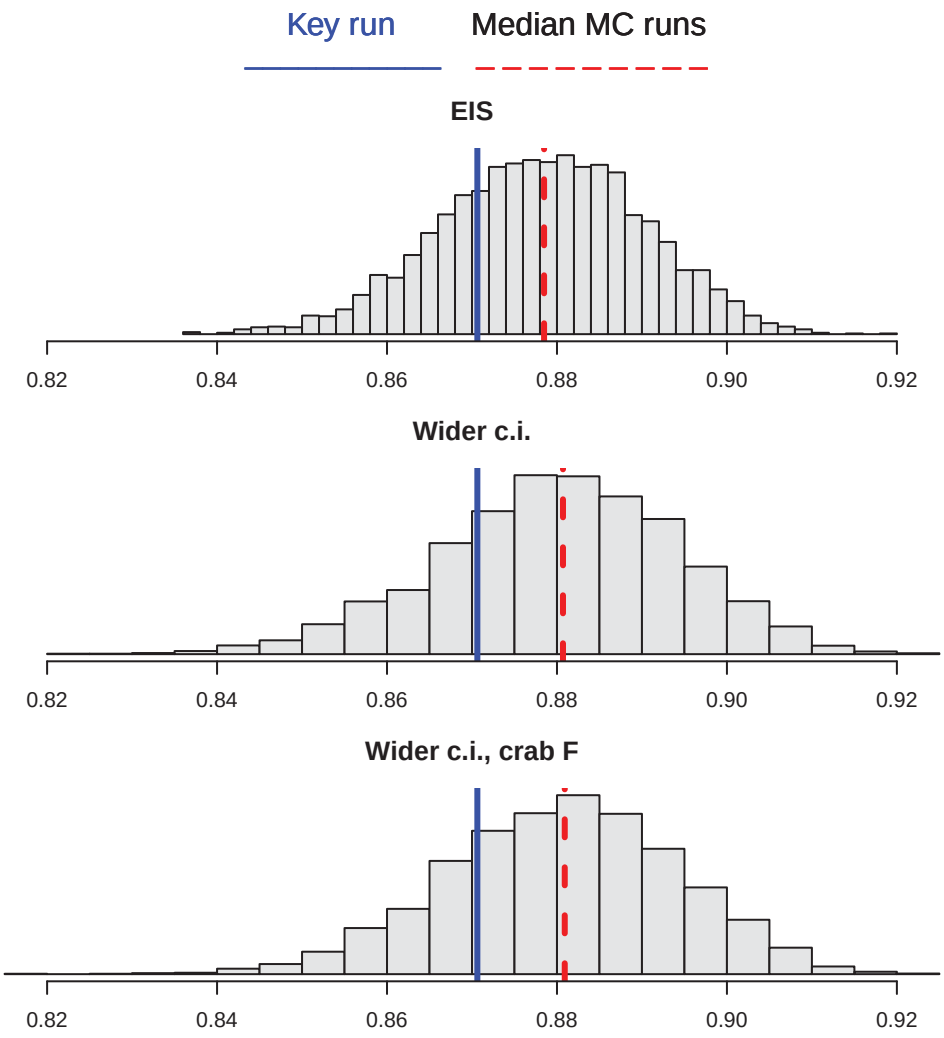
Biomass ratio (with/without project)

Shorebirds



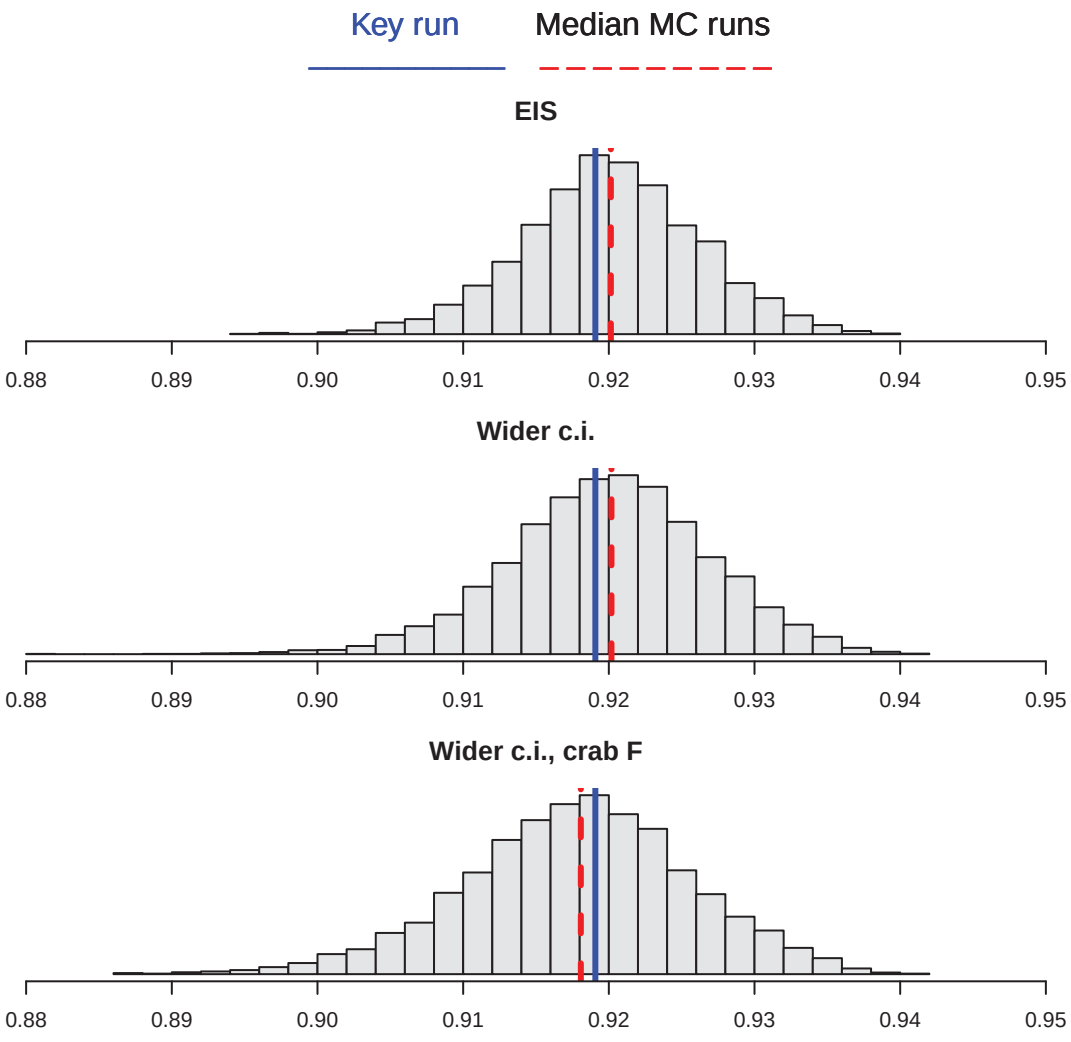
Biomass ratio (with/without project)

Shrimp



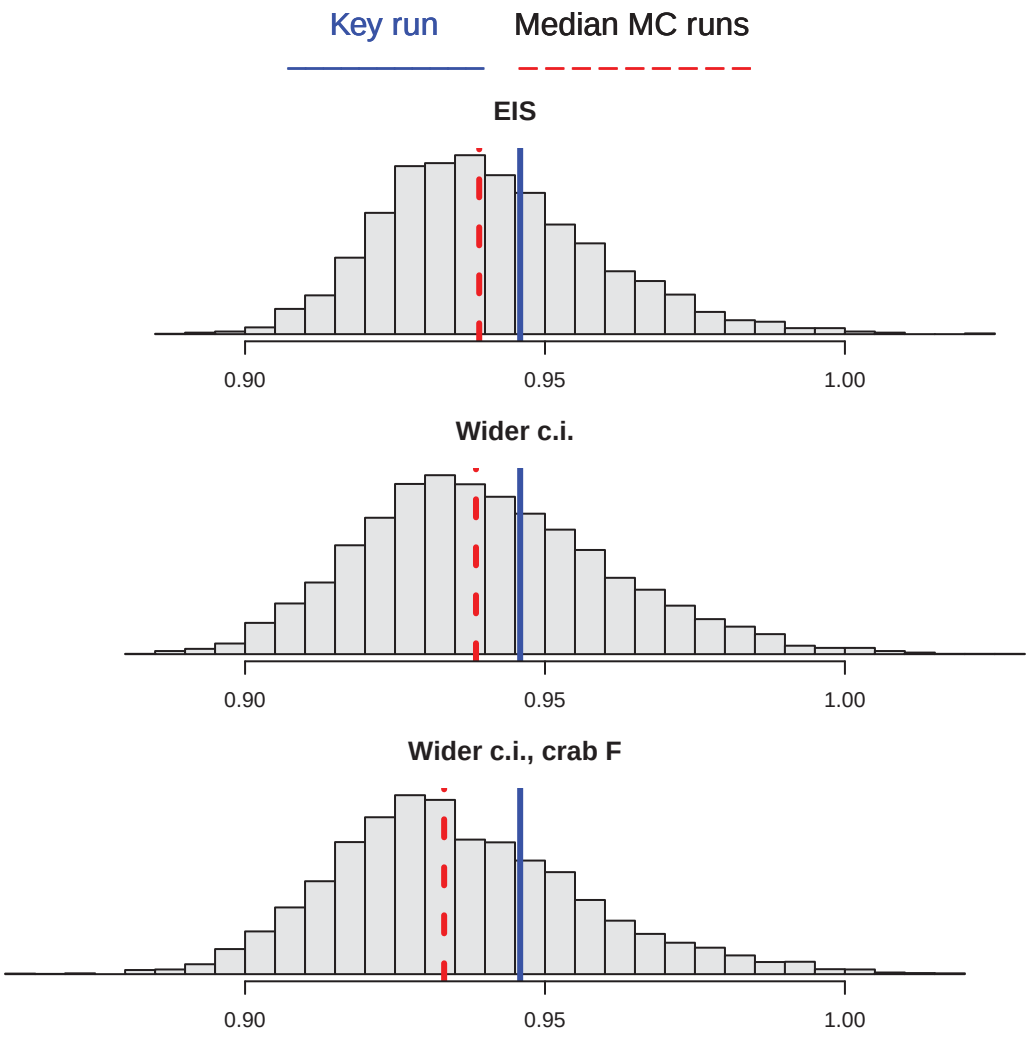
Biomass ratio (with/without project)

Skate



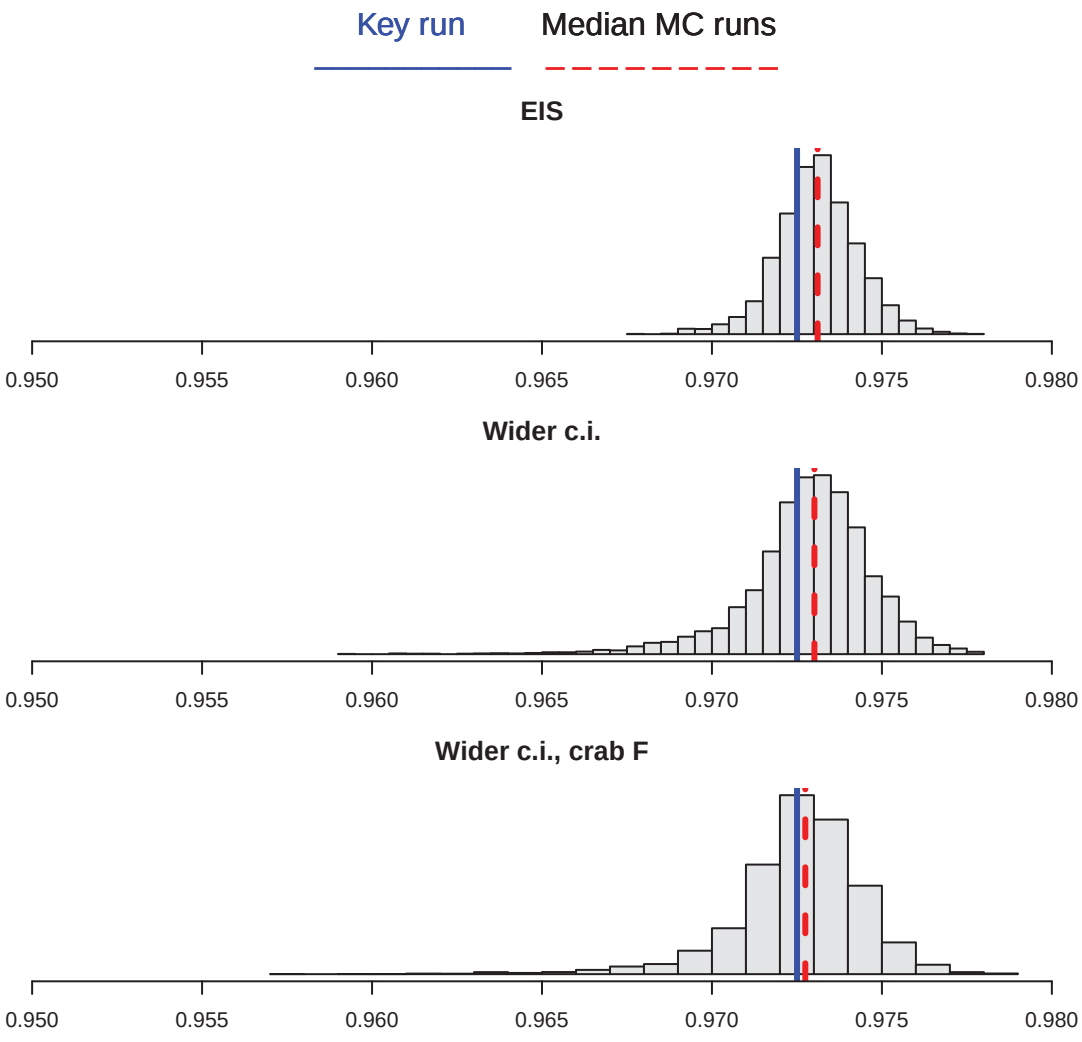
Biomass ratio (with/without project)

Small demersal fish



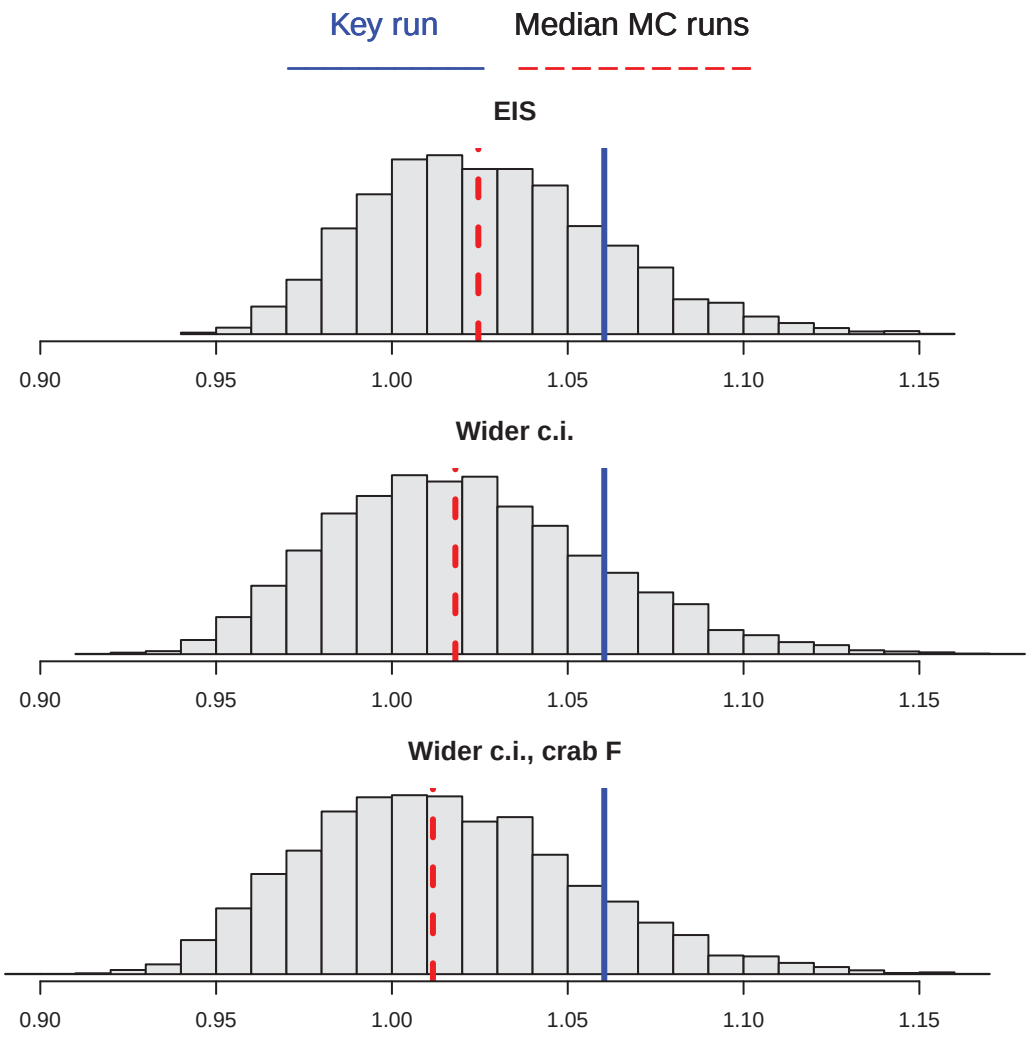
Biomass ratio (with/without project)

Southern resident killer whales



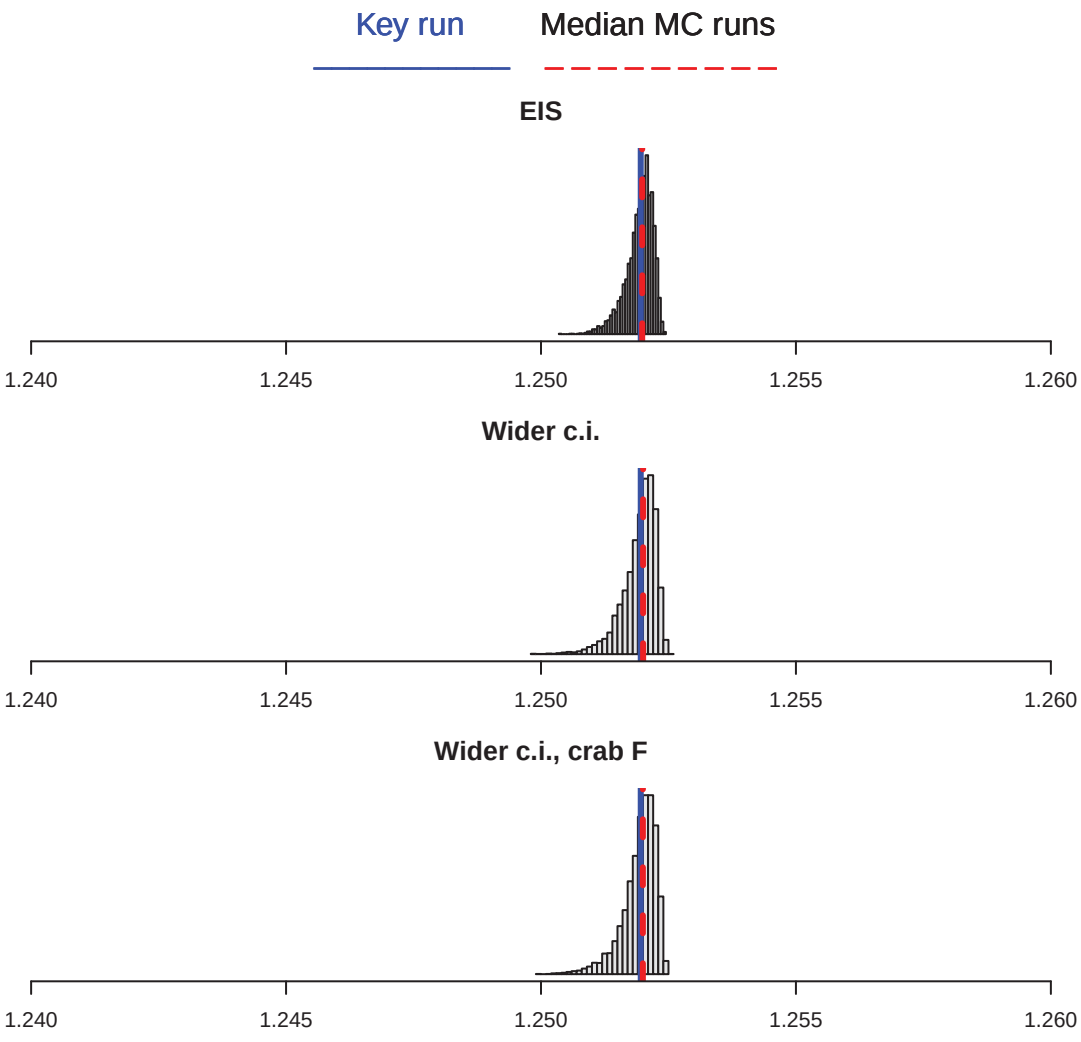
Biomass ratio (with/without project)

Starry flounder



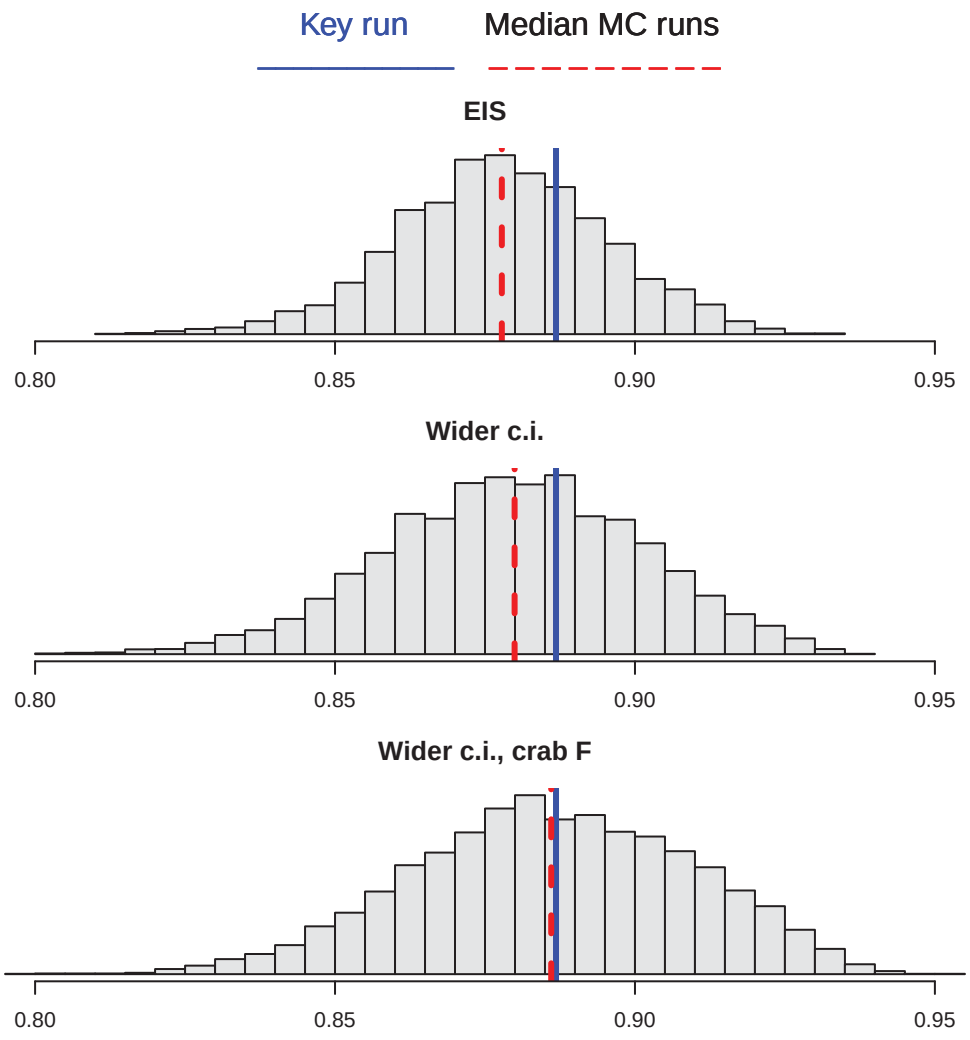
Biomass ratio (with/without project)

Tidal marsh



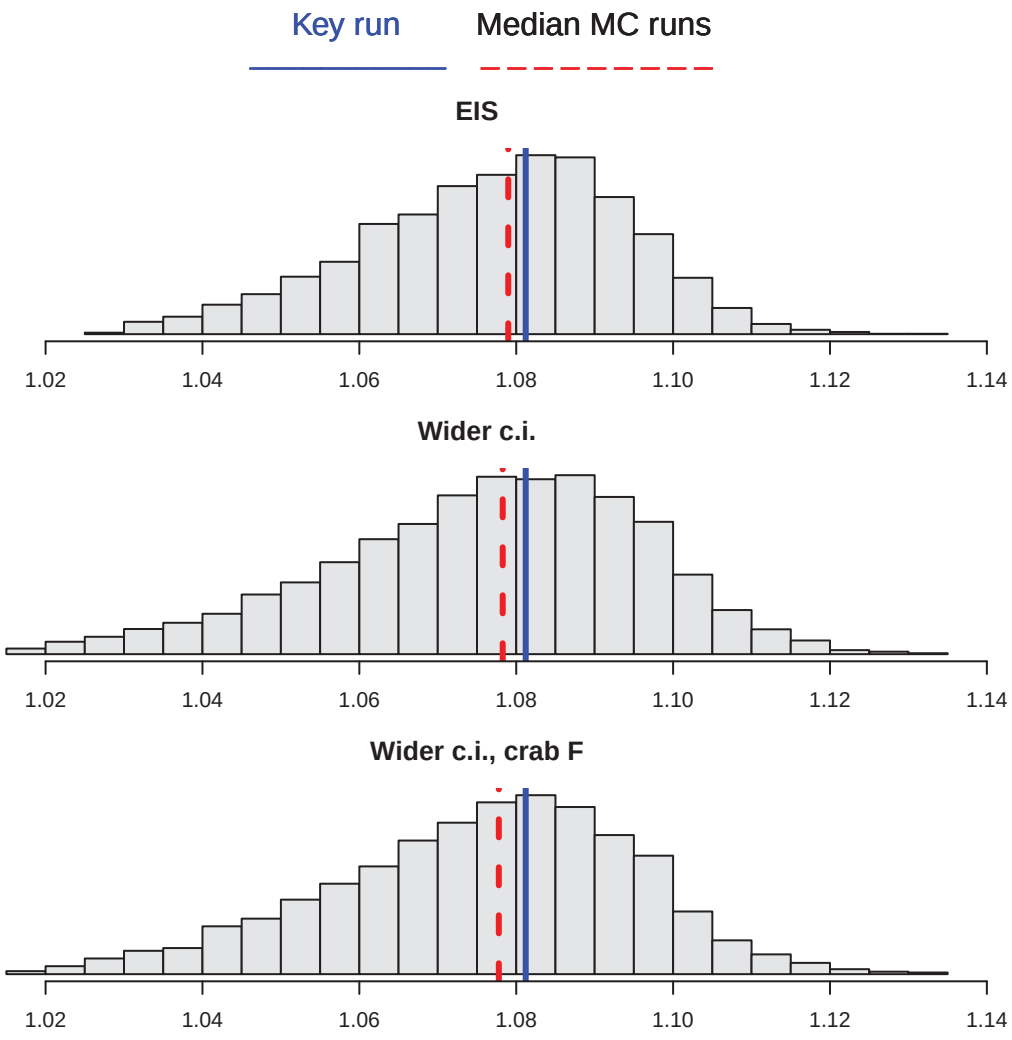
Biomass ratio (with/without project)

Transient killer whales



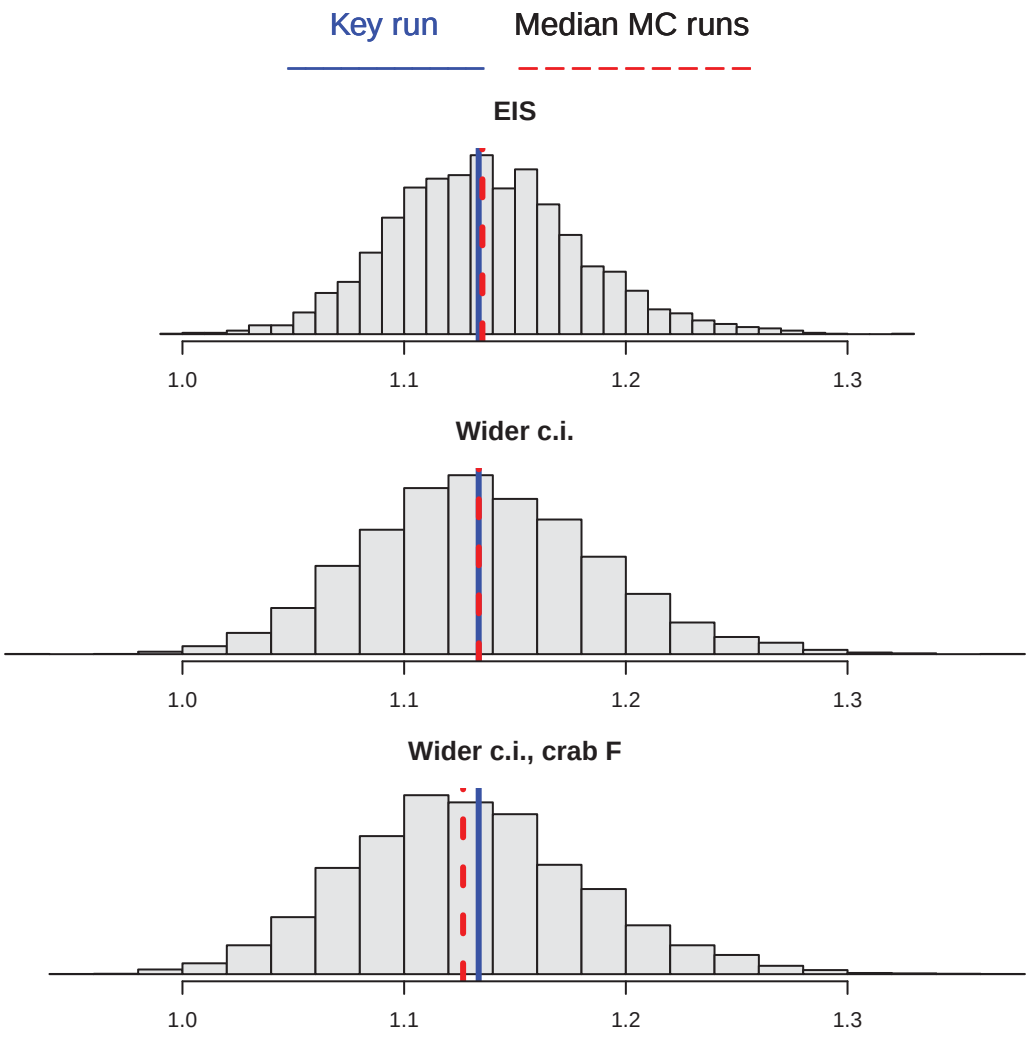
Biomass ratio (with/without project)

Waterfowl



Biomass ratio (with/without project)

Western sandpiper



Biomass ratio (with/without project)

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IR3-10 Roberts Bank Ecosystem Model – Mortality: Pathogens

Information Source(s)

EIS Volume 3: Appendix 10-C

Context

As mentioned earlier, two master equations, identified In Appendix 10-C, were used by the Proponent for parameterisation in Ecopath. The Proponent stated that Ecopath aimed to describe all mortality factors, hence what is termed as other mortality should only include minor factors such as mortality due to old age or diseases.

Fish, marine mammals, waterfowl, shorebirds and invertebrates in the regional assessment area serve as hosts for many pathogens, including nematodes, protozoans, bacteria, viruses, and crustaceans. A suite of environmental and ecological factors may affect the population-level impacts of disease.

Information Request

Identify pathogens that occur within functional groups evaluated by the RB EwE model and summarize any documented disease outbreaks that have occurred over the past 50 years.

Provide rationale for considering disease as a minor factor and evaluate the impact this could have on model predictions of including disease as an input to the Ecopath model.

VFPA Response

Identify pathogens that occur within functional groups evaluated by the RB EwE model and summarize any documented disease outbreaks that have occurred over the past 50 years.

There are numerous pathogens that can occur within the functional groups in the Roberts Bank ecosystem model (RB model), and some pathogens have been associated with disease outbreaks that can result in population-level effects (e.g., Hershberger et al. 2013, Hewson et al. 2014). The VFPA is not aware of and has not been able to locate any existing published summary of mass mortalities or disease outbreaks. There are intermittent published accounts of isolated events during the past 50 years. For example, a pathogen found in Chinook salmon, a protozoan *Ichthyophonus* spp., can cause systemic infections and mass fish die-offs (Hershberger et al. 2016, Bass et al. 2017). Similarly, a pathogen found in native eelgrass, the marine protist *Labyrinthula zosterae*, can cause death of plant tissue which has been associated with mass eelgrass wasting events (Groner et al. 2014).

Disease outbreaks in functional groups have not been recorded specifically from Roberts Bank; however, disease outbreaks have been recorded from outside the RB model study area,

including the Strait of Georgia. While the number of disease outbreaks that may have occurred is unknown, some occurrences have been recorded in publicly available literature. For example, mass mortality events occurred in Pacific herring in the Strait of Georgia from November 1998 to February 1999. Pacific herring were reported floating moribund or dead on the water surface caused by an outbreak of the viral haemorrhagic septicaemia virus (Traxler et al. 1999). Similarly, mass die-offs of sea stars have occurred along the B.C. coastline since June 2013 due to the sea star wasting disease. Sea star mass mortalities have been linked to a densovirus (Parvoviridae) that leads to rapid tissue degradation ('melting' or 'wasting') (Hewson et al. 2014, Montecino-Latorre et al. 2016).

Roberts Bank is an open system, with exchanges taking place over tidal cycles and through river inflow, and is characterised by the seasonal presence of and habitat use by migratory marine organisms. Pathogens are naturally occurring, ubiquitous in marine waters and sediments (Wilhelm and Suttle 1999). Moreover, many marine organisms that use habitats at Roberts Bank serve as hosts for pathogens. In an open system like Roberts Bank, pathogens disperse through circulation of ocean currents (e.g., Wilhelm and Suttle 1999, Hellberg et al. 2002, McCallum et al. 2003), and are introduced into the system from outside sources, such as freshwater input and tidal mixing (Wilhelm and Suttle 1999).

As demonstrated in Section 9.5 of the EIS, the Project is not anticipated to result in incremental cumulative changes to coastal geomorphology, including tidal mixing, and current circulation; therefore, the Project will not change pathogen dispersal through ocean circulation in the Roberts Bank area. Since RBT2 is not anticipated to affect the potential for disease outbreaks within the local assessment area, diseases are not considered an environmental effect that may result from the Project.

Therefore, the Project is not anticipated to disrupt existing pathogen dispersal mechanisms, and no increase in the risk of disease outbreaks is expected.

Provide rationale for considering disease as a minor factor and evaluate the impact this could have on model predictions of including disease as an input to the Ecopath model.

The rationale for considering disease as a minor factor is fivefold:

- The open nature of the Roberts Bank system and its exposure to pathogens via tidal currents and freshwater inputs (see above);
- The ubiquity of disease and pathogens throughout the Strait of Georgia (see above);
- The Project will not change rates or mechanism of disease transmission (see above), and no one has to date proposed any such mechanisms;
- The VFPA has received no prior input pertaining to pathogens and disease outbreaks at Roberts Bank by regulators, Aboriginal groups, scientific and technical experts of the Productive Capacity Technical Advisory Group (see Appendix IR3-A in the Preamble at the beginning of this response package), or during public consultations throughout the Project's environmental assessment process to date; and

- Disease exposure and dispersal is expected to be the same with and without the Project (and hence inclusion in the RB model would not change related Project effects to productivity).

For the above reasons, inclusion of disease as an input in the RB model would have no impact on RB model results or effects assessment conclusions.

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IR3-11 Roberts Bank Ecosystem Model – Substrate Selection

Information Source(s)

EIS Volume 3: Section 10.3, Appendix 10-B, Appendix 10-C, Appendix 10-D

Context

In Appendix 10-C, the Proponent, identified that the forecasted changes in productivity (measured in biomass and production) by the RB EwE model were based on abiotic outputs from the coastal geomorphology analysis and supplemented with maps of hard or soft substrate distributions, environmental conditions (bottom current, salinity, wave height, depth, and hard/soft bottom), with and without the proposed Project. It was also reported that since changes in sediment grain size distribution as a result of the Project were not assessed in the coastal geomorphology model, the RB EwE model was limited to only the use of a hard or soft bottom layer. Areas with gravel or larger materials were considered as hard substrate.

According to Fisheries and Oceans Canada, the restriction of the abiotic factors for, substrate in the RB EwE model, to hard or soft options, may not provide the sensitivity required to assess substrate preference for taxa such as motile organisms that span hard, mixed, and soft substrate types.

Information Request

Provide a rationale for limiting the RB EwE model substrate categories to only hard or soft.

Clarify whether changes in the hard/soft categories were considered over time by the RB EwE model within identified depositional or erosional settings before and after construction.

VFPA Response

Provide a rationale for limiting the RB EwE model substrate categories to only hard or soft.

To clarify, substrate categories were not 'limited' to only hard or soft; rather, they were deliberately chosen as binary to distinguish between solid rocky substrates such as rip-rap and boulders, and all soft substrates such as sands, muds, and silts (see Section 2.3 of EIS Appendix 10-C). Further, these categories were not used, or intended, to assess changes in sediment grain size distribution. The intention of this simplification is to constrain the model to account for groups that have obligate (or specific) substrate requirements, thereby improving the ecological realism and accuracy of habitat associations for those taxa that naturally associate with hard (i.e., rip-rap, boulders) or soft (i.e., sand, mud, silt) substrates (for a list of taxa, see Section 2.13 of EIS Appendix 10-C). For example, bull kelp (included in the RB model within the brown algae functional group) requires a hard substrate upon which to attach. If no attempt was made to distinguish between hard and soft substrates in

the RB model, given the combination of other environmental factors, changes in productivity of bull kelp (and in turn of brown algae) would likely be forecasted in soft sediment areas where bull kelp does not grow.

For those functional groups that occupy varying, or 'mixed', substrate types, preference curves were generated that reflect use of each of these substrates (see Section 2.13 of EIS Appendix 10-C). No preference functions were applied to functional groups that are not limited by substrate type (e.g., raptors) (see Section 2.12 of EIS Appendix 10-C).

Clarify whether changes in the hard/soft categories were considered over time by the RB EwE model within identified depositional or erosional settings before and after construction.

Changes in the hard/soft substrate categories were not evaluated before and after construction, because the RB model forecasted direct and indirect changes in productivity based on instantaneous placement of the terminal and causeway footprints (see EIS Appendix 10-C)[1], and was not intended to assess short-term effects associated with construction activities. The changes in the hard/soft categories are meant to reflect the conversion of existing soft substrate to hard substrate (i.e., rip-rap, caissons, and other structures) through the placement of Project infrastructure.

After the Project is built, substrate characteristics will not change from one state (e.g., hard substrate) to another (e.g., soft substrate) as a result of coastal geomorphic processes (i.e., within identified zones of deposition or erosion; see EIS Figure 9.5-35). These localised scour and depositional areas are included as 'soft substrate' before terminal and causeway placement and will continue to be 'soft substrate' after terminal and causeway placement. Similarly, the caissons, rip-rap, and pilings used in terminal and causeway construction will remain 'hard substrate' over time, and will not change to become 'soft'.

[1] This was because the RB model relied on outputs from the coastal geomorphology study which assessed the future changes to coastal geomorphology arising from the completed terminal and causeway footprint, and did not consider changes associated with incremental stages of the Project during the construction phase as acknowledged in question 2.2 of CEAR Document #547. The rationale for this is further explained in EIS Section 10.3.3, question 2.5 in CEAR Document #547, and IR2-16 (CEAR Document #930). Other lines of evidence (e.g., sediment dispersion modelling (EIS Appendix 9.6-C), studies conducted for Deltaport Third Berth environmental assessment, and literature) were used to address potential effects from construction phase activities.

IR3-12 Roberts Bank Ecosystem Model – Dungeness Crab

Information Source(s)

EIS Volume 3: Section 10.3, Appendix 10-B, Section 12

Context

The Proponent, in Appendix 10-B of the EIS, identified that the total adult biomass of Dungeness crab, including females, was estimated by doubling the biomass of fished males, then increased by five percent to account for males not caught, and finally doubled to include an estimate for adult females. This resulted in an adult Dungeness crab biomass estimate of 4.631 t/km^2 for the Roberts Bank ecosystem study.

According to Fisheries and Oceans Canada, it is unclear why these assumptions were made and the implications of the assumptions were not adequately described. In addition, it is unclear if the slower growth of female crabs once they have reached sexual maturity in comparison with male crabs was considered in the parameterisation process.

Justification for estimating total Dungeness crab adult biomass (including females) from the biomass of fished male Dungeness crab is required.

Information Request

For Dungeness crab, provide justification for estimating total adult biomass (including females) from the biomass of fished males and confirm whether the slower growth of female crabs once they have reached sexual maturity, in comparison with male crabs, was considered in the adult Dungeness crab biomass estimate. If the slower growth rate of females was not considered, describe the likely implications of this exclusion to the estimates of total adult biomass.

VFPA Clarification

EIS Appendix 10-B: Section 5.5, page 90 incorrectly states that "the total adult biomass of Dungeness crab, including females, was estimated by doubling the biomass of fished males, then increased by five percent to account for males not caught, and finally doubled to include an estimate for adult females". To clarify, the male biomass was doubled only once to account for females, as a 50:50 sex ratio was assumed.

EIS Appendix 10-B: Section 5.5, page 90 should read: "the total adult biomass of Dungeness crab, including females, was estimated by starting with the mean biomass of legal-size males

(an output of the Dungeness crab productivity model[1], TDR MI-4), then increasing this by five percent to account for males not caught[2], and finally doubling it to include an estimate for adult females."

VFPA Response

For Dungeness crab, provide justification for estimating total adult biomass (including females) from the biomass of fished males.

Dungeness crab population and biomass data for males and females are not available as commercial Dungeness crab fisheries in B.C. do not rely on estimates of abundance for management and do not record such data. Instead, available data on Dungeness crabs relates to landings from commercial fisheries (modelled into biomass and production estimates in the Dungeness Crab productivity model, see footnote 1), and is specific only to males given licences for this fishery are for males only. Therefore, assumptions are required to estimate information on female crabs, from data that is specific only to males. Since no published or unpublished data on sex ratios of Fraser River estuary Dungeness crab populations exist, it was assumed to be 50:50 (an assumption that aligns with sex ratios reported in the literature (e.g., Rasmuson 2013), though is not specific to Roberts Bank). Accordingly, the biomass estimate for male crabs was doubled to account for female crabs.

Confirm whether the slower growth of female crabs once they have reached sexual maturity, in comparison with male crabs, was considered in the adult Dungeness crab biomass estimate. If the slower growth rate of females was not considered, describe the likely implications of this exclusion to the estimates of total adult biomass.

The slower growth of female crabs once they have reached sexual maturity was not considered in the adult Dungeness crab biomass estimate because available data only allowed for estimation of male biomass.

The likely implication of excluding the slower growth rates of female crabs is a slight overestimation of female crab biomass in the Roberts Bank ecosystem model (RB model); however, even if female Dungeness crab biomass was initially overestimated, the RB model

[1] The biomass input into the Roberts Bank ecosystem model (RB model) comes from the Dungeness crab productivity model (see TDR MI-4 in Additional Information Request #10 (AIR-12.04.15-10), Appendix AIR10-C, submitted to registry and posted as CEAR Document #388), which employed size-structured Bayesian methods (which are standard for invertebrate fishery stock assessments) to generate rigorous quantitative estimates of Dungeness crab population parameters, where none previously existed. The model uses a combination of fishery-dependent and fishery-independent data collected by DFO to estimate the levels of biomass and production needed to support the observed crab catch and size-composition over the past two decades. The Dungeness crab productivity model was well suited to provide biomass input parameters into the RB model because i) data are local and site-specific to Roberts Bank and the Fraser River estuary (i.e., Area 29 and Subareas 29-6 and 29-7); ii) the biomass estimates used long time series of both harvest data and fisheries-independent data, providing reliable outputs that were not biased by changes in fishing patterns; and iii) Bayesian methods provide more accurate estimates of population parameters because of the ability to include prior biological knowledge.

[2] This assumption was based on Zhang et al. (2002), who reported "the fishery is intensive with exploitation rates well over 90% in the Fraser Delta".

would still be considered biologically realistic and robust because the model estimates relative changes in productivity with and without the Project and implications of input uncertainty in biomass numbers were tested through rigorous sensitivity analyses.

Initial sensitivity analysis on adult crab biomass used in the RB model was undertaken in which input biomass was varied up to 20% to account for potential sources of uncertainty in input data (see EIS Appendix 10-D). Results of the sensitivity analysis show that potential changes in productivity with and without the Project are small and insensitive to changes in input biomass estimates. Additionally, initial Monte Carlo simulations were run where inputs were drawn randomly from distributions that reflected their uncertainty (using 30% confidence limits, see EIS Appendix 10-D). Further, in response to questions from DFO during the EIS completeness phase, a pedigree performance analysis was undertaken, which involved conducting a new series of Monte Carlo runs in which the pedigree classification for each functional group was reduced by one pedigree category, thereby increasing the confidence interval for Dungeness crabs from 30% to 50% (see question 2.7 and appendix 2.7B, CEAR Document #547). Results showed very little change compared to the key run results presented in the EIS (Appendix 10-D: Section 3.4), providing increased confidence that the forecasted Project impact for Dungeness crab was robust to uncertainty about input crab biomass.

Collectively, results demonstrate that changes to input parameters do not materially influence the with and without Project related change forecasts; the influence of the Project is consistent, even with a greater range of input values, demonstrating the model's robustness. This means that even if female crab biomass was initially overestimated by not accounting for slower female growth rates post sexual maturity, the ratio between with/without Project conditions will not change. Therefore, when considered in the context of model objectives (i.e., to quantify productivity change as a result of the Project footprint), there are no material implications of this potential exclusion to the estimates of total adult biomass.

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IR3-13 Roberts Bank Ecosystem Model – Spatial Boundaries

Information Source(s)

EIS Volume 3: Section 13.6.3, Appendix 10-C

TDR MF-3 Juvenile Salmon Surveys

Context

The Proponent, in Appendix 10-C, identified that annual averages for seasonally varying abiotic parameters (salinity, bottom current, and wave height) were used in the RB EwE model. It was also identified that, although it was possible to evaluate the impact of seasonally varying environmental drivers, the main reason for the use of annual averages for the environmental drivers rather than seasonal values was because it would require information about seasonal variation in production for the functional groups, and the sampling scheme for the study area was not designed to consider this.

The RB EwE model was run with an annual time step, with all sub-annual values being averaged to annual values. This method did not incorporate important seasonal processes such as winter-summer differences in salinity and storm properties, and the seasonal appearances of abundances of predators and prey - such as migratory salmon and birds - that are much larger than the annual average.

Some functional groups are present in the RB EwE model study area for restricted periods and/or have restricted spatial distributions throughout the year. As reported in the Proponent's Technical Data Report TDR MF-3 Juvenile Salmon Surveys, for example, juvenile Chinook and chum salmon annually occur within the study area for a period of weeks and concentrate in intertidal and shallow sub-tidal 'shore-tied' habitats along Roberts Bank.

Information Request

Explain how the RB EwE model predicted changes in biomass, with and without the Project, for functional groups that have restricted distributions, both seasonally and spatially, within the RB EwE model study area.

VFPA Response

The context to this request states that "the RB EwE model was run with an annual time step". The VFPA would like to clarify that, while input rates were annual, the model was run with monthly time steps, though seasonality within the year was not included.

Annual averages are a standard metric for ecological questions and are necessary when conducting an ecosystem level assessment (Harvey 2013; Preikshot 2013; Mackinson and Daskalov 2008). All Ecopath with Ecosim and Ecospace (EwE) models developed to date are annualised, and represent an ecologically valid approach to forecasting changes in

productivity with and without the Project. The Roberts Bank ecosystem model (RB model) was developed to include the representative components that best describe the Roberts Bank ecosystem from available data. Seasonal data for all parameter inputs (e.g., biomass, consumption, diet, environmental preferences, environmental conditions) do not exist such that the creation of a seasonal ecosystem model was neither feasible nor scientifically defensible.

The following response explains how the RB model forecasts changes in biomass, with and without the Project, first for functional groups that have restricted seasonal distributions, and second for functional groups that have restricted spatial distributions in the RB model study area. In addition, this response describes how a multiple lines of evidence approach provides additional confidence that assessment conclusions are valid.

Seasonal

The model forecasted changes in biomass, with and without the Project, for functional groups that have restricted seasonal distributions in the Roberts Bank study area by normalising seasonal input parameters to create annual averages[1]. For an example of how this was accomplished in the RB model, please refer to question 2.17 of CEAR Document #547 (where many years of high quality, Roberts Bank specific data on western sandpiper were averaged annually for use in the RB model). This approach ensures populations that exhibit large daily or seasonal fluctuations, or that have large-scale ranges relative to the study area, are proportionally accounted for in the RB model relative to their residency period. This issue is also discussed in IR3-05.

For highly seasonal groups, such as juvenile salmon, biomass estimates (for use in the RB model) are put in context of their short, but potentially intense, use of the study area. For example, empirical data from juvenile salmon surveys conducted seasonally during 2012 and 2013 were used to generate biomass estimates by multiplying abundance with mean body weight of fish measured in the field. All body weight measurements were corrected for the sampled area per survey type and sampling event, generating a biomass estimate (in tonnes per square kilometre (t/km^2)) specific to each sampling event (i.e., generating a seasonal biomass estimate); for juvenile Chinook, average seasonal biomass estimates were 0.016 t/km^2 for spring, 0.032 t/km^2 for summer, and 0.0 t/km^2 for fall. Annual average biomass reflects the sum of seasonal average biomass, as well as a correction for habitat use, explained in the "spatial" subsection below; for juvenile Chinook, the annual average biomass estimate was 0.012 t/km^2 (see TDR MF-3 in Appendix AIR10-C of Additional Information

[1] The use of annual averages is an ecologically valid approach to forecasting annual changes in productivity with and without the Project because they have been identified as a standard metric for ecological questions and considered necessary when conducting an ecosystem level assessment (Harvey et al. 2012; Preikshot et al. 2012; Mackinson and Daskalov 2007).

Request #10 (AIR-12.04.15-10) in CEAR Document #388[2] and EIS Appendix 10-B for additional details on average biomass estimates and how they were calculated).

Spatial

The model forecasted biomass changes, with and without the Project, for functional groups that have restricted spatial distributions using environmental preferences. The Ecospace module used a spatially explicit habitat capacity model (a combination of habitat suitability and food web conditions) to evaluate overall change to productivity on a cell by cell basis within the study area grid.

The RB model accounts for species distribution by annual averaging of environmental preferences for the abiotic parameters of current velocity, wave height, salinity, depth, and hard/soft substrate; see question 2.11 in CEAR Document #547 for a detailed explanation of how environmental preferences were derived and applied. Estimates of biomass for each functional group reflect the biomass of the group in the whole model area, not just the part of the ecosystem that they occupy; thus, for species that only occupy part of the area, the biomass was pro-rated by area (Heymans et al. 2015).

For example, juvenile salmon biomass estimates come from beach and purse seine surveys conducted seasonally from spring 2012 through summer 2013. Abundance and biomass data recorded during each survey were weighted to the proportion of habitat types sampled at each survey location (e.g., location EG1 was mapped as 75% eelgrass and 25% bare sand), and extrapolated across the entire model study area, thereby generating a habitat-corrected biomass estimate per season (see EIS Appendix 10-B for further details).

Multiple Lines of Evidence

The assessment of potential effects of the Project on biophysical valued components considered the RB model forecasts as one line of evidence in an approach that involved multiple lines of evidence. Conclusions on significance of residual effects from the Project on migratory or highly mobile species with restricted seasonal and/or spatial distributions also weighed information from field studies, other models, literature, information from other Projects, information on mitigation measures, and the productivity increases from proposed onsite habitat offsetting (see respective EIS marine biophysical valued component sections—EIS Sections 12.0, 13.0, and 15.0).

For example, western sandpipers are migratory, present in the Roberts Bank study area for two brief stopover periods in the spring and summer, corresponding to their northward and southward migrations. Eleven models (including the RB model)[3] were used to analyse the

[2] CEAR Document #388 From Port Metro Vancouver to the Canadian Environmental Assessment Agency re: Completeness Review - Responses to Additional Information Requirements Follow-Up (See Reference Document #345) including 22 Technical Data Reports.

[3] These models include 1) RB model, 2) Northward Migration Biofilm Foraging Opportunity, 3) Southward Migration Biofilm Foraging Opportunity, 4) Northward Migration Biofilm Capacity 1 Model, 5) Southward Migration Biofilm Capacity 2 Model, 6) Northward Migration Meiofauna Foraging Opportunity, 7) Southward Migration Meiofauna Foraging Opportunity, 8) Northward Migration Meiofauna Capacity

potential effects of the Project on western sandpiper spatial distribution, their food sources (i.e., biofilm and small invertebrates), and the capacity of the area to support sandpiper populations during the specific migratory windows in which they are present at Roberts Bank. These other lines of evidence provide increased resolution on important seasonal processes such as the influence of the annual Fraser River freshet on food abundance and availability, the effect of predators on habitat usage, and seasonal peaks in shorebird abundance that are much larger than the annual average (see Technical Report Shorebird Foraging Opportunity during Migration (SFOM; EIS Appendix 15-B) for details on these other models). While results are not directly comparable, SFOM and RB model forecasts appear to align, both indicating that western sandpiper productivity will not be affected by the Project and that capacity of both biofilm and invertebrate food sources will be sufficient to support migratory populations under with-Project conditions.

In the case of juvenile salmon, information from the RB model was also supplemented through multiple lines of evidence, with including literature, information from previous environmental assessments in the region (e.g., Deltaport Third Berth), and site-specific field studies.

Additionally, mitigation and offsetting were designed to capture restrictions in the seasonal and spatial distributions of juvenile salmonids. For example, sensitive timing windows are proposed during construction as an avoidance measure to protect juvenile Pacific salmon during their estuarine residence (i.e., from March 1 to August 15) in the shallow waters in which they rear (i.e., above –5.0 m chart datum). Onsite habitat offsetting considers the spatial distributions and habitat preferences of juvenile salmonids, where eelgrass and intertidal marsh creation are proposed to provide additional rearing habitat.

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IR3-14 Roberts Bank Ecosystem Model – Dispersal Rate

Information Source(s)

EIS Volume 3: Section 10.3, Appendix 10-C

CEAR Doc #547

Context

The Proponent's approach for Ecospace was to impose a low (and conservative) dispersal rate among model spatial units (pixels) of 1 km/yr to forecast the RB EwE model productivity. The Proponent identified that the approach taken was to not consider the spill-over effects between cells. In CEAR Doc #547, the Proponent also identified that the use of higher dispersal rates would reduce adverse impact predictions by the RB EwE model since species can move rapidly away from less desirable areas.

According to Fisheries and Oceans Canada, the approach taken to impose a low dispersal rate may be appropriate for low mobility benthic organisms but it likely underestimates the movements of many mobile functional groups. The effects of using higher and functional-group-specific dispersal rates was not considered in the assessment.

Several highly mobile functional groups included in the RB EwE model such as Baleen whales, salmon and migratory birds, utilize the Roberts Bank study area.

The EwE model must be rerun using higher and functional group-specific dispersal rates between cells to more accurately reflect the mobility of certain groups.

Information Request

Complete and evaluate model runs using functional-group-specific dispersal rates.

Present the information using the same format as Tables 3.2 and 3.3 in Appendix 10-C of the EIS and explain the effects of using functional-group-specific dispersal rates.

VFPA Response

The context for this information request states "effects of using higher and functional-group-specific dispersal rates[1] was not considered in the assessment". To clarify, and as indicated in the VFPA's response to question 2.3 in CEAR Document #547, the Roberts Bank ecosystem model (RB model) included both high and low dispersal rates. For most functional groups, the

[1] In this response, 'dispersal rate' refers to Ecospace's 'base dispersal rate' (expressed in km/year), which is one of several Ecospace parameters that regulate spatial distribution of species and groups (Christensen et al. 2005).

RB model applied a low dispersal rate (equal to 1 kilometre per year (km/year)); additionally, highly mobile functional groups were assigned higher dispersal rates[2] (as discussed in CEAR Document #547, specifically lines 633 and 634). For a discussion on rationale for dispersal rates used in the EIS, see CEAR Document #547, question 2.3. Tables 3.2 and 3.3 in EIS Appendix 10-C (respectively, biomass and production of functional groups with and without the Project) reflect the incorporation of these varied dispersal rates.

Notwithstanding the above clarification, and in response to this request, the RB model was re-run using functional group specific dispersal rates. Dispersal rates were calculated for each functional group based on methodology described below, resulting in dispersal rates varying by functional group (shown in **Tables IR3-14-1** and **IR3-14-2**). This model re-run is henceforth referred to as the dispersal run, and outputs of the dispersal run provided below constitute new information not previously presented in the EIS. In general, functional group specific dispersal rates were higher than dispersal rates used in the EIS (except for the dispersal rate of phytoplankton that changed from 10,000 km/year to 300 km/year to maintain consistency among all primary producer functional groups). The use of high dispersal rates tends to underestimate productivity losses with the Project and therefore is considered less conservative. For a discussion on rationale on dispersal rates used in the EIS and implications on RB model forecasts, see CEAR Document #547, question 2.3.

Methods

All functional groups (not just highly mobile groups) were assigned a functional group specific dispersal rate (greater than the 1 km/year used in the EIS), to account for differences in the rate species/groups of the Roberts Bank ecosystem would disperse as a result of random movement.

Dispersal rates were estimated based on the following approach.

Highly mobile and migratory pelagic and benthic groups: Dispersal rates for this group category were estimated by multiplying average body length for each group (in centimetres; extracted from Kozloff 1996, Reeves et al. 2002, Froese and Pauly 2017) by 100 km/year/cm (Christensen et al. 2005). This method was applied to all marine mammal and fish functional groups, and four invertebrate groups (i.e., Dungeness crab, epifaunal grazers, epifaunal omnivore, shrimp).

Highly mobile bird groups: Dispersal rate for this group category was set to 6,000 km/year, based on and rounded up from a dispersal rate for seabirds of 5,761 km/year published by Alexander et al. (2016). The dispersal rate was considered the same across all bird groups in the RB model, on the premise that dispersal rates are consistent among bird groups that use

[2] Highly mobile functional groups with high dispersal rates in the RB model included baleen whales (100 km/year), pinnipeds (1,000 km/year), transient killer whales (100 km/year), forage fish (1,000 km/year), salmon (adult and juvenile; 1,000 km/year), and phytoplankton (10,000 km/year). These dispersal rates used in the EIS for highly mobile functional groups are presented in this response for the first time.

flight regardless of differing flight styles (Spear 1997). This dispersal rate is also indicative of the distance birds travel in a given year during north- and southward migration.

Low mobile benthic groups: The dispersal rate for this group category was set to 10 km/year, based on a dispersal rate for infaunal organisms published by Alexander et al. (2016). This method was applied to six invertebrate groups and detritus. Generally, the dispersal rate for low mobile benthic groups (e.g., orange sea pens, epifaunal sessile organisms) is a function of the near static movement of adults combined with passive movement of individuals through tidal and current flows. As these groups spend most of their time attached or buried in sediment, a low dispersal rate is reasonable.

Pelagic passively dispersed groups: The dispersal rate for this group category was set to 300 km/year, extracted from Alexander et al. (2016), on the premise that these groups (or life stages) are passively dispersed by tide and current driven water movement. This method was applied to three invertebrate groups (i.e., carnivorous zooplankton, jellyfish, omnivorous and herbivorous zooplankton) and all primary producers.

Results

In general, the application of higher rates of dispersal (compared to those used in the EIS) results in less variation in biomass ratios across functional groups (**Figure IR3-14-1**). There is a smaller range of forecasted losses in productivity, as well as a smaller range of forecasted increases in productivity related to terminal and causeway footprints. Higher dispersal rates allow species/groups to move between cells in the RB model when conditions within the cell become less favourable. As a result, the RB model forecasts lower decreases in biomass and production due to terminal and causeway footprints. Hence, the approach taken in the EIS is conservative, in that it overestimates potential Project footprint productivity losses. Details are provided below.

Results from the dispersal run for each functional group are included in **Tables IR3-14-1** and **IR3-14-2**. Specifically, **Table IR3-14-1** presents new biomass estimates (in tonnes (t)) without and with the Project, new biomass difference (with-without Project, in t), and a new biomass ratio (with/without Project), using the functional group specific dispersal rates. **Table IR3-14-2** presents new production estimates (in tonnes per year (t/year)) without and with the Project, new production difference (with-without Project, in t/year), and new production ratio (with/without Project) using the functional group specific dispersal rates. Production ratios with and without the Project are equal to biomass ratios for each functional group (since P/B values are constant).

Table IR3-14-1 New Biomass Estimates (without and with Project, in t), New Biomass Difference (with-without Project, in t), and New Biomass Ratio (with/without Project) from the Roberts Bank Ecosystem Model Run with Functional Group Specific Dispersal Rates (Dispersal Run)

No.	Functional Group	Group Specific Dispersal Rate (km/year)	New Biomass (without Project, t)	New Biomass (with Project, t)	New Difference (with - without, t)	New Biomass Ratio (with/ without)	Biomass Ratio presented in the EIS (with/ without)
1	Baleen whales*	110000	0.273	0.270	-0.003	**0.99**	0.92
2	Dolphins and porpoises*	25000	0.273	0.264	-0.008	0.97	0.97
3	Pinnipeds*	18000	21.832	21.209	-0.623	0.97	0.97
4	Southern resident killer whales*	80000	0.546	0.530	-0.016	0.97	0.97
5	Transient killer whales*	80000	0.284	0.275	-0.008	**0.97**	0.89
6	American wigeon	6000	4.765	4.679	-0.086	**0.98**	0.92
7	Bald eagle	6000	0.120	0.116	-0.004	**0.97**	0.93
8	Brant goose	6000	1.088	1.044	-0.044	**0.96**	0.95
9	Diving waterbirds	6000	1.506	1.446	-0.061	**0.96**	0.94
10	Dunlin	6000	0.471	0.472	0.001	*1.00*	1.13
11	Great blue heron	6000	0.671	0.661	-0.011	*0.98*	1.00
12	Gulls and terns	6000	2.639	2.575	-0.065	*0.98*	0.99
13	Raptors	6000	0.008	0.008	0.000	*0.98*	1.31
14	Shorebirds	6000	0.045	0.046	0.000	**1.01**	0.98
15	Waterfowl	6000	16.559	16.117	-0.442	*0.97*	1.08
16	Western sandpiper	6000	0.058	0.059	0.001	*1.01*	1.13
17	Chinook salmon (adult)	7000	187.099	178.361	-8.738	0.95	0.95
18	Chinook salmon (juvenile)	100	0.655	0.754	0.099	*1.15*	1.16
19	Chum salmon (adult)	5800	111.643	106.444	-5.198	0.95	0.95
20	Chum salmon (juvenile)	100	0.491	0.561	0.070	1.14	1.14
21	Dogfish	10000	35.953	34.829	-1.124	*0.97*	0.98
22	Flatfish	3000	20.441	19.672	-0.769	*0.96*	0.98
23	Forage fish	1500	573.086	559.732	-13.353	*0.98*	0.99
24	Herring	2000	242.712	236.396	-6.316	*0.97*	0.98
25	Large demersal fish	3500	8.386	8.059	-0.327	*0.96*	0.99
26	Lingcod	7000	32.031	40.468	8.437	**1.26**	0.97

No.	Functional Group	Group Specific Dispersal Rate (km/year)	New Biomass (without Project, t)	New Biomass (with Project, t)	New Difference (with - without, t)	New Biomass Ratio (with/ without)	Biomass Ratio presented in the EIS (with/ without)
27	Rockfish	4000	18.475	22.717	4.242	**1.23**	0.91
28	Salmon (adult)	2500	55.454	52.907	-2.548	*0.95*	0.96
29	Salmon (juvenile)	100	0.092	0.104	0.011	**1.12**	0.97
30	Sandlance	1200	11.323	11.070	-0.254	*0.98*	1.06
31	Shiner perch	1200	8.921	8.820	-0.101	*0.99*	1.18
32	Skate	8000	12.584	11.830	-0.754	**0.94**	0.92
33	Small demersal fish	500	3.945	3.787	-0.159	**0.96**	0.95
34	Starry flounder	5700	11.453	11.128	-0.325	*0.97*	1.06
35	Carnivorous zooplankton	300	1,623.743	1,518.133	-105.610	**0.93**	0.89
36	Dungeness crab	1500	252.769	231.671	-21.098	*0.92*	0.97
37	Epifaunal grazer	100	835.674	800.395	-35.278	**0.96**	0.92
38	Epifaunal omnivore	900	105.284	98.792	-6.492	*0.94*	0.98
39	Epifauna sessile suspension feeder	10	48.876	63.968	15.092	**1.31**	1.19
40	Infaunal bivalve	10	6,590.176	5,636.554	-953.621	*0.86*	0.92
41	Jellyfish	300	599.746	577.409	-22.336	**0.96**	0.92
42	Macrofauna	10	2,743.430	3,516.523	773.093	**1.28**	1.27
43	Meiofauna	10	1,588.644	1,784.182	195.538	**1.12**	1.11
44	Omnivorous and herbivorous zooplankton	300	2,970.768	2,820.832	-149.935	**0.95**	0.93
45	Polychaetes	10	1,099.779	995.372	-104.407	**0.91**	0.89
46	Orange sea pen	10	7.692	3.424	-4.268	0.45	0.45
47	Shrimp	1000	27.290	19.877	-7.413	*0.73*	0.87
48	Biofilm (freshwater)	300	1,642.846	3,101.217	1,458.371	1.89	1.89
49	Biofilm (marine)	300	1,819.684	1,401.255	-418.429	0.77	0.77
50	Brown algae	300	448.060	392.842	-55.219	0.88	0.88
51	Eelgrass (native)	300	304.576	315.242	10.666	1.04	1.04
52	Green algae	300	6,894.604	6,312.071	-582.533	0.92	0.92
53	Japanese eelgrass (non-native)	300	6.855	6.670	-0.185	*0.97*	0.99
54	Red algae	300	15.168	13.541	-1.626	*0.89*	0.90
55	Phytoplankton	300	2,183.184	2,055.588	-127.596	*0.94*	1.03
56	Tidal marsh	300	1,329.832	1,667.475	337.643	1.25	1.25

No.	Functional Group	Group Specific Dispersal Rate (km/year)	New Biomass (without Project, t)	New Biomass (with Project, t)	New Difference (with - without, t)	New Biomass Ratio (with/ without)	Biomass Ratio presented in the EIS (with/ without)
57	Biomat	300	1,217.125	865.192	-351.934	0.71	0.71
58	Detritus	10	545.796	545.700	-0.096	*1.00*	1.01

Notes:

- Estimates are rounded to three significant digits. Information is at a point in time after equilibrium at Roberts Bank has been reached.
- * Marine mammals are included in the RB model due to their role as top predators; forecast biomass changes are not anticipated and the RB model has not been used to assess effects to marine mammals.
- Groups with a higher biomass ratio (in the dispersal run vs the EIS) are bolded, and groups with a lower biomass ratio are shown in italics. Functional groups that shift from a forecasted negligible change in the EIS to a forecasted minor decrease with the dispersal run are highlighted in orange. Functional groups that shift from a forecasted negligible or minor decrease in the EIS to a forecasted minor increase with the dispersal run are highlighted in green.

Table IR3-14-2 New Production Estimates (without and with Project, in t/year), New Production Difference (with-without Project, in t/year), and New Production Ratio (with/without Project) from the Roberts Bank Ecosystem Model Run with Functional Group-specific Dispersal Rates (Dispersal Run)

No.	Functional Group	Group Specific Dispersal Rate (km/year)	New Production (without Project, t/year)	New Production (with Project, t/year)	New Difference (with – without, t/year)	New Production Ratio (with/ without)	Production Ratio presented in the EIS (with/ without)
1	Baleen whales*	110000	0.008	0.008	0.000	**0.99**	0.92
2	Dolphin and porpoises*	25000	0.044	0.042	-0.001	0.97	0.97
3	Pinnipeds*	18000	3.056	2.969	-0.087	0.97	0.97
4	Southern resident killer whales*	80000	0.022	0.021	-0.001	0.97	0.97
5	Transient killer whales*	80000	0.011	0.011	0.000	**0.97**	0.89
6	American wigeon	6000	0.953	0.936	-0.017	**0.98**	0.92
7	Bald eagle	6000	0.030	0.029	-0.001	**0.97**	0.93
8	Brant goose	6000	0.218	0.209	-0.009	**0.96**	0.95
9	Diving waterbirds	6000	0.362	0.347	-0.015	**0.96**	0.94
10	Dunlin	6000	0.240	0.241	0.001	*1.00*	1.13
11	Great blue heron	6000	0.329	0.324	-0.005	*0.98*	1.00

No.	Functional Group	Group Specific Dispersal Rate (km/year)	New Production (without Project, t/year)	New Production (with Project, t/year)	New Difference (with – without, t/year)	New Production Ratio (with/ without)	Production Ratio presented in the EIS (with/ without)
12	Gulls and terns	6000	0.607	0.592	-0.015	*0.98*	0.99
13	Raptors	6000	0.003	0.003	0.000	*0.98*	1.31
14	Shorebirds	6000	0.023	0.023	0.000	**1.01**	0.98
15	Waterfowl	6000	3.312	3.223	-0.088	*0.97*	1.08
16	Western sandpiper	6000	0.030	0.030	0.000	*1.01*	1.13
17	Chinook salmon (adult)	7000	58.001	55.292	-2.709	0.95	0.95
18	Chinook salmon (juvenile)	100	0.524	0.603	0.079	*1.15*	1.16
19	Chum salmon (adult)	5800	48.006	45.771	-2.235	0.95	0.95
20	Chum salmon (juvenile)	100	0.442	0.505	0.063	1.14	1.14
21	Dogfish	10000	4.314	4.179	-0.135	*0.97*	0.98
22	Flatfish	3000	7.563	7.279	-0.284	*0.96*	0.98
23	Forage fish	1500	544.432	531.746	-12.686	*0.98*	0.99
24	Herring	2000	194.170	189.117	-5.053	*0.97*	0.98
25	Large demersal fish	3500	4.277	4.110	-0.167	*0.96*	0.99
26	Lingcod	7000	9.929	12.545	2.616	**1.26**	0.97
27	Rockfish	4000	4.065	4.998	0.933	**1.23**	0.91
28	Salmon (adult)	2500	23.845	22.750	-1.095	*0.95*	0.96
29	Salmon (juvenile)	100	0.079	0.088	0.010	**1.12**	0.97
30	Sandlance	1200	5.322	5.203	-0.119	*0.98*	1.06
31	Shiner perch	1200	11.330	11.202	-0.128	*0.99*	1.18
32	Skate	8000	1.133	1.065	-0.068	**0.94**	0.92
33	Small demersal fish	500	3.945	3.787	-0.159	**0.96**	0.95
34	Starry flounder	5700	4.581	4.451	-0.130	*0.97*	1.06
35	Carnivorous zooplankton	300	11,366.202	10,626.932	-739.270	**0.93**	0.89

No.	Functional Group	Group Specific Dispersal Rate (km/year)	New Production (without Project, t/year)	New Production (with Project, t/year)	New Difference (with – without, t/year)	New Production Ratio (with/ without)	Production Ratio presented in the EIS (with/ without)
36	Dungeness crab	1500	631.923	579.177	-52.746	*0.92*	0.97
37	Epifaunal grazer	100	1,210.056	1,158.972	-51.083	**0.96**	0.92
38	Epifaunal omnivore	900	368.494	345.773	-22.721	*0.94*	0.98
39	Epifaunal sessile suspension feeder	10	83.351	109.088	25.737	**1.31**	1.19
40	Infaunal bivalve	10	13,569.172	11,605.665	-1,963.507	*0.86*	0.92
41	Jellyfish	300	5,757.559	5,543.131	-214.428	**0.96**	0.92
42	Macrofauna	10	10,973.722	14,066.093	3,092.371	**1.28**	1.27
43	Meiofauna	10	12,709.148	14,273.454	1,564.306	**1.12**	1.11
44	Omnivorous and herbivorous zooplankton	300	71,298.423	67,699.977	-3,598.446	**0.95**	0.93
45	Polychaetes	10	5,498.895	4,976.860	-522.035	**0.91**	0.89
46	Orange sea pen	10	9.231	4.109	-5.122	0.45	0.45
47	Shrimp	1000	65.496	47.704	-17.792	*0.73*	0.87
48	Biofilm (freshwater)	300	59,142.455	111,643.802	52,501.348	1.89	1.89
49	Biofilm (marine)	300	65,508.619	50,445.183	-15,063.436	0.77	0.77
50	Brown algae	300	4,032.543	3,535.576	-496.967	0.88	0.88
51	Eelgrass (native)	300	5,482.368	5,674.349	191.981	1.04	1.04
52	Green algae	300	89,629.855	82,056.929	-7,572.926	0.92	0.92
53	Japanese eelgrass (non-native)	300	68.552	66.698	-1.854	*0.97*	0.99
54	Red algae	300	303.353	270.828	-32.525	*0.89*	0.90
55	Phytoplankton	300	283,813.920	267,226.459	-16,587.461	*0.94*	1.03
56	Tidal marsh	300	19,947.479	25,012.131	5,064.652	1.25	1.25
57	Biomat	300	101,021.382	71,810.899	-29,210.482	0.71	0.71

Notes:

- Production is not defined for detritus (functional group #58) as this is a non-living group.

- Estimates are rounded to three significant digits. Information is at a point in time after equilibrium at Roberts Bank has been reached.
- * Marine mammals are included in the RB model due to their role as top predators; forecast biomass changes are not anticipated and the RB model has not been used to assess effects to marine mammals.
- Groups with a higher production ratio (in the dispersal run versus the EIS) are bolded, and groups with a lower production ratio are shown in italics. Functional groups that shift from a forecasted negligible change in the EIS to a forecasted minor decrease with the dispersal run are highlighted in orange. Functional groups that shift from a forecasted negligible or minor decrease in the EIS to a forecasted minor increase with the dispersal run are highlighted in green.
- Production ratios with and without the Project are equal to biomass ratios for each functional group (since P/B values are constant).

In general, consideration of functional group specific dispersal rates in the RB model decreased the range of forecasted losses in productivity as a result of terminal and causeway footprints, in comparison to forecasted changes presented in the EIS, which did not consider dispersal rates specific to functional groups. The range of forecasted increases also narrowed in the dispersal run, relative to the forecasts presented in the EIS.

Specifically (as presented in **Table IR3-14-3** and **Figure IR3-14-1**), the number of functional groups with negligible biomass losses (i.e., up to 5%) increased from 20 (in the EIS) to 29 (dispersal run). In contrast, the number of functional groups with minor biomass losses (i.e., 5%-30%) decreased from 19 (in the EIS) to 13 (dispersal run). A similar pattern was observed in the number of functional groups with minor biomass gains that changed from 12 (in the EIS) to 8 (dispersal run). For six functional groups (i.e., dunlin, raptors, waterfowl, sandlance, shiner perch, and starry flounder), forecasted biomass gains in the EIS, shifted to negligible losses in the dispersal run (**Tables IR3-14-1** and **IR3-14-2**). Overall, the number of functional groups with negligible biomass change increased from 23 (in the EIS) to 32 (dispersal run), while the number of functional groups with minor biomass change decreased from 31 (in the EIS) to 21 (dispersal run).

This tendency of forecasted biomass change of functional groups to move closer to 1.00 (i.e., no change with the Project; **Figure IR3-14-1**) when higher dispersal rates were considered in the RB model indicates that the ranges of productivity losses and gains from the dispersal run are lower than forecasted ranges presented in the EIS. These findings confirm that higher dispersal rates tend to make Project-related productivity changes less apparent, as discussed in detail in CEAR Document #547, question 2.3.

Three functional groups (i.e., Dungeness crab, epifaunal omnivore, and phytoplankton; orange highlights in **Tables IR3-14-1** and **IR3-14-2**) showed a change from a forecasted negligible decrease in biomass and production as presented in the EIS to a forecasted minor decrease with the dispersal run. For Dungeness crab, and epifaunal omnivore, and as productivity changes of functional groups in the RB model are partially influenced by predator-prey linkages within the Roberts Bank ecosystem, this loss in productivity is likely attributed to the ability of these groups' prey to move between cells in the RB model more freely given higher dispersal rates. It is noted, however, that Dungeness crab and epifaunal omnivore productivity ratios from the dispersal run fall within the range of values (and are closer to the

median) previously reported during Monte Carlo sensitivity analyses undertaken for the EIS (see Section 3.4 of EIS Appendix 10-D).

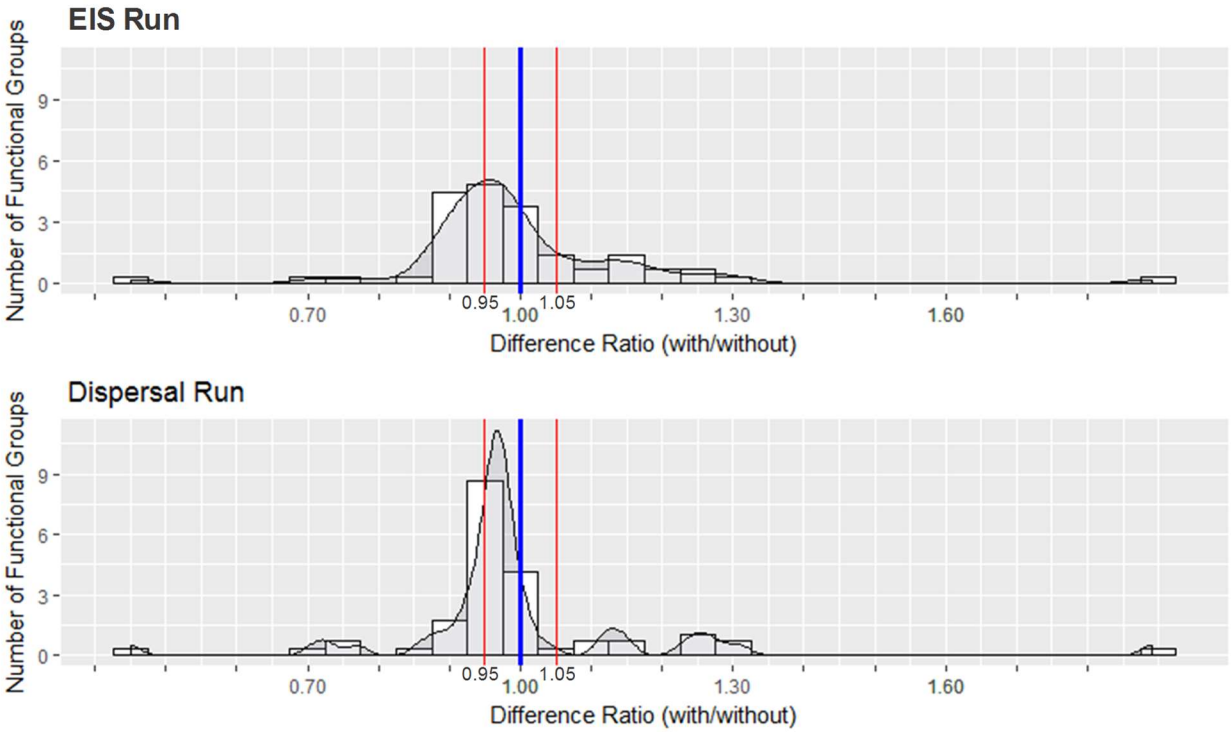
In the case of phytoplankton, a minor (6%) decrease in productivity is forecasted during the dispersal run, compared to a negligible (3%) increase presented in the EIS (see **Tables IR3-14-1** and **IR3-14-2**). This is attributed to a lower dispersal rate (i.e., 300 km/year) assigned to phytoplankton for the dispersal run compared to that used in the EIS (i.e., 10,000 km/year). As a result, terminal and causeway footprint effects on phytoplankton are more apparent.

Three functional groups (i.e., lingcod, rockfish, and juvenile salmon; green highlights in **Tables IR3-14-1** and **IR3-14-2**) showed a change from a forecasted negligible or minor decrease in biomass and production as presented in the EIS to a forecasted minor increase with the dispersal run. Lingcod and rockfish, in particular, are spatially restricted in the RB model by depth and rocky substrate. An increase of dispersal rates from 1 km/year (EIS) to 7,000 km/year and 4,000 km/year, respectively, resulted in biomass gains during the dispersal run of 26% and 23%, respectively (**Table IR3-14-1**). This is likely because higher dispersal rates allow these groups to swim away from their rocky habitat when conditions become unfavourable and make use of adjacent more favourable habitats.

Table IR13-14-3 Number of Functional Groups with Biomass Change Forecasted to be Negligible, Minor, and Moderate with the Project (EIS run) and the Dispersal Run (Functional Group Specific Dispersal Rates)

Biomass Difference Ratio (with/without)		Number of Functional Groups	
		Key Run (presented in EIS)	Dispersal Run
No Change		1	2
Increase	Negligible (0%-5%)	3	3
	Minor (6%-30%)	12	8
	Moderate (>30%)	2	2
Decrease	Negligible (0%-5%)	20	29
	Minor (6%-30%)	19	13
	Moderate (>30%)	1	1

Figure IR3-14-1 Number of Functional Groups with Biomass Forecasted to Change with the Project up to 5%, Between 5% and 30%, and More than 30%, for the Key Run Presented in the EIS and for the Dispersal Run



Note: Red lines represent the 0.05 (5%) range of negligible biomass change with the Project (0.95 – 1.00: negligible biomass decrease; 1.00 – 1.05: negligible biomass increase). Blue line represents no biomass change with the Project.

In conclusion, the approach taken as presented in the EIS is conservative in that it makes productivity changes due to terminal and causeway footprints more apparent, even though lower dispersal rates may not reflect the natural reality at Roberts Bank. Lower dispersal rates restrict the speed at which functional groups move between cells in the RB model, meaning they are more likely to be affected by Project-related activities. In contrast, application of higher dispersal rates tends to diminish the range of forecast productivity losses due to the Project footprint (relative to forecasts presented in the EIS). Higher dispersal rates also diminish the range of forecast productivity increases due to the Project footprint. As a result, there is no change to the effects conclusions presented in the EIS.

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IR3-15 Roberts Bank Ecosystem Model – Functional Group Life History

Information Source(s)

EIS Volume 3: Section 10.3, Appendix 10-B, Appendix 10-C

Context

As defined in the EIS, functional groups are species or collections of species that share similar life history traits and ecological functions and were used to represent pools of biomass in the RB EwE model. The RB EwE model has 58 functional groups, 28 of these were modeled as focal species groups.

In the RB EwE model, the only species in which different life history stages were considered as independent functional groups were chum and Chinook salmon (Appendix 10-C p. 56).

For many functional groups, the life history stages can have different characteristics and occupy different habitats than the adults. It is unclear how different life history stages were considered in the RB EwE modelling.

Information Request

Describe the approach utilized in the RB EwE model for considering larval and/or juvenile life history stages for each functional group in consideration of the relative vulnerability of specific life history stages to Project effects.

Include a discussion of the implications of not including early life history stages in the assessment.

VFPA Response

Describe the approach utilized in the RB EwE model for considering larval and/or juvenile life history stages for each functional group in consideration of the relative vulnerability of specific life history stages to Project effects.

While only juvenile Chinook and chum salmon were directly included in the model as functional groups, early life history stages for other invertebrate and fish functional groups were indirectly accounted for within 1) initial biomass estimates and 2) trophic interactions. In addition, the assessment also considered effects on early life history stages through other lines of evidence—e.g., literature, field studies, and habitat modelling—including the recommendation of mitigation measures to reduce effects to Dungeness crabs and salmon during their sensitive early life history stages. Therefore, effects on early life history stages for invertebrate and fish groups have been captured in the assessment.

Only marine invertebrate and fish functional groups (totalling 31 functional groups) are considered to have larval and/or juvenile life history stages that may potentially be vulnerable

to Project effects. The 27 functional groups comprised of marine vegetation, marine mammal, and coastal bird species or guilds are therefore not discussed further in this response.

As indicated in the Preamble at the beginning of this response package, the primary objective of the Roberts Bank ecosystem model (RB model) is to quantify direct and indirect changes in productivity resulting from the placement of the terminal and causeway footprints, including indirect ecological effects of the footprints transmitted through their effects on physical conditions (specifically salinity, depth, wave heights, and water velocities), the consequent changes in biological productivity of functional groups, and the ramifications of these changes through the food web. The RB model included juvenile life history stages for chum and Chinook salmon because these life stages are ecologically important in the Roberts Bank ecosystem, they constitute a significant amount of biomass, and there was sufficient information to include them in the RB model. The juvenile life history stages of other invertebrate and fish functional groups either had insufficient information to be represented separately in the RB model, or their biomass was very small compared to the overall biomass of that functional group, or the juvenile life history stages could be represented implicitly through the RB model inputs for the functional group as a whole (e.g., biomass, diet matrix, P/B and Q/B ratios). As discussed below, the overall set of functional groups included in the RB model was driven and peer-reviewed by the Productive Capacity Technical Advisory Group (TAG).

Productive Capacity Technical Advisory Group

As indicated previously (EIS Section 10.3.1 and in the Preamble at the beginning of this response package), a TAG was struck to determine how productive capacity at Roberts Bank could best be scientifically defined and measured to evaluate RBT2-related effects. TAG participants included nine scientific and regulatory experts from Environment and Climate Change Canada (ECCC), DFO, academia, and industry; see Sections 2.2 and 3.2.1 of the Appendix IR3-A in the Preamble at the beginning of this response package for list of TAG members and the criteria on which the RB model was evaluated, respectively.

A key Productive Capacity TAG outcome was the identification of which species to use in the assessment. Over 400 species (marine vegetation, invertebrates, fish, mammals, and birds) have been documented at Roberts Bank and it is not technically possible to include all species in a single model or assessment (see Additional Information Request #9[1]). Hence, a focus group comprised of twenty-one experts from academic institutions, government (U.S. National Oceanic and Atmospheric Administration, DFO, ECCC), non-governmental organisations, and private consulting was convened, thereby drawing on expertise across the broad areas of birds, fish, invertebrates, marine vegetation, and marine mammals that utilise the Roberts Bank area (see Section 2.3 and Appendix A of Appendix IR3-A in the Preamble at the beginning of this response package for more information on the focus group process and participants). Together, the focus group and TAG used a structured decision-making process, including 13 social and ecological criteria, to select 25 focal species on which to base the

[1] Additional Information Request #9 (IR-12.04.15-9) in CEAR Document #388 From Port Metro Vancouver to the Canadian Environmental Assessment Agency re: Completeness Review - Responses to Additional Information Requirements Follow-Up (See Reference Document #345) including 22 Technical Data Reports

assessment. This was supplemented with another 33 species, in order to represent predator-prey relationships of potential importance to the 25 focal species, for a total of 58 functional groups within the model; a detailed list is provided in EIS Appendix 10-B.

During this process, no other species' life stage was as frequently and repeatedly flagged by the TAG and focus group participants as juvenile salmonids. Therefore, Chinook and chum salmon are the only species for which specific life history stages (i.e., juvenile and adult) are included as separate functional groups within the RB model.

Input Biomass Values and Trophic Interactions

Biomass of larval and/or juvenile life history stages is included in the input biomass estimates for many invertebrate and fish functional groups. However, the proportion of total biomass that is represented by early life history stages is generally very small (relative to the biomass of adults)—particularly in light of high early life stage mortality rates—and, therefore, unlikely to influence productivity[2] estimates.

Further, inclusion of larval/juvenile life stages was achieved through food web linkages among predators and early life stages. For example, jellyfish diet includes macrofauna, and this specifically refers to the early pelagic larval stage of the macrofaunal functional group because, once settled on or within the substrate, macrofauna are no longer accessible to pelagic jellyfish. In addition, cannibalism—whereby early life stages are consumed by adults in the same population—was included for 18 functional groups. For example, Dungeness crabs, particularly females, are well known to be cannibalistic on recently moulted juveniles (Fernandez et al. 1993; Eggleston and Armstrong 1995; Rasmuson 2013); this is reflected in the diet matrix by including a 0.005 proportion of Dungeness crab in Dungeness crab diet. By including linkages between predators and early life history stages through diet preferences including cannibalism, the model accounts for larval and/or juvenile stages.

Potential Construction Effects and Associated Mitigation

As indicated in Sections 12.6.3 and 13.6.3 of the EIS, the major mechanism of productivity change for larval and/or juvenile life history stages of marine invertebrates and fish is predicted to occur during construction particularly during dredging activities. The RB model does account for direct and indirect effects of the Project, but does not account for the impacts of construction, including dredging. As outlined in the next subsection of this response, effects of construction activities on larvae/juveniles as well as adults were assessed through other lines of evidence (including literature review, empirical sampling, and habitat modelling)

[2] Natural mortality rates are highest in early life, often becoming relatively stable after maturity is reached. For example, high juvenile mortality is widespread among benthic marine invertebrates, with levels often exceeding 90% (Gosselin and Qian 1997) and levels as high as 98.7% have been reported for marine bivalves (Thorson 1966). Similar trends have been noted in marine teleost fishes, where mortality exceeds 99% during the egg and larval stages (Houde 2002).

within each respective valued component section, taking into account ontogenetic shifts[3] in habitat use.

Larval/juvenile life stage vulnerability to Project effects was qualitatively considered from a broader ecological perspective. Roberts Bank is an open system in terms of larval supply and recruitment, and will remain so post-Project with the terminal and causeway footprints in place. In other words, larvae of several functional groups, such as Dungeness crabs and bivalve shellfish, are often sourced outside the Roberts Bank system and undergo long pelagic phases (i.e., several weeks and/or months), and are expected to continue to settle at Roberts Bank.

The relative vulnerability of specific life stages to Project effects was not only assessed through lines of evidence other than the RB model, but also mitigated for through the identification of appropriate avoidance and reduction measures. For example, as outlined in EIS Section 13.7.1.2, to minimise direct mortality and physical injury effects of construction activities on sensitive life stages, dredging guidelines have been established by DFO for the protection of marine resources (and have successfully been used previously at Roberts Bank). Specifically, to protect juvenile Pacific salmon, the guidelines include a fisheries-sensitive window from March 1 to August 15, above –5.0 m chart datum (CD). To the extent feasible, no Project-related construction activities that may result in adverse effects to juvenile Pacific salmon will occur during this window. A DFO fisheries-sensitive window for Dungeness crab will also be in effect from October 15 to March 30 below –5.0 m CD to protect the sensitive gravid life history stage; therefore, dredging is scheduled to occur from April 1 to October 14 at depths below –5.0 m CD.

Within the context of the RB model, the following approaches were used for considering larval and/or juvenile life history stages of marine fish and invertebrates, explained in more detail below:

- Soliciting local and regional expert input, through the Productive Capacity TAG process (see Appendix IR3-A in the Preamble at the beginning of this response package), on which species/life stages to include in the RB model (given it is not possible to model all of the many hundreds of species that use Roberts Bank for all or part of their life histories); and
- Inherently including the productivity of such life stages into input biomass estimates and/or trophic interactions.

Include a discussion of the implications of not including early life history stages in the assessment.

This response clarifies that early life stages were included in the assessment: quantitatively in the RB model where appropriate (as described above), and both qualitatively and

[3] It is common for individuals to exploit several niches (including habitats) sequentially in the course of their life history (Werner and Gilliam 1984). The change during life history from one niche (or habitat) to another is referred to as an ontogenetic shift (Claessen and Dieckmann 2002).

quantitatively through other lines of evidence, as demonstrated through the following cross-references:

- Juvenile Dungeness Crab Technical Data Report (provided as TDR MI-2 in Appendix AIR10-C of AIR-12.04.15-10, CEAR Document #388);
- Juvenile Salmon Surveys Technical Data Report (provided as TDR MF-3 in Appendix AIR10-C of AIR-12.04.15-10, CEAR Document #388);
- Lingcod Egg Mass Survey within the Reef Fish Surveys Technical Data Report (provided as TDR MF-5 in Appendix AIR10-C of AIR-12.04.15-10, CEAR Document #388);
- Interaction between Project construction activities and post-larval and juvenile Dungeness crabs is discussed in EIS Section 12.6.3.3 (p. 12-64);
- The Dungeness crab habitat suitability model, provided in EIS Appendix 12-A, quantifies Project effects on suitable habitat by life stage including juveniles, adults, and gravid females;
- Implications of Project effects on orange sea pen larval settlement is discussed in EIS Section 12.6.3.4 (p. 12-67);
- Tables 13-4 and 13-5 in EIS Section 13.3.2 show sensitive adult and juvenile life history periods for marine fish, respectively;
- Direct mortality of early reef fish life stages, including larvae and eggs, is discussed in EIS Section 13.6.3.2 (p. 13-103) along with the effects of changes in habitat availability on the productivity of these life history stages (pp. 13-104 to 13-105);
- Potential effects of construction activities on the benthic eggs of flatfish sub-components is raised in EIS Section 13.6.3.4 (pp. 13-113 to 13-114);
- Sensitive life history stages of demersal fish are discussed in EIS Section 13.6.3.5 (p. 13-119); and
- EIS Sections 12.7.1.2 and 13.7.1.2 include mitigation for sensitive life stages, including gravid female Dungeness crabs and juvenile Pacific salmon.

In summary, while the only early life history stages directly included in the model as functional groups were juvenile Chinook and chum salmon, early life history stages for other invertebrate and fish functional groups were indirectly accounted for within 1) initial biomass estimates and 2) trophic interactions (as described above). In addition, the assessment also considered effects on early life history stages through other lines of evidence—e.g., literature, field studies, and habitat modelling—including the recommendation of mitigation measures to reduce effects to Dungeness crabs and salmon during their sensitive early life history stages. Effects on early life history stages for invertebrate and fish groups have therefore been captured in the assessment.

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IR3-16 Roberts Bank Ecosystem Model – Balancing: Seasonal Dietary Shifts

Information Source(s)

EIS Volume 3: Appendix 10-C

CEAR Doc #314

Context

The Proponent, in Table IR6-2 of CEAR Doc #314, provided a summary for parameter input changes made during model balancing for a number of functional groups including adult Chinook salmon.

Many functional groups' diets change seasonally. For example, juvenile Chinook are known to peak in abundance in intertidal and sub tidal habitats at Roberts Bank in the spring and thereafter migrate offshore. They consume epibenthic crustaceans and other invertebrates in the spring and forage on pelagic prey thereafter.

Information Request

Describe how seasonal dietary shifts were incorporated into the RB EwE model during model balancing.

VFPA Response

Seasonal dietary shifts were incorporated into the Roberts Bank ecosystem model (RB model) in the creation of the diet matrix, which is a step undertaken prior to model balancing. Seasonal dietary shifts were not directly incorporated into the model balancing process, which is accomplished by adjusting input biomass, production estimates, and/or diet allocations (e.g., balancing does not change what a species may eat, but may change how much of a particular prey item a species may eat, or the relative proportion of species that comprise the diet). Diet allocation adjustment during model balancing was performed for only three of the 58 functional groups—transient killer whale, bald eagle, and Dungeness crab. A detailed overview of model balancing, and explanation of the rationale behind these three specific instances, is provided in question 2.9 of CEAR Document #547.

Seasonal dietary shifts were incorporated into the diet matrix by determining the time-weighted annual average diet composition, as is standard best practice (outlined in IR3-13; Harvey 2012; Preikshot 2013; Mackinson and Daskalov 2008). Seasonal shifts in diet are represented implicitly within the annual average proportions of prey consumed. For example, the diet composition for juvenile Chinook used in the RB model reflects the spring preference for epibenthic crustaceans and other invertebrates (e.g., in the RB model, juvenile Chinook

diet comprised of: macrofauna 0.3798[1], polychaetes 0.05, meiofauna 0.00999). It also included their shift to pelagic prey as they migrate into deeper waters (e.g., their diet changes to zooplankton 0.1199, jellyfish 0.04997, herbivorous zooplankton 0.05, forage fish 0.015, flatfish 0.004, herring 0.0015, large demersal 0.01, sandlance 0.0001, shiner perch 0.005, small demersal 0.01, shrimp 0.05, import 0.234). This diet composition reflects a low degree of intra- and interspecific cannibalism (e.g., Chinook juvenile 0.0002, chum juvenile 0.0004, salmon juvenile 0.0003; refer to Appendix A of EIS Appendix 10-B for further details on the information and numbers presented here on juvenile Chinook). Hence, seasonal shifts in diet (of numerous different prey sources), based on best available literature, were accounted for in the RB model diet matrix within the annual average values.

Further information on how seasonal diet shifts were taken into account in the diet matrix are provided in the Preamble at the beginning of this response package, and in the VFPA's responses to IR3-06, -07, -08, -13 and -18.

References

Harvey, C. J., G. D. Williams, and P. S. Levin. 2012. Food Web Structure and Trophic Control in Central Puget Sound. Estuaries and Coasts 35:821–838.

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[1] The numbers presented in the diet matrix reflect proportions, such that 0.3798 for macrofauna means that 37.98% of juvenile Chinook diet is composed of macrofauna etc. All proportions together sum to 1, representing the full diet.

IR3-17 Roberts Bank Ecosystem Model – Balancing: Confidence Intervals for Parameter Values

Information Source(s)

EIS Volume 3: Section 10.3, Appendix 10-C

CEAR Doc #547

Context

According to the Proponent, in Section 10.3 of the EIS, all ecosystem models contain assumptions on the amount of food that is available to support all the predators in the ecosystem. Consumption rates for all predators in the system were obtained from peer-reviewed scientific sources and applied to the RB EwE model. Balancing is a standard approach where literature-derived values are adjusted to more accurately reflect local conditions. If the literature-derived consumption rate for a certain species was not supported by the estimated prey available to it in the Roberts Bank ecosystem, the RB EwE model would not be balanced, and would have to be balanced based on professional expertise.

The Proponent, in CEAR Doc #547, reported that the process of determining site-specific diet compositions was done through a quality assessment of the diet preferences during the construction of the RB EwE model. However, there were three cases – transient killer whale, bald eagle and Dungeness crab - where site-specific information was not adequately accounted for and led to unrealistic diet preferences and an unbalanced RB EwE model. Modifications to diet preferences were completed to better reflect the ecological conditions at Roberts Bank as part of the balancing procedure, after the quality assessment process.

According to Fisheries and Oceans Canada, expert opinion was used to examine parameter values and to adjust for errors or inconsistencies in logic in the RB EwE model. For a few functional groups, large changes to initial parameter estimates were not necessarily based on Roberts Bank specific data, for example, transient killer whales. When such initial parameters were adjusted by expert opinion to balance the model, broader confidence intervals about these parameters could have been applied so as to avoid underestimating the uncertainty of the model outputs.

Information Request

Provide confidence intervals for parameter values that were adjusted during balancing of the RB EwE model.

VFPA Response

Table IR3-17-1 shows the pedigree and confidence interval (defined in Section 2.5 of EIS Appendix 10-C) of initial (unbalanced) input parameter values that were adjusted during balancing of the Roberts Bank ecosystem model (RB model) (presented in Table 3.1 of

EIS Appendix 10-C) and then again during sensitivity analyses conducted using wider confidence intervals (presented in table 3 of CEAR Document #547, question 2.7). Hence, broader confidence intervals for parameters adjusted during RB model balancing have already been applied to avoid underestimating the uncertainty of model outputs.

This response summarises information (presented in Table 3.1 of EIS Appendix 10-C) on confidence intervals for parameter values adjusted during RB model balancing. In addition, new information from a Monte Carlo sensitivity analysis for transient killer whales (previously undertaken to respond to CEAR Document #547, question 2.7) is also included herein which shows that the use of larger confidence intervals does not influence RB model outputs.

During RB model construction and parameterisation, diet compositions were adjusted for transient killer whales, bald eagles, and Dungeness crab, to incorporate local knowledge, account for local conditions (e.g., local prey availability, local habitat use of predators), and correct for unrealistic estimates (i.e., estimates that violated mass-balance constraints[1]). Species and location specific rationale for these examples is provided in CEAR Document #547, question 2.9.

Following parameterisation, balancing of the RB model required adjustment of (i) biomass values for baleen whales, dolphins and porpoises, and forage fish; and (ii) production/biomass values for diving waterbirds, gulls and terns, raptors, and Chinook salmon (adult). Rationale for these seven instances is provided in EIS Appendix 10-B and Table IR6-2 of Information Request #6 (IR-7.31.15-06 in CEAR Document #314[2]).

During balancing of the RB model, consumption rates of functional groups were not changed.

As part of RB model parameterisation and balancing, pedigree values (and associated confidence intervals) were assigned to each input parameter. These pedigree values for all functional groups are presented in Table 3.1 of EIS Appendix 10-C, and in **Table IR3-17-1** (Pedigree (% Confidence Interval) in EIS) for only those input parameters adjusted during RB model parameterisation and balancing.

Wider confidence intervals were applied, than those presented in the EIS, in CEAR Document #547, question 2.7 to all functional groups in the RB model to further evaluate potential uncertainty in related input data. **Table IR3-17-1** presents confidence intervals that were increased for those functional groups for which input parameter values were adjusted during balancing of the RB model.

[1] In a mass-balance model, the total amount of biomass produced by a group is equal to the amounts extracted from the group as a result of predation, fishing, migration, and other types of mortality.
[2] CEAR Document #314 From Port Metro Vancouver to the Canadian Environmental Assessment Agency re: Completeness Review - Responses to Additional Information Requirements (See reference document #271) for the Environmental Impact Statement.

Table IR3-17-1 Pedigree of Input Parameter Values Modified During Balancing of the Roberts Bank Ecosystem Model

Functional Group		Pedigree (% Confidence Interval) in EIS			Pedigree (% Confidence Interval) in CEAR Document #547, Question 2.7		
		B	*P/B*	*Diet*	*B*	*P/B*	*Diet*
1	Baleen whales	4 (50)			3 (80)		
2	Dolphins and porpoises	4 (50)			3 (80)		
5	Transient killer whales			5 (40)			4 (50)
7	Bald eagle			4 (50)			3 (80)
9	Diving waterbirds		4 (50)			3 (60)	
12	Gulls and terns		4 (50)			3 (60)	
13	Raptors		4 (50)			3 (60)	
17	Chinook salmon (adult)		7 (20)*			2 (70)*	
23	Forage fish	5 (30)			4 (50)		
36	Dungeness crab			3 (80)			2 (100)

Note: B = Biomass, P/B = Production/Biomass, Diet = Diet Composition.

Pedigree (and % confidence interval) is only shown for functional groups and input parameter values that were adjusted during balancing of the RB model.

Pedigree of all RB model input values are presented in Section 3.1 of EIS Appendix 10-C.

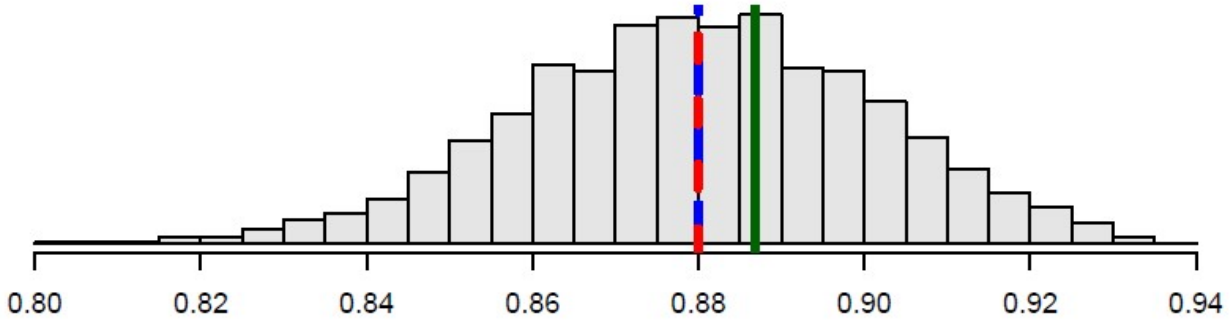
* Pedigree for Chinook salmon (adult) P/B input value was initially considered to be 20% (specific to the same species but extracted from a similar system). To reflect third party review calculations during RB model balancing, pedigree was adjusted to 70% (professional judgement).

Unbalanced and balanced values of biomass and production/biomass are shown in Table 5 of CEAR Document #547, question 2.10. Diet composition changes during balancing of the RB model are described in Section 2.6 of EIS Appendix 10-C, and CEAR Document #547, question 2.9.

For biomass, production/biomass, and diet composition input values adjusted during RB model parameterisation and balancing (as explained above), confidence intervals in the EIS (Appendix 10-C) were increased from between 20% to 30%, 10% to 50%, and 10% to 30%, respectively (**Table IR3-17-1**). For example, a confidence interval of 40% was applied to diet composition of transient killer whales, which is 10% more than initially evaluated in the EIS. For adult Chinook salmon, confidence intervals for production/biomass were increased from 20% to 70%. This increase in confidence intervals, in effect, increased the range of input values that were randomly selected during Monte Carlo runs (undertaken in response to CEAR Document #547, question 2.7) to further evaluate uncertainty associated with the input data sources. In other words, a larger amount of potential uncertainty in these parameters was explored using this approach, and this approach generally found that the forecasts of changes in biomass and productivity with and without the Project are consistently small, even with inclusion of increased uncertainty.

To demonstrate that use of larger confidence intervals did not generally affect forecasts of changes in biomass and productivity, transient killer whales are used as an example. Results of EIS Monte Carlo sensitivity analyses[3] (EIS Appendix 10-D) and subsequent sensitivity analyses with wider confidence intervals (CEAR Document #547, question 2.7) for transient killer whales are new results presented below in response to the information request (such information for other species, including bald eagle and Dungeness crab referred to in the context, is included in CEAR Document #547)[4]. For transient killer whales, the median of the biomass ratios (with/without the Project) was 0.88 (i.e., a median decrease in biomass of 12%), both with wider confidence intervals and with narrower confidence intervals. The key run presented in Table 3.2 of EIS Appendix 10-C yielded a similar biomass ratio of 0.89 (i.e., 11% decrease in biomass) (**Figure IR3-17-1**). Productivity ratios equal biomass ratios for all functional groups, so the percentage changes in productivity are the same as the percentage changes in biomass.

Figure IR3-17-1 Biomass Ratio With/Without Project for Transient Killer Whales, Based on Monte Carlo Analyses Using EIS Key Run (EIS Appendix 10-D) and Wider (CEAR Document #547, Question 2.7) Confidence Intervals



Note: Monte Carlo analyses results (EIS and subsequent RB model runs with wider confidence intervals (CEAR Document #547, question 2.7)) for transient killer whales presented here is new information.

Biomass ratio with/without Project for (i) EIS key run (Table 3.2 of EIS Appendix 10-C): 0.89 (solid green line), (ii) Median biomass ratio from Monte Carlo sensitivity analyses for EIS key run (EIS Appendix 10-D): 0.88 (dashed blue line), (iii) Median biomass ratio from Monte Carlo sensitivity analyses with wider confidence intervals (CEAR Document #547, question 2.7): 0.88 (dashed red line).

Wider confidence intervals for input parameter values adjusted during balancing of the RB model are considered as described in the Monte Carlo sensitivity analyses presented in CEAR Document #547, question 2.7 and summarised in this response. With wider confidence intervals, the forecasted changes in biomass and productivity from the terminal and causeway footprint are similar to those presented in the EIS Appendix 10-C (e.g., as described above

[3] See Section 3.4 of EIS Appendix 10-D for interpretation of such Monte Carlo results.
[4] Marine mammals were included in the RB model for completeness as they are top predators at Roberts Bank. Sensitivity analyses results for marine mammals were not included in EIS Appendix 10-D, because potential productivity changes to marine mammals were not considered in the assessment of the marine mammal valued component.

using transient killer whales). Thus, the median results from applying the RB model are insensitive to wide variation in input assumptions.

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IR3-18 Roberts Bank Ecosystem Model – Sensitivity Analysis: Different Percentages of Diet Allocation

Information Source(s)

EIS Volume 3: Section 10.3, Appendix 10-B, Appendix 10-C, Appendix 10-D

CEAR Doc #547

Context

The Proponent, in Appendix 10-D of the EIS, identified that the sensitivity analysis involved understanding which abiotic and biotic factors drove the results of the RB EwE modelling. This sensitivity analyses considered:

- increases and decreases in the predators' ability to influence prey dynamics;
- the effects of omitting one abiotic factor at a time for each functional group;
- increases and decreases in the forecasted effects of the Project on abiotic factors (to determine how uncertainty in these forecasts could influence changes in the productivity of each functional and aggregated group); and
- sensitivity to input parameter uncertainty through a Monte Carlo approach, where input parameters were drawn randomly from distributions that reflected their uncertainty.

According to Fisheries and Oceans Canada, the sensitivity of the RB EwE model to different percentages of diet allocation was not reported accurately in the EIS. As an example, for the pinniped group, 50% of the diet was assumed to come from outside the model area in order to balance the model. The rationale provided for this was that the pinnipeds caused excessive predation mortalities on numerous fish functional groups and that the biomass of pinnipeds used was an average for the Strait of Georgia, which was likely too high for Roberts Bank. Therefore, it was assumed that pinnipeds extracted only half of their diet from the study area

Information Request

Evaluate the sensitivity of the RB EwE model to different percentages of diet allocation.

VFPA Response

Sensitivity of the Roberts Bank ecosystem model (RB model) to different percentages of diet allocation was evaluated indirectly, via sensitivity analyses of input parameters (i.e., biomass, and production (P/B) and consumption (Q/B) rates), essentially manipulating the amount of prey in the model, as described in the EIS (EIS Appendix 10-D) and subsequently in CEAR Document #547, question 2.7. These sensitivity analyses randomly changed input estimates which, by extension, changed the availability of prey and hence predators' diet allocations. Therefore, the sensitivity of the RB model to different percentages of diet allocation has been considered and evaluated in the assessment. Overall, the RB model is relatively insensitive to

different percentages of diet allocation, and artificial changes in diet allocation / prey availability (via sensitivity analyses) do not change RB model conclusions regarding productivity changes from the Project. This finding is consistent with other Ecopath with Ecosim and Ecospace (EwE) models (see Essington 2007).

The example below, using pinnipeds, illustrates how sensitivity analyses on input estimates were used as a proxy to evaluate the sensitivity of diet allocation, and will demonstrate why the sensitivity is low. In addition, further clarity is provided on the use of a 50% import function for pinniped diet allocation to address comments in the context section of the information request.

Pinniped diet is allocated equally between the Roberts Bank study area (i.e., 50%, distributed among 17 functional groups (**Table IR3-18-1**)) and external areas (i.e., 50% import). Both harbour seals and Stellar sea lions have home ranges that are much larger (tens to thousands of kilometres) than the study area, meaning that the study area represents a fraction of the total area these species occupy (Hardee 2008, Raum-Suryan et al. 2004; see CEAR Document #547, table 2 of appendix 2.8 for additional literature citations). Given this, a 50% import rate is a reasonable, and conservative, estimate of prey consumed outside of the study area.

Sensitivity analyses adjusted pinniped prey biomass inputs by 50% to 80%, production inputs by 30% to 70%, and consumption inputs by 30% to 70% (**Table IR3-18-1**). Low sensitivity to initial diet allocation is explained by the dynamic treatment of diet in the model (see IR3-08); initial diet allocation estimates are not fixed, such that if a preferred prey group is less abundant, the predator's consumption for that group decreases and consumption for a more abundant group is increased. In other words, initial diet allocations adapt to availability of prey immediately after the model run starts. Since the model adapts immediately to prey availability, the initial diet allocations are less important than the changes that take place during the model run.

Table IR3-18-2 Pinniped Prey Groups, Diet Preferences Along with Confidence Interval used for the Monte Carlo Analysis for Biomass, Production (P/B), and Consumption (Q/B)

Pinniped Prey	Pinniped Diet Preference	Biomass (CI)	P/B (CI)	Q/B (CI)
Chinook adult	0.0033	80	70	70
Chinook juv.	0.0001	50	30	30
Chum adult	0.0075	80	30	30
Chum juv.	0.0002	50	60	50
Flatfish	0.0002	50	60	50
Forage fish	0.3882	50	60	50
Herring	0.0161	50	60	50
Large demersal fish	0.0008	50	60	50
Lingcod	0.0010	50	60	50

Pinniped Prey	Pinniped Diet Preference	Biomass (CI)	P/B (CI)	Q/B (CI)
Rockfish	0.0006	50	60	50
Salmon adult	0.0253	60	50	80
Shiner perch	0.0036	50	30	60
Small demersal fish	0.0014	50	60	60
Starry flounder	0.0015	50	80	70
Epifaunal omnivore	0.0441	80	60	60
Epifauna sessile	0.0015	80	60	60
Infaunal bivalves	0.0045	50	60	60

Results of sensitivity analyses demonstrate that the RB model is robust to potential uncertainties in diet allocation; for instance, biomass input values were adjusted for the Monte Carlo analyses (30% to 80%) and produced little change in model outputs (CEAR Document #547, question 2.7), such that the forecasted change in biomass and productivity from the Project remained small. In the case of pinnipeds, such small changes in diet allocation did not change the key run estimate (which showed a 3% change in biomass and productivity with the Project; EIS Appendix 10-C). Overall, sensitivity analyses on input parameters indirectly extend to diet allocations, because they manipulate the amount of biomass in the system, and the rates at which it is produced and consumed—hence the amount of food available to predators in the system.

Prior to running the RB model it was assumed that pinnipeds were in the RB model study area 100% of the time (see Table IR6-2 of Information Request #6 (IR-7.31.15-06) in CEAR Document #314[1] and CEAR Document #377[2]). As a result, the model was unbalanced, and "excessive predation mortalities on numerous fish function groups" was observed (i.e., the model was unbalanced as identified by the excessive mortality of fish by pinnipeds). Therefore, the RB model was balanced, as per standard practice in ecosystem modelling, by recognising that pinnipeds have large ranges and are not in the RB model study area full time and adjusting the import function accordingly (i.e., from 100% to 50% to reflect that pinnipeds obtain their prey to a large degree outside of the RB model study area).

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[1] CEAR Document #314 From Port Metro Vancouver to the Canadian Environmental Assessment Agency re: Completeness Review - Responses to Additional Information Requirements (See reference document #271) for the Environmental Impact Statement.
[2] CEAR Document #377 From Fisheries and Oceans Canada to the Review Panel re: Comments on the information relating to the environmental assessment of the Roberts Bank Terminal 2 Project.

Hardee, S. E. 2008. Movements and Home Range of Harbor Seals (Phoca vitulina) in the Inland Waters of the Pacific Northwest.

Raum-Suryan, K. L., M. J. Rehberg, G. W. Pendleton, K. W. Pitcher, and T. S. Gelatt. 2004. Development Of Dispersal, Movement Patterns, and Haul-Out Use by Pup and Juvenile Steller Sea Lions (Eumetopias Jubatus) in Alaska. Marine Mammal Science, 20(4), 823-850.

IR3-19 Roberts Bank Ecosystem Model – Validation: Ecotrophic Efficiency Values

Information Source(s)

EIS Volume 3: Section 10.3, Appendix 10-B, Appendix 10-C

CEAR Doc #547

Context

The Proponent, in Table 5 of CEAR Doc #547 (2.10 Balance Sheet (1.2.4)), provided input and output parameter values for unbalanced and balanced RB EwE model output results. The data included unbalanced and balanced Ecotrophic Efficiencies values.

According to Fisheries and Oceans Canada, once the Ecopath model was balanced, it was deemed to be fit for simulation. Many Ecotrophic Efficiencies (which control the transfer of biomass from prey to predators) were indicated to have been much less than one, even for taxa that would be expected to be close to one, such as carnivorous zooplankton. The low Ecotrophic Efficiencies of several functional groups suggested that full accounting of energy flows may not have been achieved (an Ecotrophic Efficiency of 1 indicates that 100% of the production of that particular group is being used by the system).

Information Request

For each functional group, provide a rationale for the specific Ecotrophic Efficiency values presented in the EIS and include explanations as to why the Ecotrophic Efficiencies of many functional groups were less than one.

VFPA Response

This response provides an overview of the ecotrophic efficiency (EE) output of the Roberts Bank ecosystem model (RB model), using carnivorous zooplankton as an example. The response presents the key run EE values for each functional group as well as the range of functional group specific EE values calculated as part of the 'crab mortality' Monte Carlo (MC) sensitivity analysis[1]. The results of the sensitivity analysis show that by varying the input parameters, a range of EE values for each functional group was analysed (with analyses confirming that productivity changes from terminal and causeway placement are relatively small).

[1] IR3-09 'crab mortality' MC sensitivity analyses are used because they include the wide confidence intervals used for CEAR document #547 and Dungeness crab fishing mortality, making this MC analyses the most conservative model to compare the key run with.

The response also provides a rationale for why all the EE values for each functional group are less than 1.

Ecotrophic Efficiency Overview

The EE value is the fraction of production that is used or consumed within the system being modelled (i.e., in the RB model study area), and this value will often approach 1 for groups that are subject to heavy predation or fishing pressure:

- Functional groups with an EE value of 0 means the model assumes no predation of that group in the model (e.g., southern resident killer whales have an EE value of '0' which indicates they are not consumed in the RB model study area);
- Functional groups with EE values closer to 0 are those at low trophic levels (e.g., primary producers such as eelgrass (EE of 0.04)) and those with little predation pressure (e.g., dogfish (EE of 0.004) which is a small component of only four predators with broad diets);
- An EE value of 0.5 indicates that half (50%) of the prey production is consumed within the model study area (e.g., carnivorous zooplankton (EE of 0.48)); and
- An EE value approaching 1 means a greater proportion of the functional group is used or consumed[2]; the highest EE value in the RB model is juvenile salmon at 0.99, indicating the model calculates high predation pressure on this functional group (e.g., 99% of juvenile salmon in the RB model are consumed by predators[3]; see discussion below on marine biophysical valued component specific EE values in the RB model).

In ecosystem modelling, EE values are rarely measured directly and typically do not exist in the literature; normally, biomass, production, consumption, and diets are inputs of Ecopath with Ecosim and Ecospace (EwE) models, while EE is an output, which is calculated by the EwE model (Christensen et al. 2005). However, in cases when data on biomass are not available, EE values can be set to allow the model to calculate the missing biomass parameter (Christensen and Walters 2004).

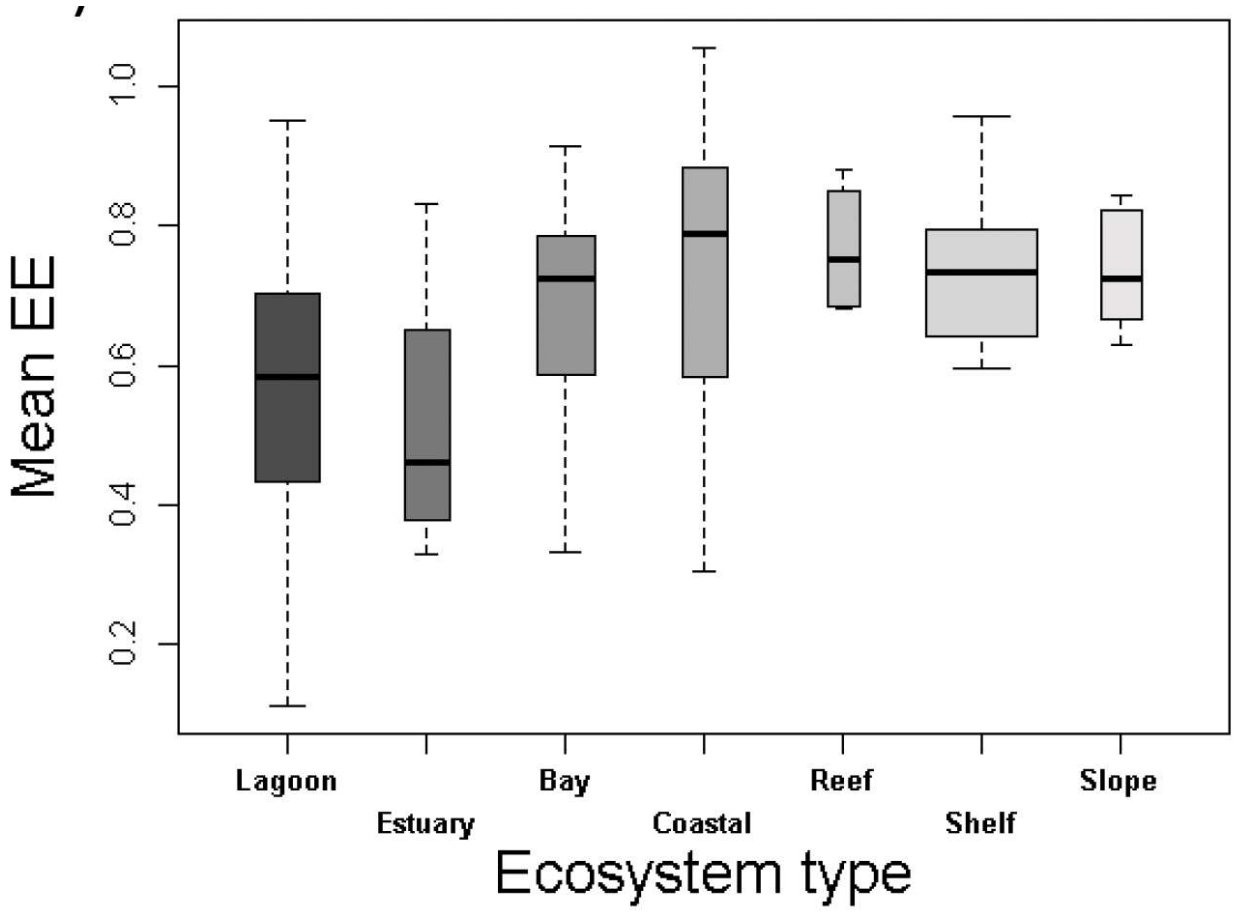
Generally, the whole range of EE values (0 to 1) can be found in nature, and EwE models, like the RB model, can be expected to include large ranges in EE values (Christensen et al. 2005), especially in an estuarine open system like Roberts Bank with many functional groups and trophic linkages between those groups (Heymans 2016). Hence, an EE less than one does not imply that a full accounting of energy in the ecosystem has not been achieved (as indicated in the context).

Smaller, shallower systems such as estuaries generally have lower mean EE values (~0.44) due to shorter residence times, with a larger proportion of species that either migrate in and out of the system, decreasing their use in the system, thus increasing the unexplained mortality in that system (**Figure IR3-19-1**, Heymans et al. 2014). The RB model mean

[2] A theoretical EE value of 1 indicates that a prey's production is entirely consumed, fished, or explained through net migration or biomass accumulation.
[3] This number is consistent with their known biology as indicated by their brief residency time and high mortality rate (Levings 2016).

EE value of 0.38 falls within the likely range of mean EE values for estuarine models (**Figure IR3-19-1**).

Figure IR3-19-1 Boxplot of Global Mean Ecotrophic Efficiency Values for Habitat Types, including Estuary Habitats



Note: The smallest observation (minimum), lower quartile, median, upper quartile, largest observation (maximum), and outliers are indicated. The boxes are drawn with widths proportional to the square-roots of the number of observations in each class.
Mean EE = mean ecotrophic efficiency (proportion).

Source: Heymans et al. 2014.

Carnivorous zooplankton are used here as an example to describe the EE approach used in the RB model. Following balancing (for overview on balancing see CEAR document #547, question 2.9), the RB model calculated an EE value of 0.48 for carnivorous zooplankton. Not all carnivorous zooplankton production generated within the Roberts Bank study area are expected to be used within the RB model study area. However, carnivorous zooplankton are pelagic and are broadly distributed by tides and currents, with oceanic circulation transporting carnivorous zooplankton outside of the Roberts Bank study area to adjacent areas (Shanks 2009). Therefore, the RB model EE value for carnivorous zooplankton is realistic for the system being modelled (Roberts Bank and RB model study area as indicated in the context;

also, see **Figure IR3-19-1** above which shows that an EE of 0.48 for carnivorous zooplankton falls within the estuarine mean EE range).

How Ecotrophic Efficiency Values in the Roberts Bank Ecosystem Model were Determined and Related Sensitivity Analyses

The RB model calculated EE values[4] (based on the master balance equation (Polovina 1984)) based on the input of four parameters (biomass, production, consumption, and diet). Hence, EE values calculated by the RB model are location specific, based on local field data and reflect the potential for prey to move in and out of the RB model study area.

Related MC sensitivity analyses were conducted (based on EIS values from Appendix 10-D and new information presented in IR3-09; referred to here as the 'crab mortality' MC sensitivity analysis) to assess sensitivity of the RB model to variation in input parameters. In the 'crab mortality' MC sensitivity analysis there were many models with carnivorous zooplankton EE values that were near 1; however, this produced little variation in model outputs (**Figure IR3-19-2;** i.e., the red dashed lines in the 'biomass ratio' panel o**f Figure IR3-19-2**, for the EIS histogram and the 'wider CI crab F' histogram are nearly identical and the range of biomass ratios is the same).

Figure IR3-19-2 represents MC inputs (biomass, production, and consumption) and MC outputs (EE values, biomass ratio) for the 4,000 EIS model runs (pink bars) and 6,000 model runs for IR3-09 (blue bars), which included wider confidence intervals and Dungeness crab harvest. The input frequency histograms (top part of **Figure IR3-19-2**) show the number of times (y-axis) a parameter value (x-axis) was used for the total range of values used in or calculated for the MC analyses. The output frequency histograms (bottom part of **Figure IR3-19-2**) show the number of times and the range of output EE value and biomass ratio values, which were calculated. See **Appendix IR3-19-A** for similar MC figures for each functional group.

Each alternative model (i.e., the frequency on the y-axis of **Figure IR3-19-2** represents the number of models; for example, in **Figure IR3-19-2** a frequency of 1,000 would indicate a 1,000 models) represents new combinations of input parameters that are randomly varied within defined confidence intervals for each group and creates a different EE value. The range of EE value examined for carnivorous zooplankton ranged from 0.2 to 1 (**Figure IR3-19-2**).

Moreover, given that sensitivity analyses were conducted on these input parameters (as described above; to evaluate potential sources of uncertainty), the EE values were also, indirectly, evaluated for uncertainty. For example, the 'crab mortality' MC sensitivity analysis conducted in IR3-09, included a biomass range for carnivorous zooplankton from 6 tonnes per kilometre (t/km^2) to 53 t/km^2 (**Table IR9-19-1**). MC simulations across this range of zooplankton biomass did not affect the distribution of forecast changes in productivity or biomass of carnivorous zooplankton (and all other functional groups presented in

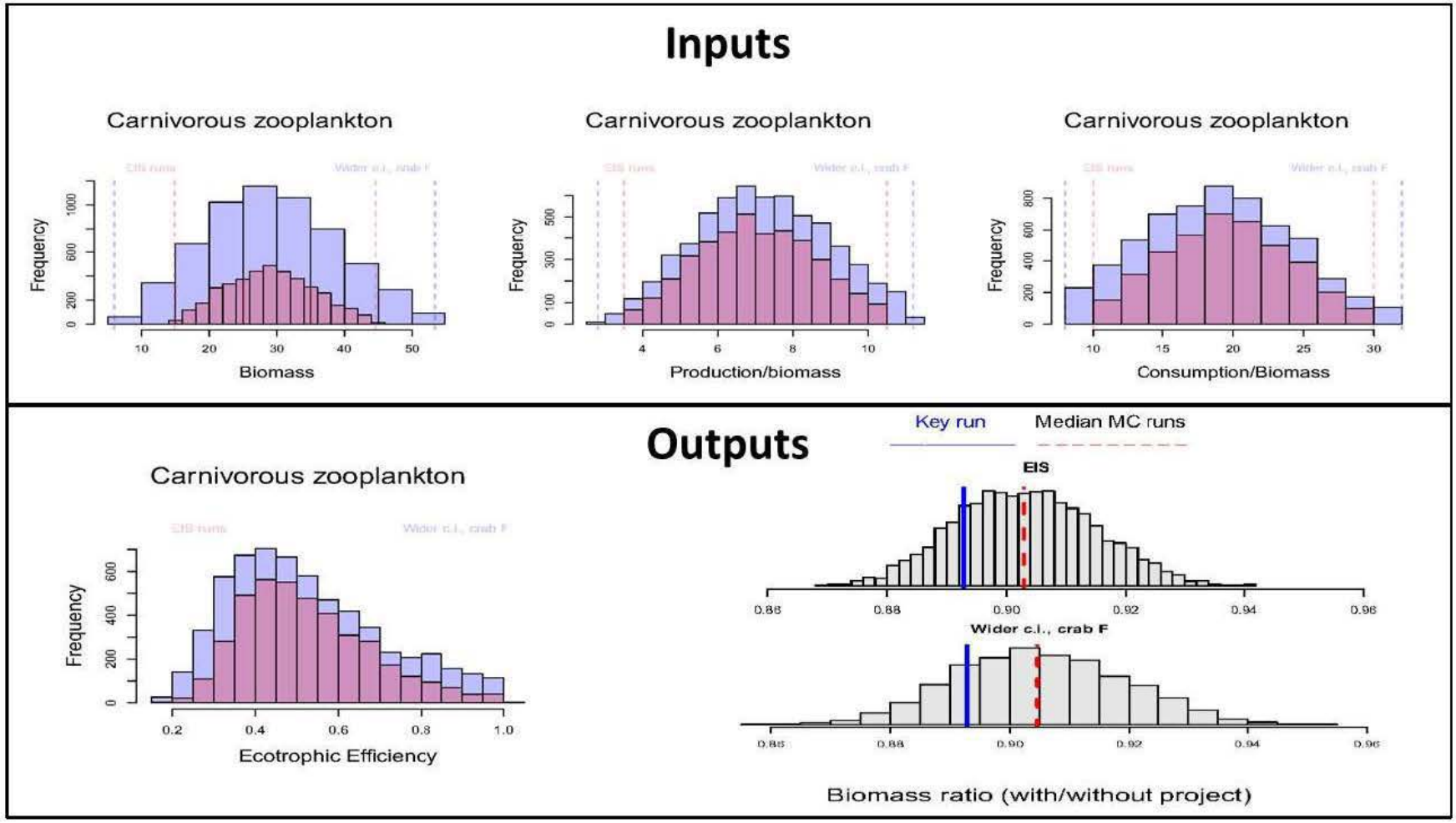
[4] Note one EE value was assigned manually (adult salmon, EE value of 0.5) because a reliable estimate of biomass was not available.

Appendix IR3-19-A), with and without the terminal and causeway footprint (**Figure IR3-19-2**) (see CEAR Document #900[5], p.20 for similar conclusion).

Therefore, the range of EE values calculated by the RB model based on all of the other model assumptions (e.g., B, P/B, Q/B, diet) are generally comparable to the range of EE values estimated in other applications of the EwE modelling approach (Heymans et al. 2014). The results of multiple sensitivity analyses provide confidence that varying EE values do not affect the stability of the EIS estimates of potential changes in biomass and productivity due to the terminal and causeway footprint .

[5] CEAR Document #900 From the Review Panel Secretariat to the Review Panel re: Technical Review of Roberts Bank Terminal 2 Environmental Assessment: Section 10.3 - Assessing Ecosystem Productivity - by Fisheries and Oceans Canada.

Figure IR3-19-2 Frequency Histogram of Biomass, Consumption, and Production Inputs, and Ecotrophic Efficiency Values and Ratio Outputs for Carnivorous Zooplankton from the Monte Carlo Analyses (extracted from Appendix IR3-19-A)



Note: Pink bars represent EIS MC runs and blue bars represent the additional MC analyses from CEAR Document #547. The term 'crab F', presented above refers to the specific MC analysis conducted for IR3-09 to evaluate the influence of inclusion of 'crab' fishing mortality in the RB model. The biomass ratio histogram presented above is specific to carnivorous zooplankton and not crabs.

Ecotrophic Efficiency Values in the Roberts Bank Ecosystem Model

All but one EE value was calculated by the RB model; the adult salmon group was assigned an EE value of 0.5 based on rationale which has not previously been presented[6].

To evaluate potential uncertainty in EE values generated by the RB model, MC sensitivity analyses (as described above and based on the 'crab mortality' MC sensitivity analyses presented in IR3-09) were undertaken for all functional groups. The following discussion presents how these 'crab mortality' MC sensitivity analyses, by functional group used in the RB model, evaluate potential uncertainty in EE values. In summary, despite large artificial changes in EE values (via the 'crab mortality' MC sensitivity analyses), potential productivity changes with and without terminal and causeway footprint placement remain small (as indicated in the EIS).

A tabular summary (**Table IR3-19-1**) of the 'crab mortality' MC sensitivity analysis is presented here as new information (and is based on the MC analysis undertaken in IR3-09). **Table IR3-19-1** compares the key run EE value (i.e., values presented in the EIS) and key run biomass ratio; additionally, the range of EE values (max/min) produced for the 'crab mortality' MC sensitivity analyses is compared with the range of biomass ratio outputs for the 'crab mortality' MC sensitivity analyses.

Table IR3-19-1 Key Run Ecotrophic Efficiency Values and Key Run Biomass Ratios with 'Crab Mortality' Monte Carlo Sensitivity Analyses Ecotrophic Efficiency Value Range and Biomass Output Range

Group Name	Key Run		'Crab Mortality' MC Sensitivity EE Range		'Crab Mortality' MC Sensitivity Biomass Ratio (with/without)
	Key Run EE Value	Key Run Biomass Ratio (with/without)	EE Value Min	EE Value Max	Biomass Ratio Median
Baleen whales	0.052	0.92	0.006	0.562	0.93
Dolphins and porpoises	0.780	0.97	0.101	1.000	0.97
Pinnipeds	0.915	0.97	0.132	1.000	0.97
S. res. killer whales	0.000	0.97	0.000	0.000	0.97
Transient killer whales	0.000	0.89	0.000	0.000	0.89
American wigeon	0.208	0.92	0.042	0.949	0.92
Bald eagle	0.000	0.93	0.000	0.000	0.92

[6] The adult salmon group was assigned an EE value of 0.5 because information on the amount of 'adult salmon' (as a functional group used in the RB model, which did not include adult Chinook and adult chum salmon because they are separate groups already included in the RB model) biomass in the RB model study area was not available; the EE value of 0.5 was chosen as a reasonable estimate based on professional judgement by the EwE team and reviewed by fisheries experts. The uncertainty of this EE value was assessed by the 'crab mortality' MC sensitivity analyses which examined a range of EE values (0.085 to 1.00), as later explained in this response.

Group Name	Key Run		'Crab Mortality' MC Sensitivity EE Range		'Crab Mortality' MC Sensitivity Biomass Ratio (with/without)
	Key Run EE Value	Key Run Biomass Ratio (with/without)	EE Value Min	EE Value Max	Biomass Ratio Median
Brant goose	0.025	0.95	0.006	0.088	0.95
Diving waterbirds	0.116	0.94	0.035	0.398	0.93
Dunlin	0.026	1.13	0.006	0.123	1.12
Great blue heron	0.000	1.00	0.000	0.000	0.98
Gulls and terns	0.811	0.99	0.167	1.000	0.97
Raptors	0.000	1.31	0.000	0.000	1.23
Shorebirds	0.295	0.98	0.067	0.996	0.96
Waterfowl	0.033	1.08	0.008	0.172	1.08
Western sandpiper	0.215	1.13	0.046	0.997	1.12
Chinook adult	0.118	0.95	0.023	0.998	0.95
Chinook juv.	0.435	1.16	0.168	0.989	1.10
Chum adult	0.070	0.95	0.015	0.552	0.96
Chum juv.	0.703	1.14	0.244	1.000	1.09
Dogfish	0.004	0.98	0.001	0.055	0.98
Flatfish	0.203	0.99	0.042	0.970	0.98
Forage fish	0.978	0.99	0.304	1.000	0.98
Herring	0.363	0.98	0.105	0.998	0.96
Large demersal fish	0.828	0.99	0.233	1.000	0.96
Lingcod	0.077	0.97	0.021	0.345	0.97
Rockfish	0.195	0.91	0.064	0.886	0.93
Salmon ad.	0.500	0.96	0.085	1.000	0.96
Salmon juv.	0.987	0.97	0.238	1.000	0.97
Sandlance	0.542	1.06	0.139	1.000	1.02
Shiner perch	0.941	1.18	0.251	1.000	1.10
Skate	0.363	0.92	0.083	0.999	0.92
Small demersal fish	0.945	0.95	0.285	1.000	0.94
Starry flounder	0.761	1.06	0.173	1.000	1.01
Carnivorous zooplankton	0.479	0.89	0.162	1.000	0.90
Dungeness crab	0.109	0.97	0.113	0.999	0.93
Epifaunal grazers	0.737	0.92	0.172	1.000	0.88
Epifaunal omnivore	0.819	0.98	0.243	1.000	0.93
Epifauna sessile	0.761	1.19	0.209	1.000	1.20
Infaunal bivalves	0.050	0.92	0.014	0.260	0.90
Jellyfish	0.516	0.92	0.113	1.000	0.92

Group Name	Key Run		'Crab Mortality' MC Sensitivity EE Range		'Crab Mortality' MC Sensitivity Biomass Ratio (with/without)
	Key Run EE Value	Key Run Biomass Ratio (with/without)	EE Value Min	EE Value Max	Biomass Ratio Median
Macrofauna	0.690	1.27	0.250	1.000	1.20
Meiofauna	0.612	1.11	0.219	1.000	1.09
Omniv. & herbiv. zooplk.	0.751	0.93	0.265	1.000	0.93
Polychaetes	0.103	0.89	0.036	0.507	0.87
Orange sea pen	0.029	0.45	0.008	0.110	0.45
Shrimp	0.913	0.87	0.262	1.000	0.88
Biofilm fresh	0.000	1.89	0.000	0.000	1.89
Biofilm marine	0.000	0.77	0.000	0.000	0.77
Brown algae	0.103	0.88	0.027	0.631	0.88
Native eelgrass	0.044	1.04	0.013	0.142	1.04
Green algae	0.073	0.92	0.016	0.595	0.91
Japanese eelgrass	0.948	0.99	0.210	1.000	0.99
Red algae	0.453	0.90	0.128	1.000	0.89
Phytoplankton	0.909	1.03	0.188	1.000	1.00
Tidal marsh	0.049	1.25	0.007	0.272	1.25
Biomat	0.001	0.71	0.000	0.005	0.71

In summary, **Table IR3-19-1** shows that even with a large (artificial) range of EE values used in the RB model (to evaluate potential uncertainty in EE values), the changes in productivity with and without the terminal and causeway footprint remain consistent with the results presented in the EIS.

Using pinnipeds as an example (**Table IR3-19-1**), the key run outputs had EE value of 0.915 and biomass ratio (with/without) of 0.97. The 'crab mortality' MC sensitivity analyses had an EE value range of 0.132 to 1.00 and a median biomass ratio of 0.97, showing no difference with the key run biomass ratio.

Why Ecotrophic Efficiencies in the Roberts Bank Ecosystem Model are Less than One

EE values greater than 1 are not thermodynamically possible (more prey being eaten than is present) and represent an unbalanced model that requires modification of the input values; therefore, all EE values in an EwE model must be at or less than 1 to be considered balanced (see EIS Appendix 10-C and CEAR document #547 for information on model balancing).

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Appendices

Appendix IR3-19-A Crab Mortality MC Sensitivity Analysis

APPENDIX IR3-19-A

CRAB MORTALITY MC SENSITIVITY ANALYSIS

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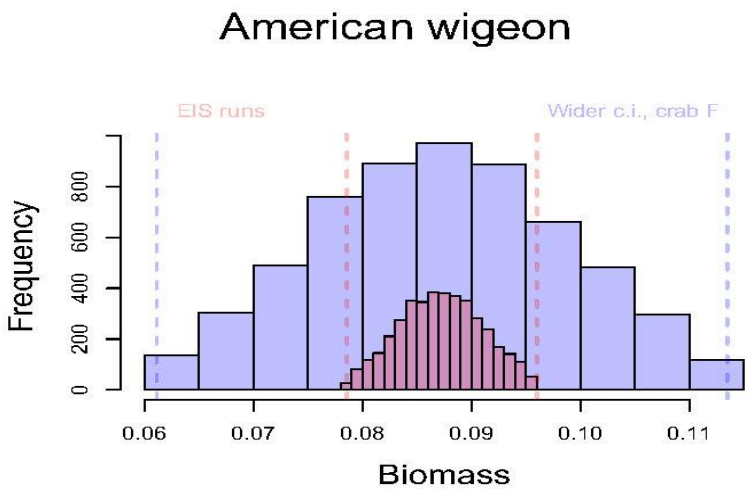
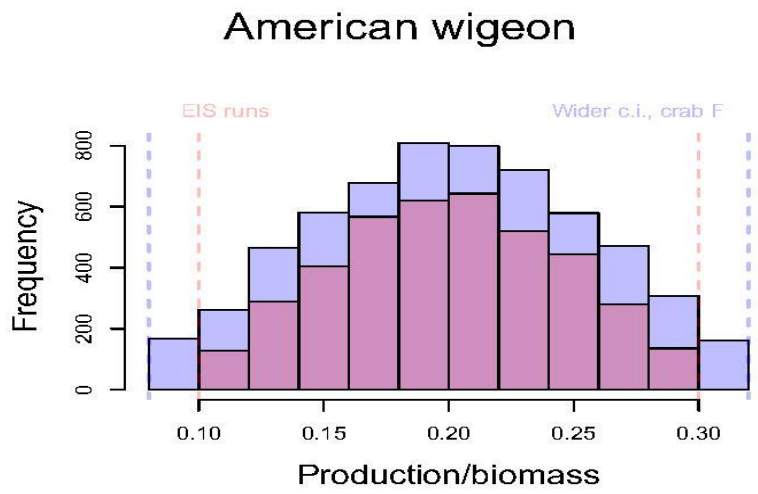
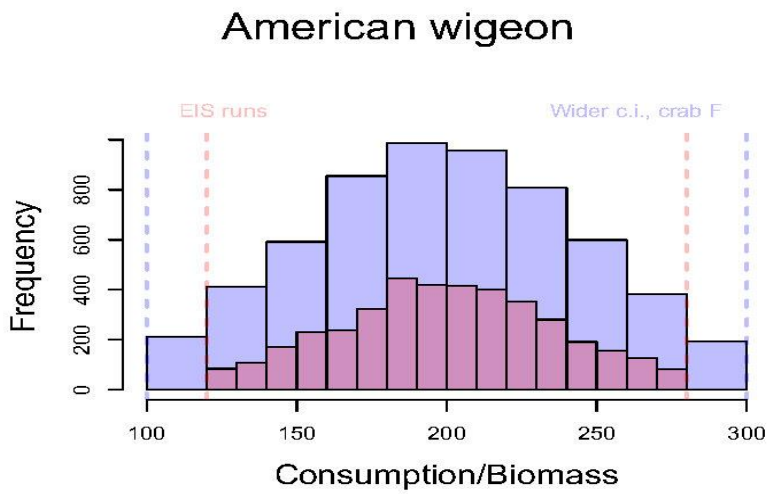
Inputs







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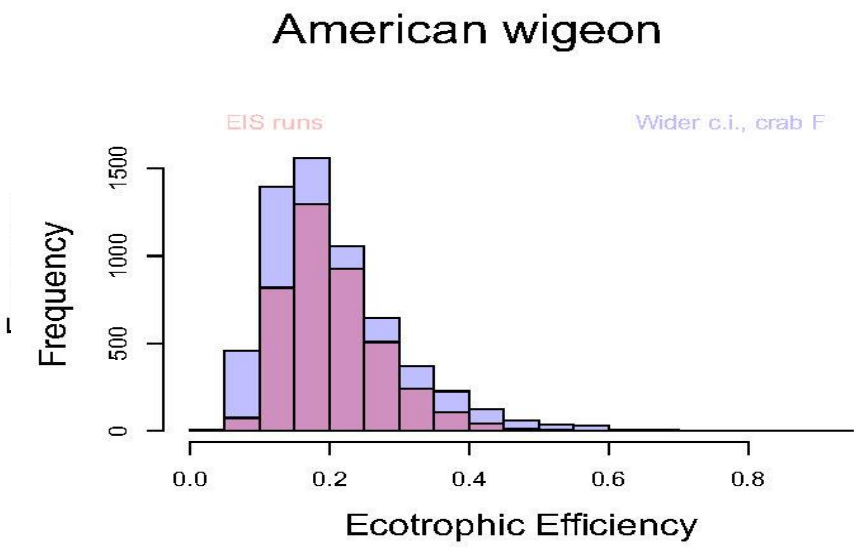

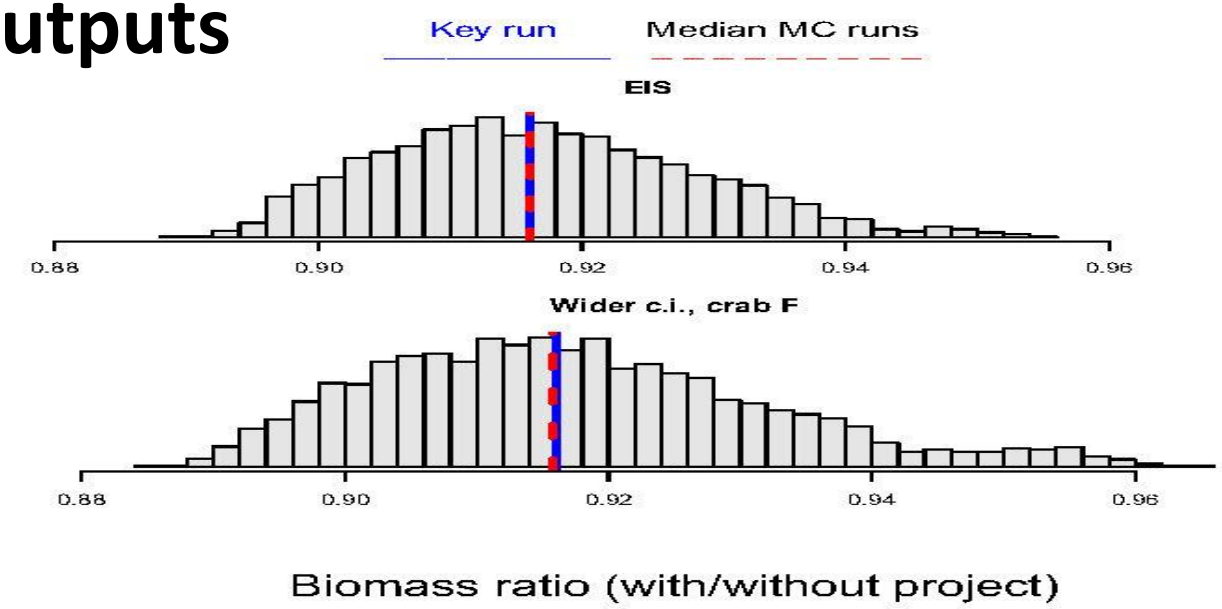

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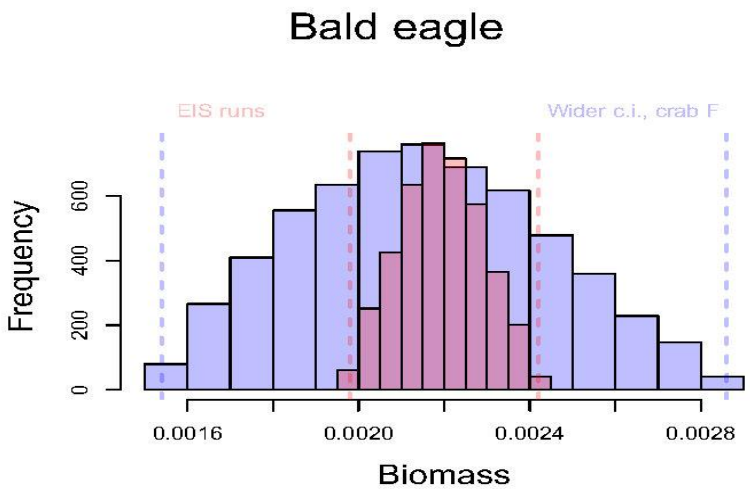

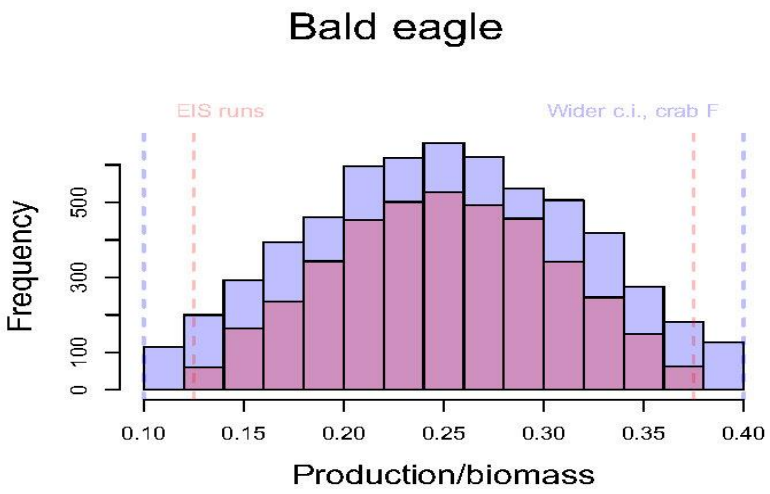

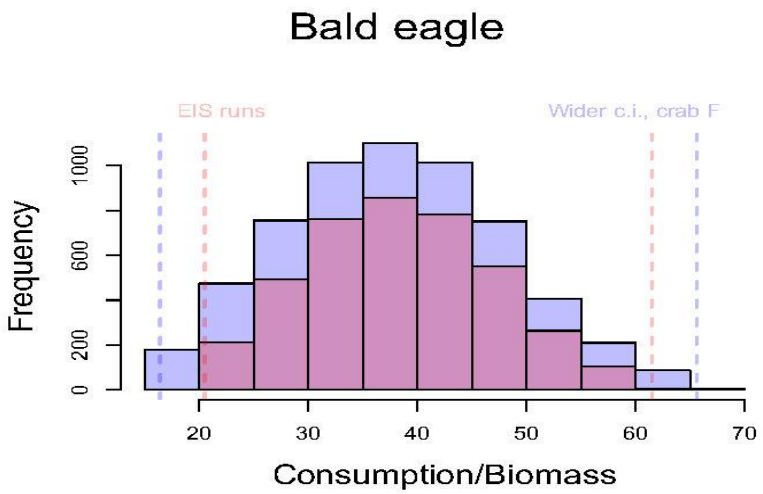

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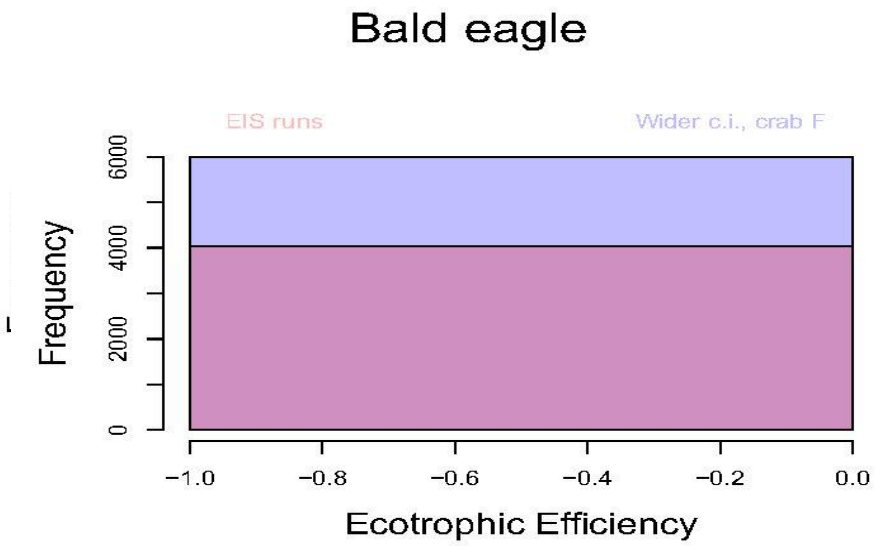

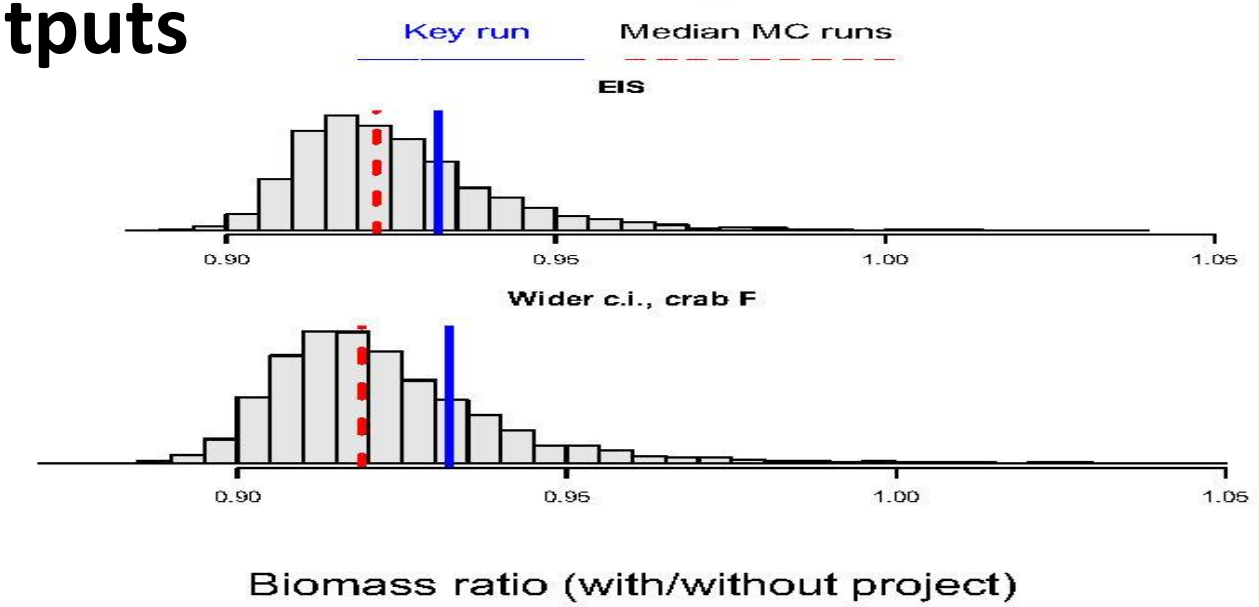

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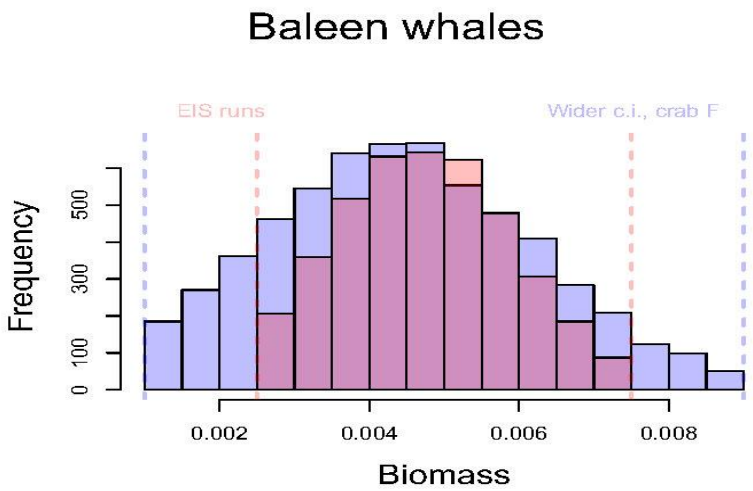

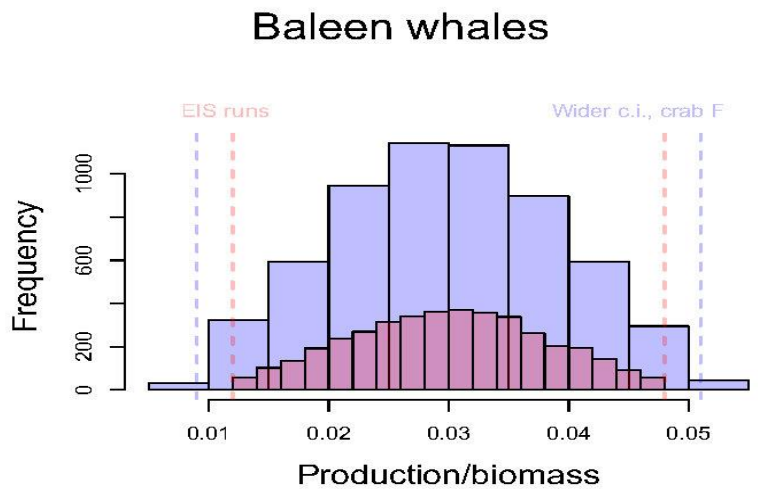

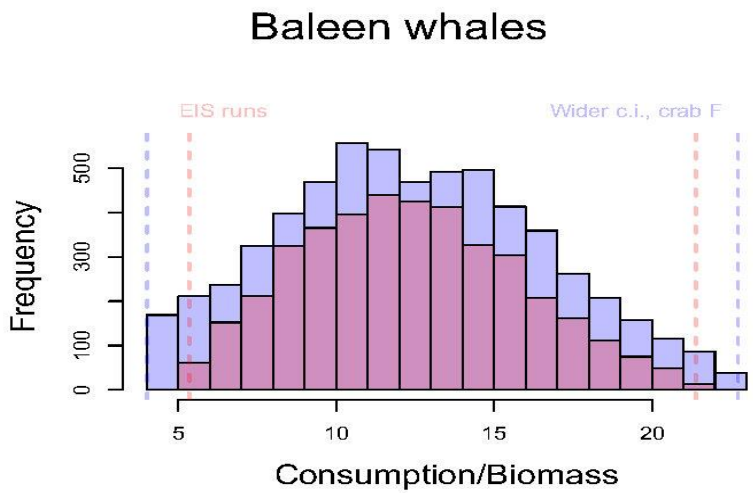

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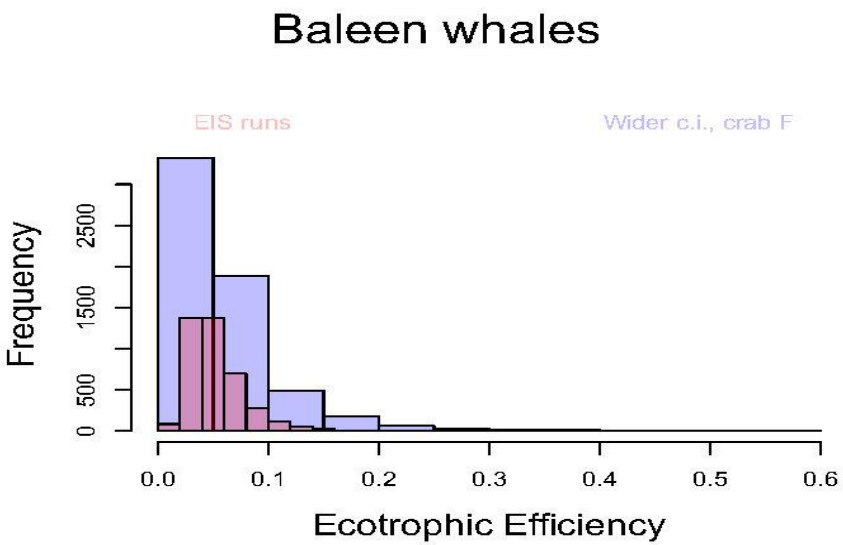

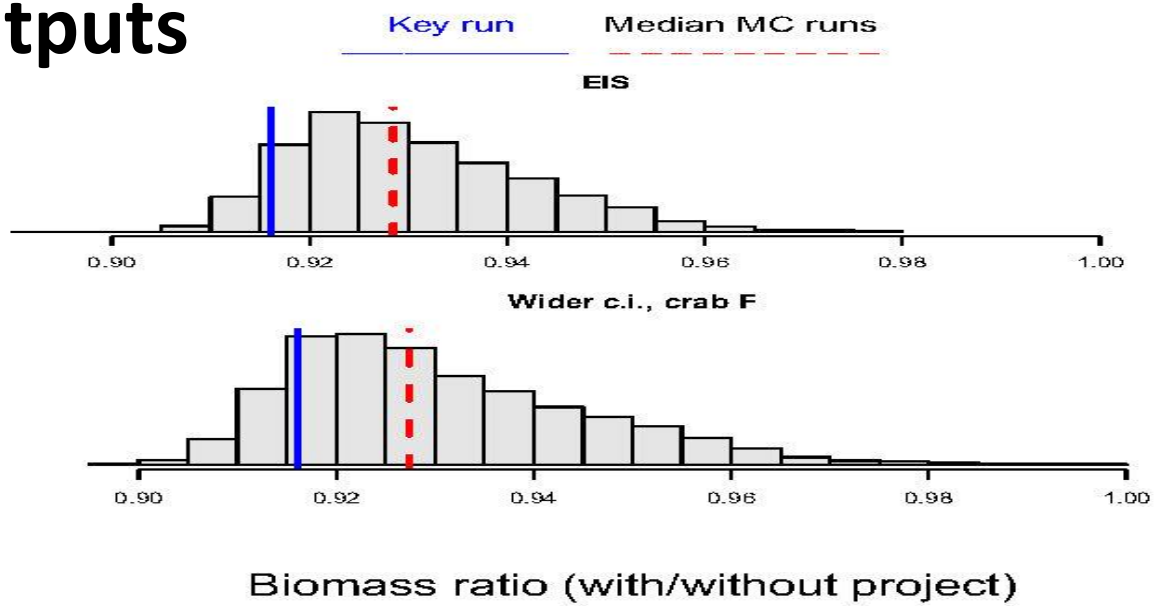

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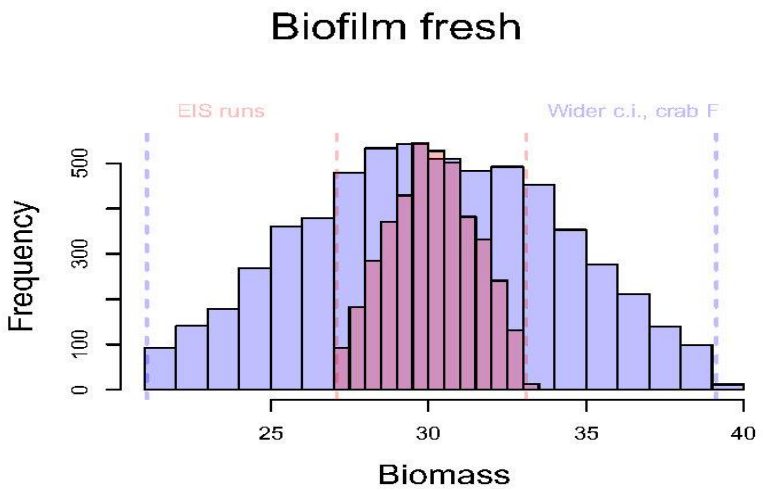

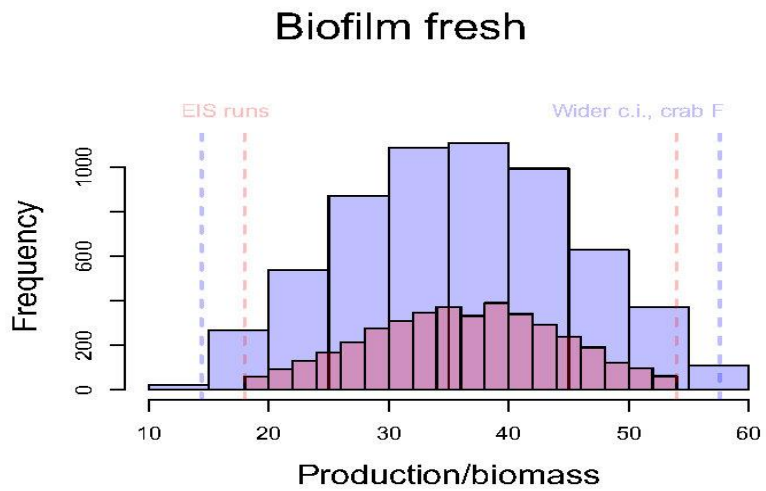

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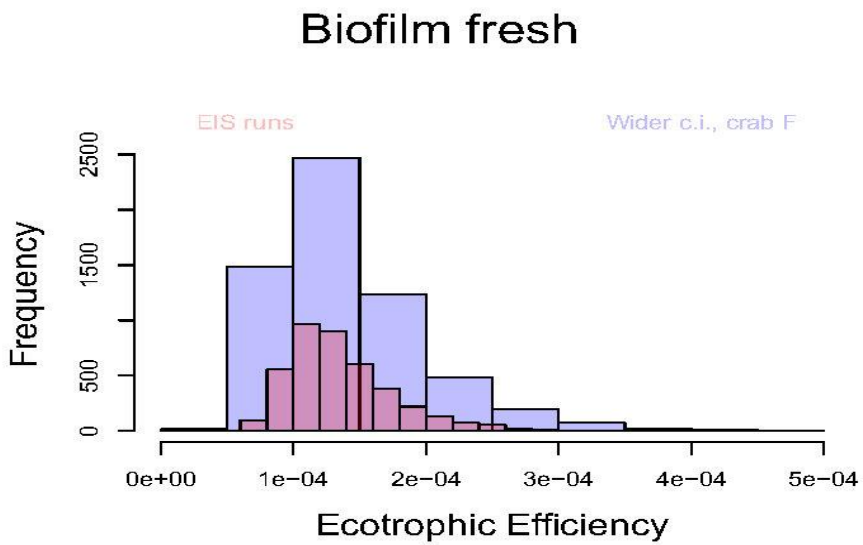

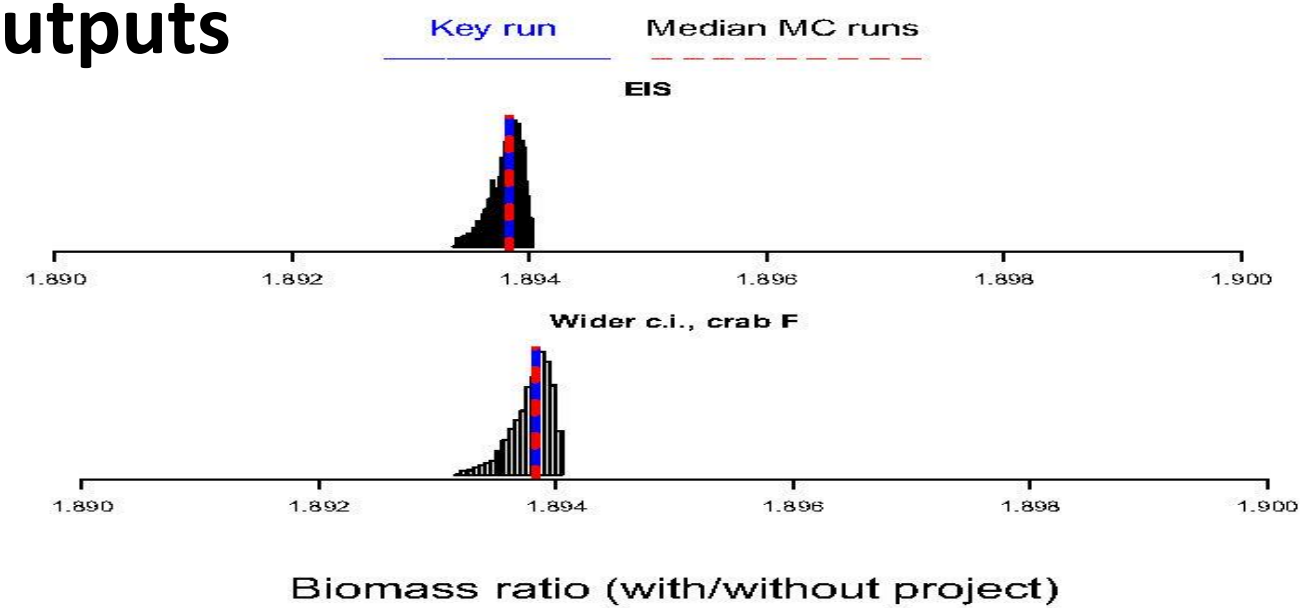

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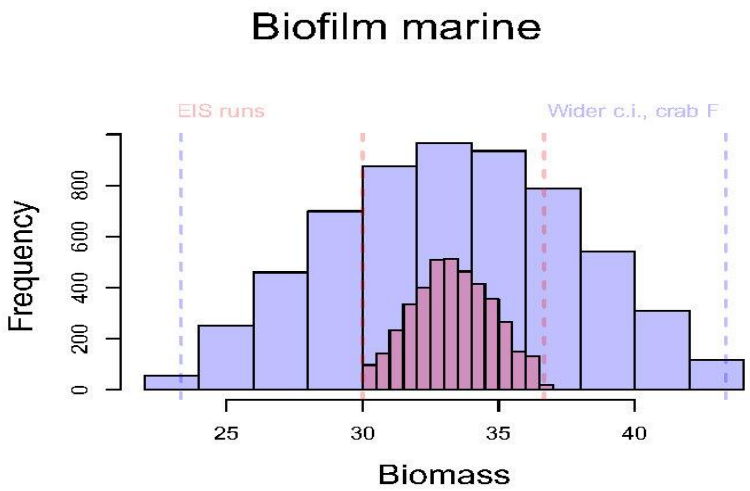

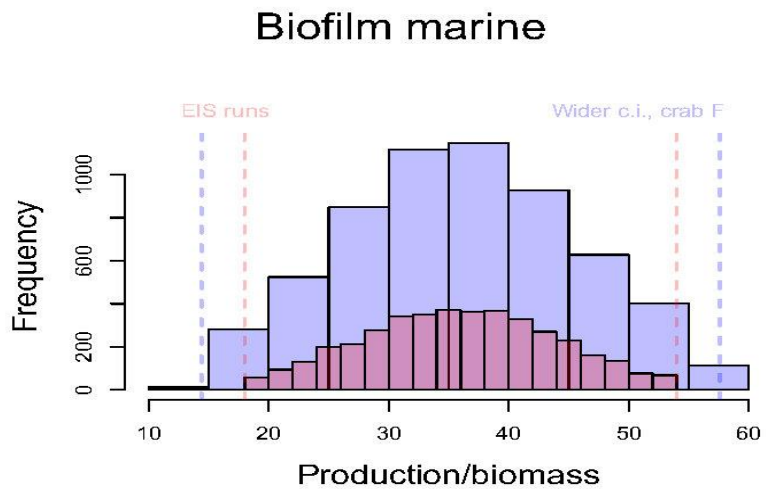

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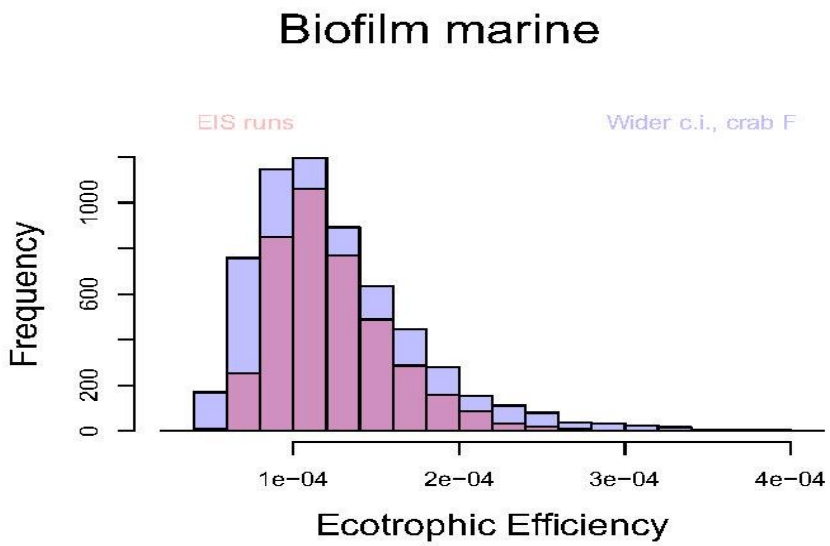

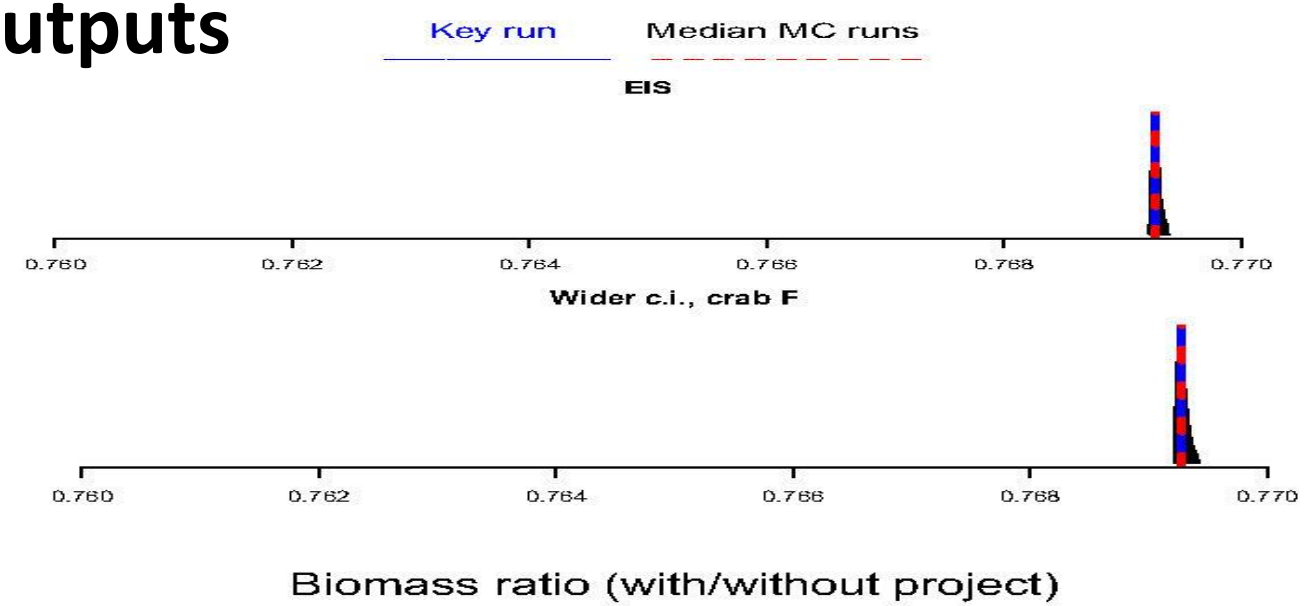

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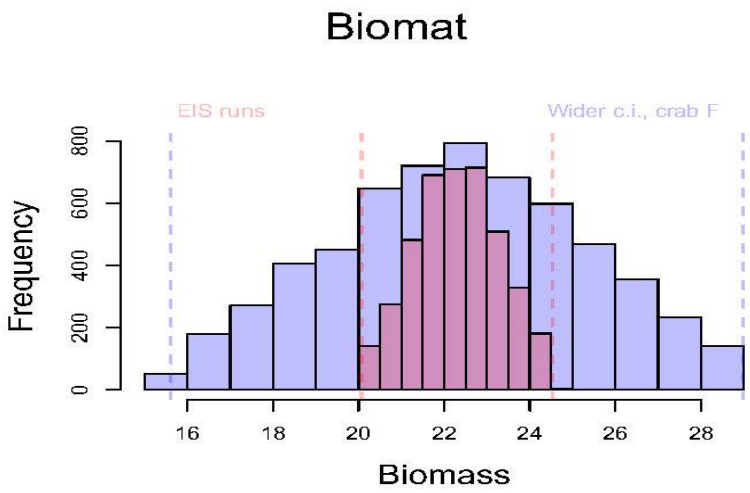

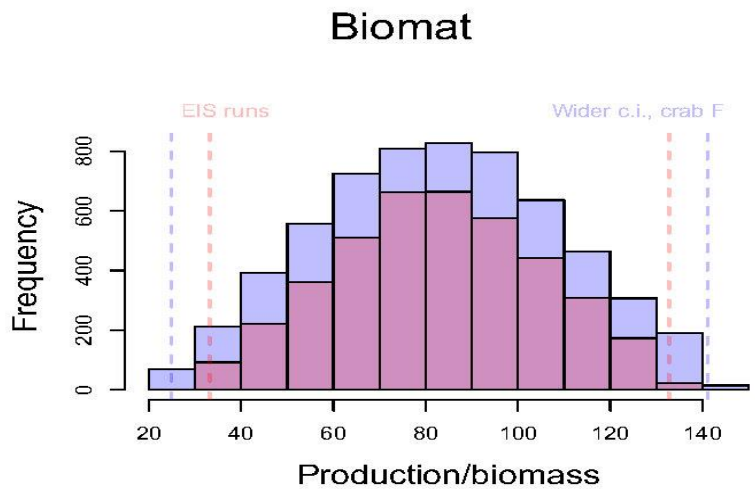

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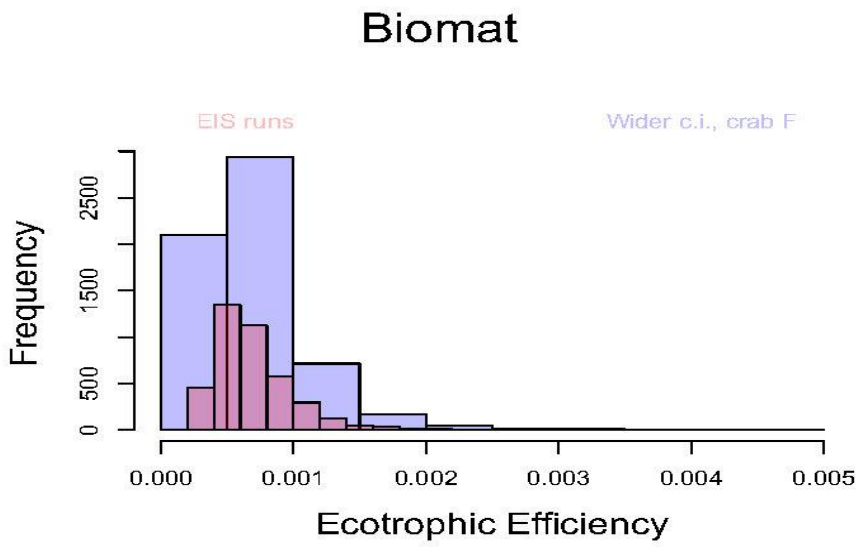

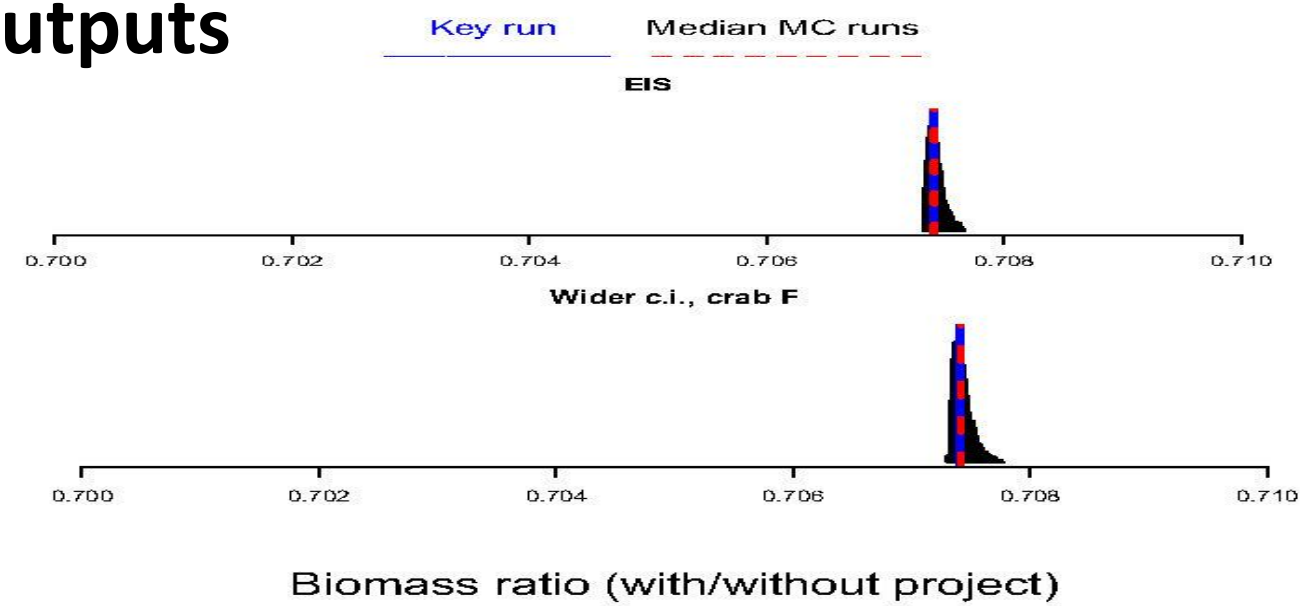

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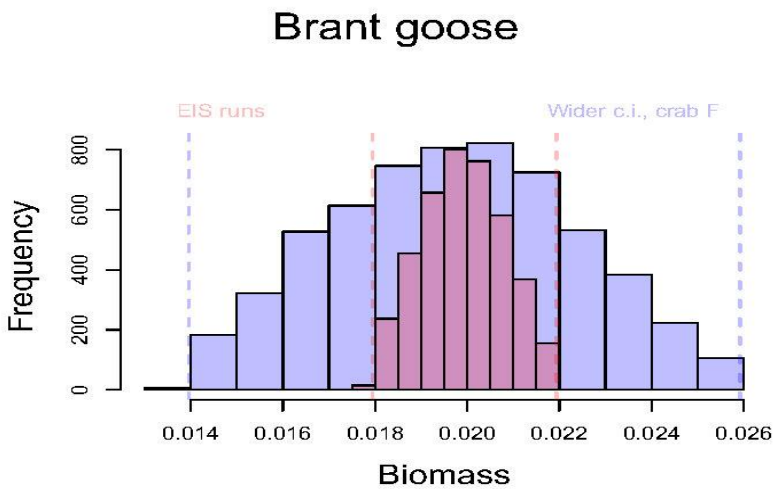

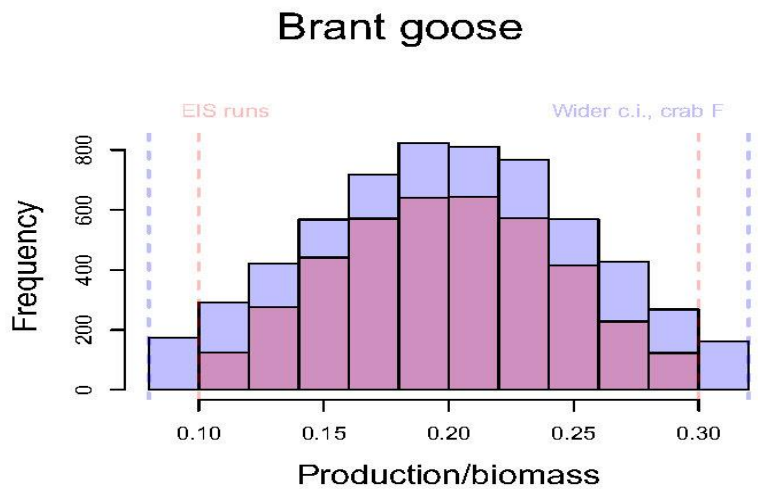

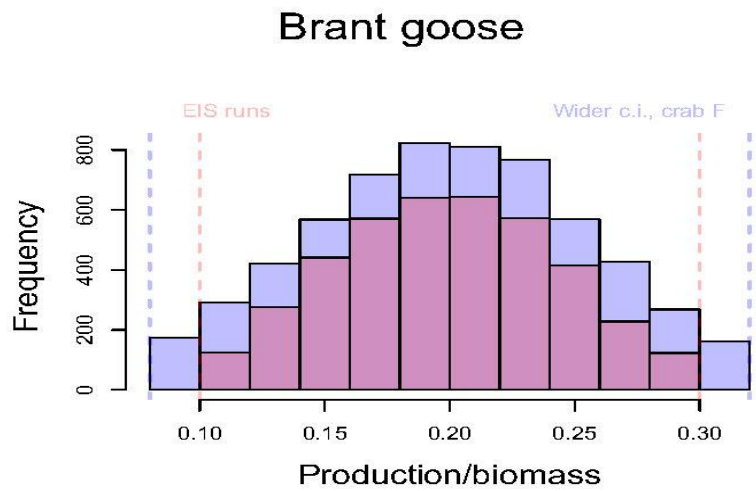

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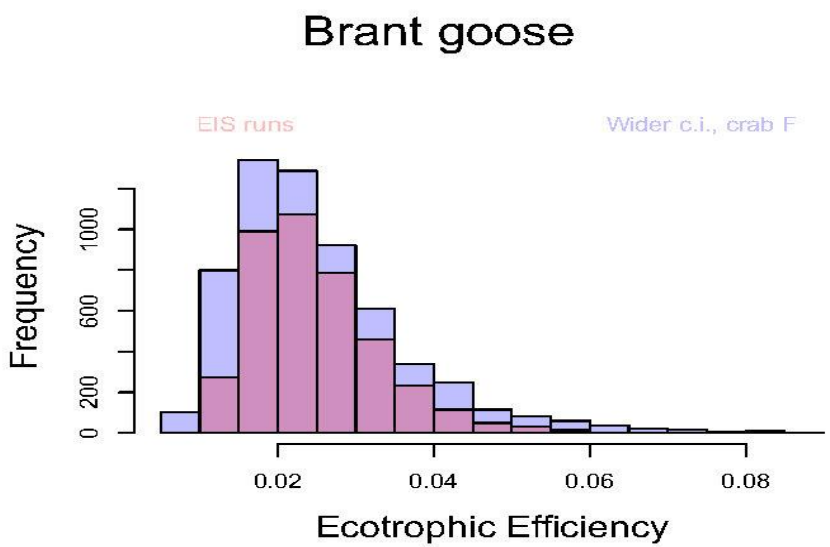

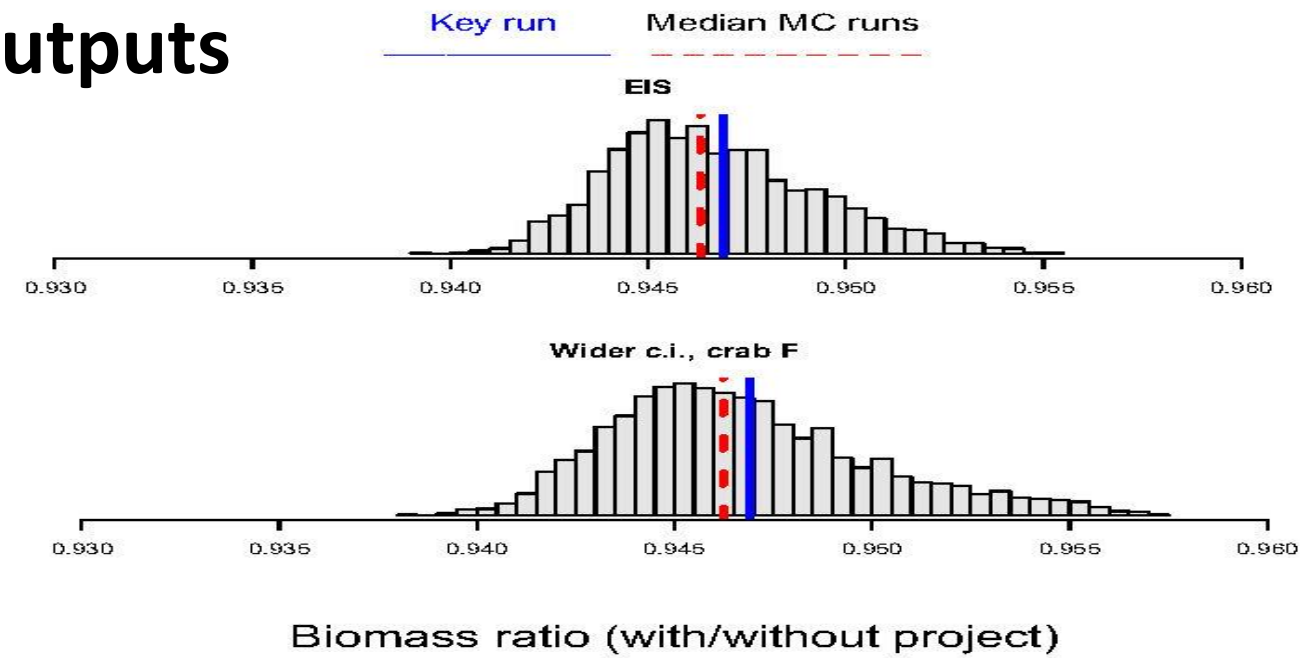

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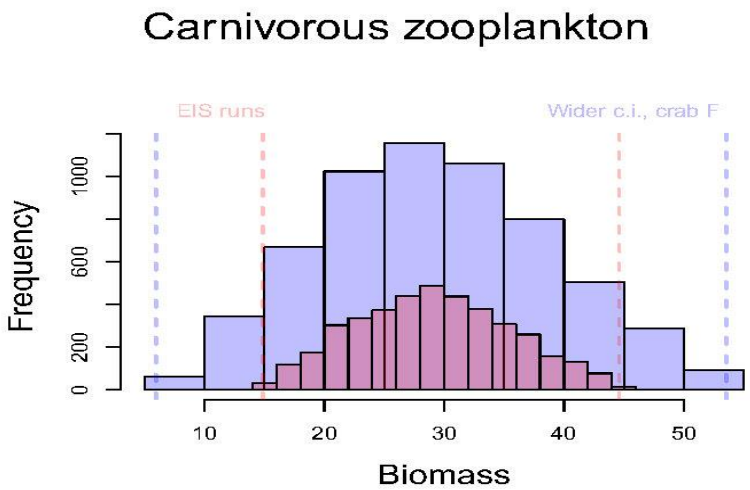

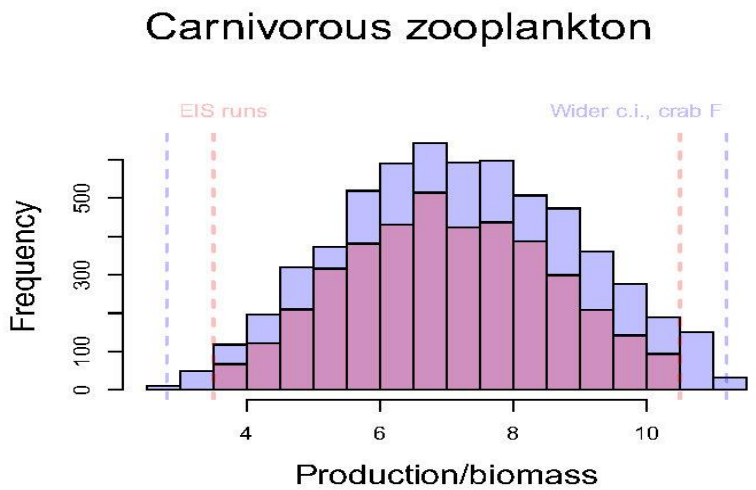

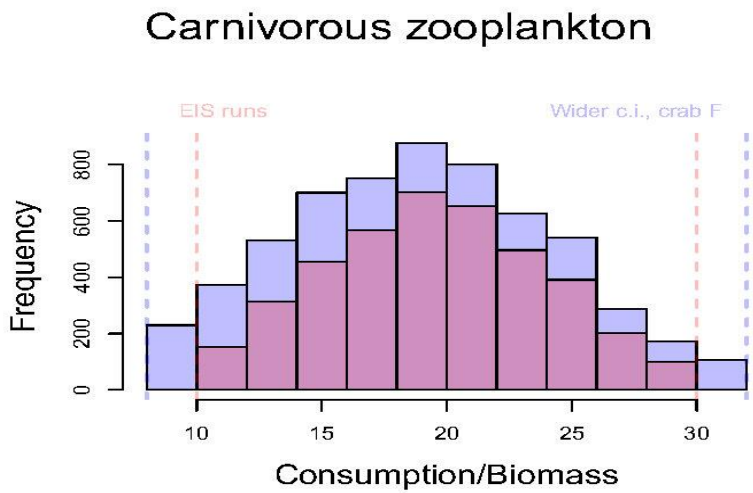

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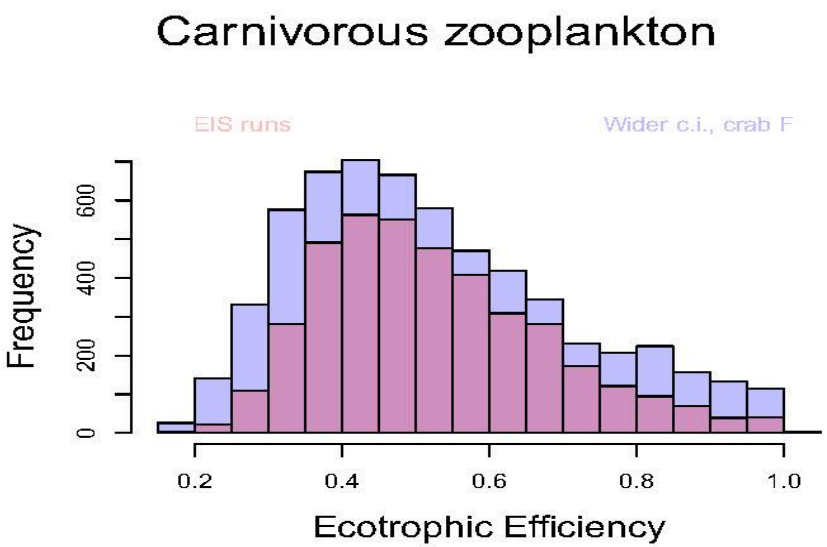

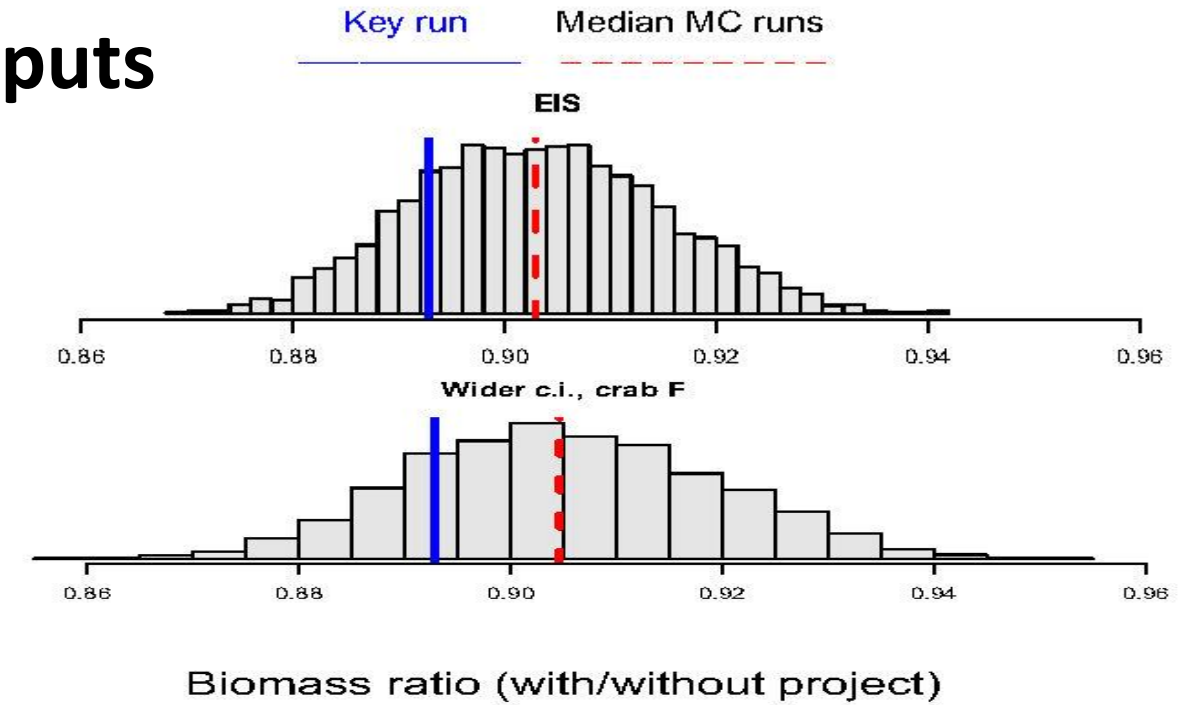

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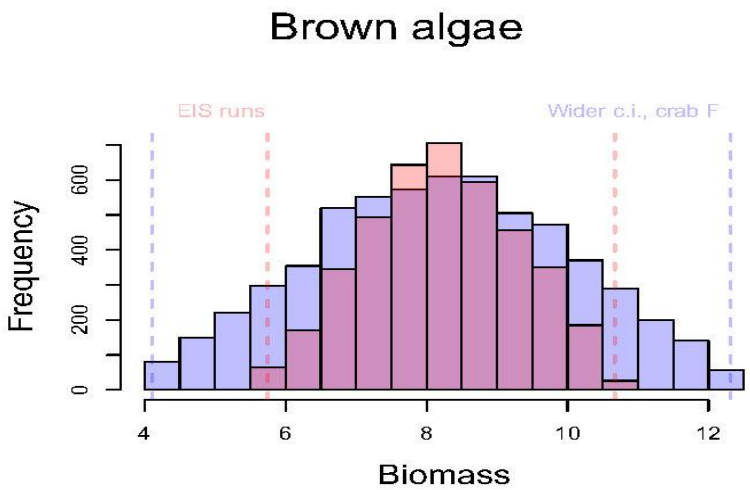

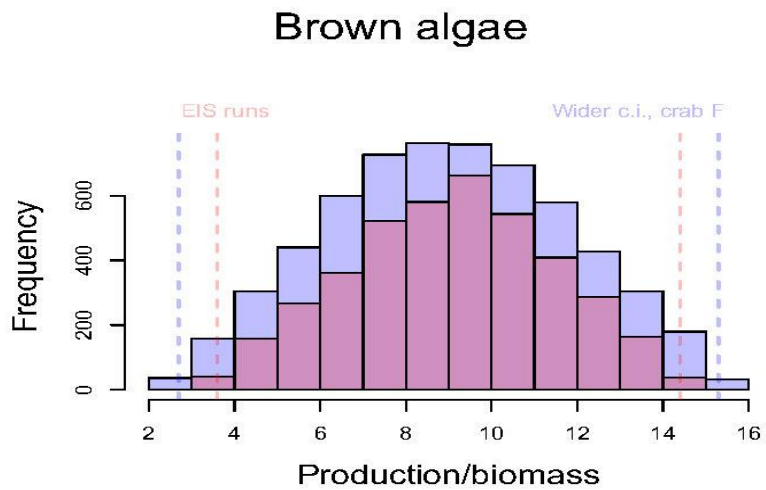

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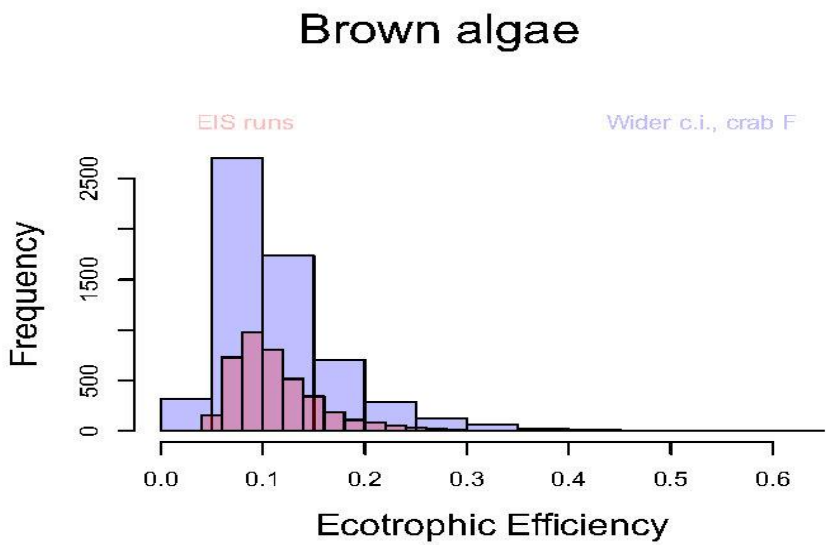

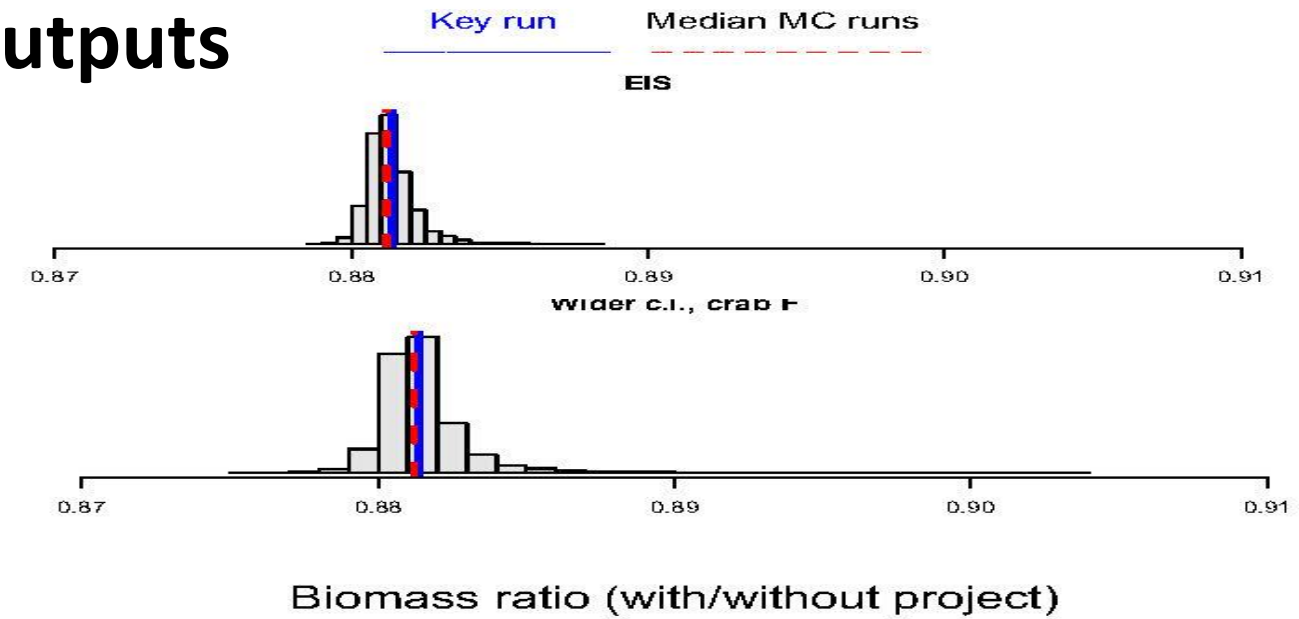

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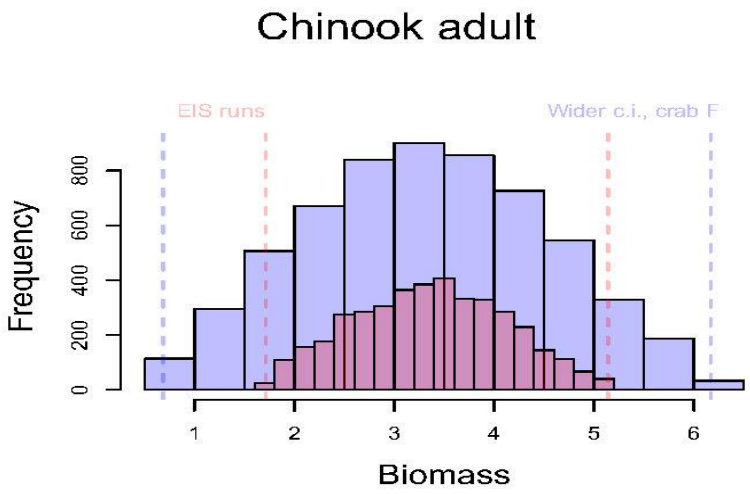

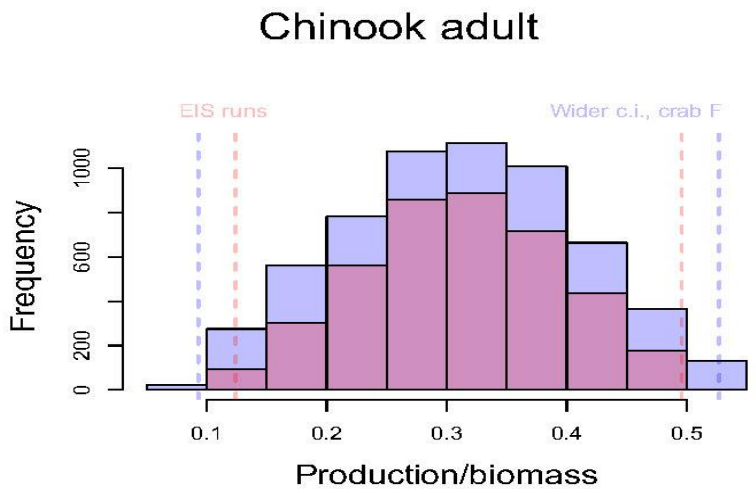

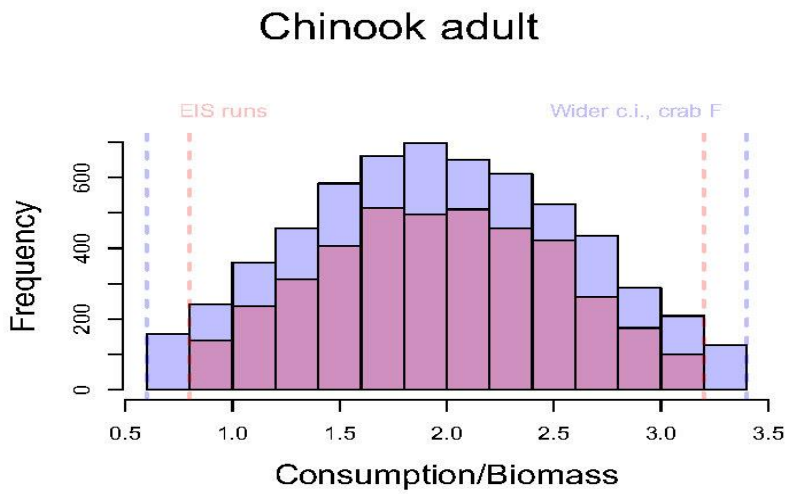

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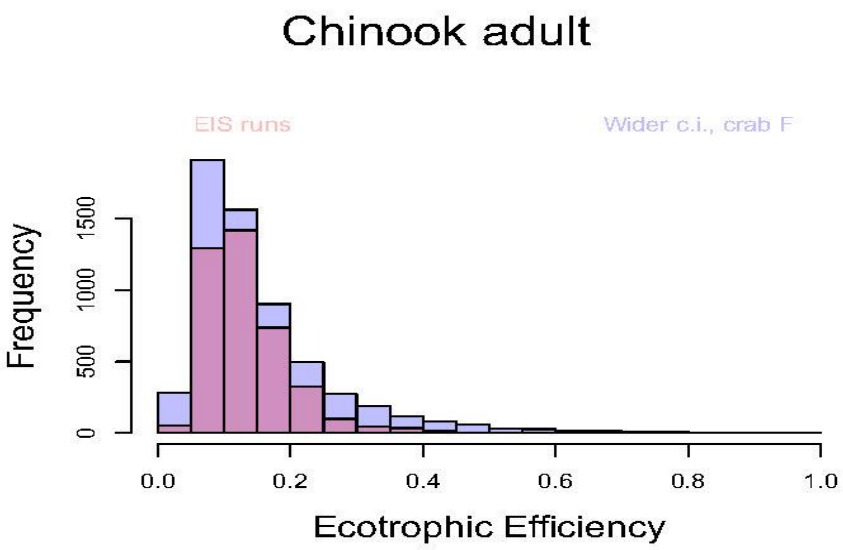

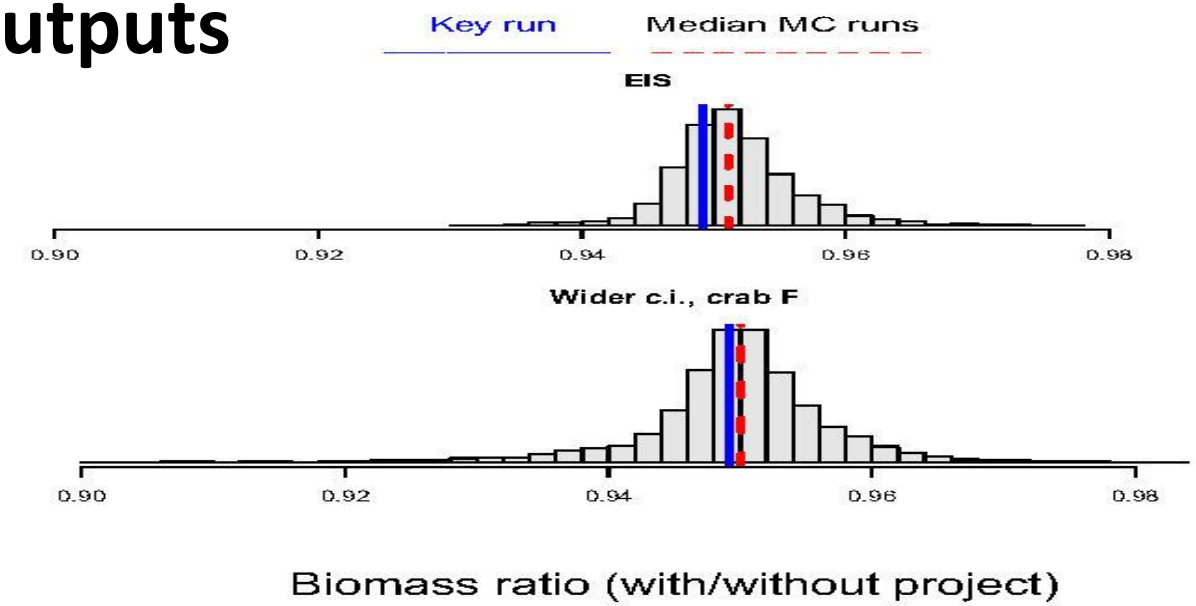

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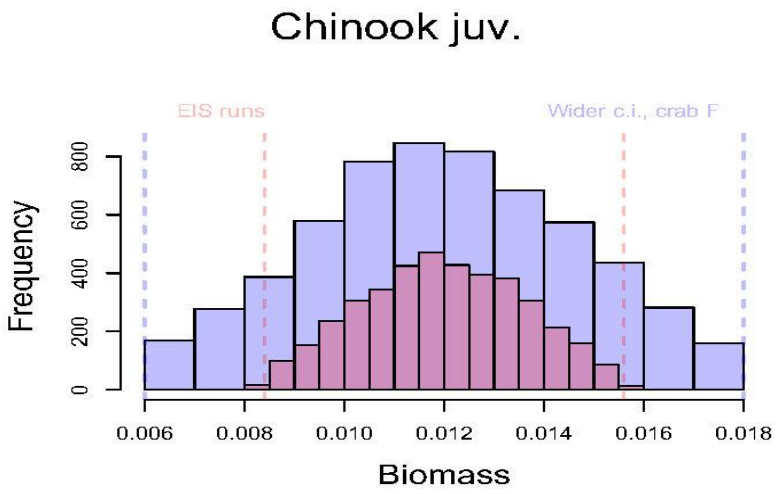

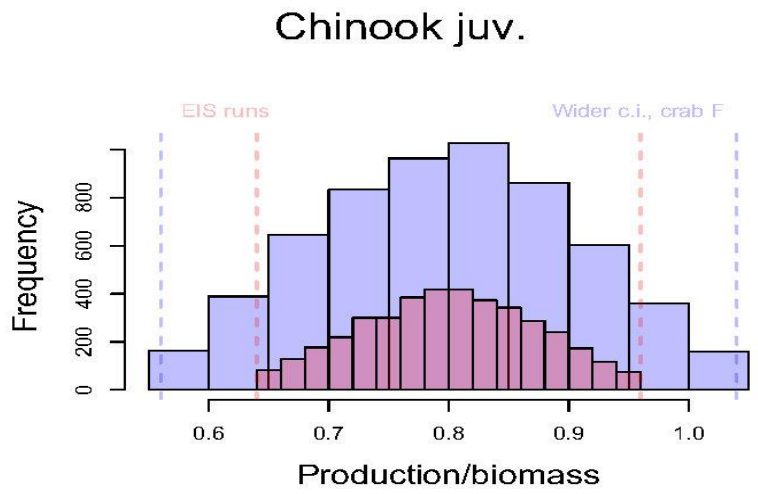

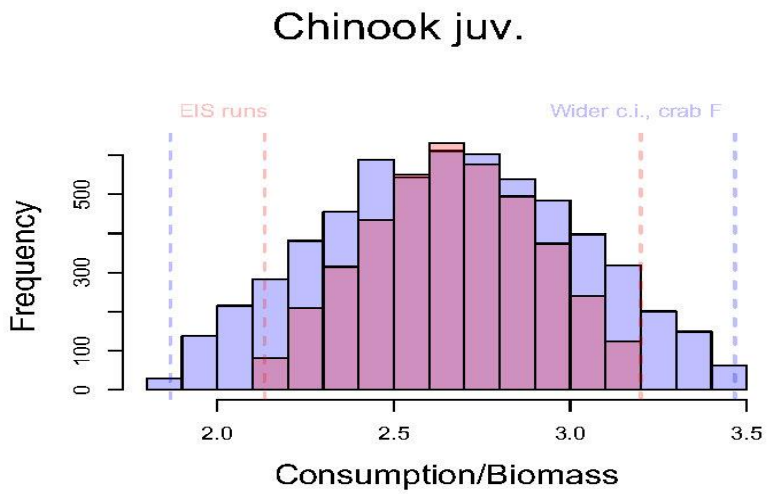

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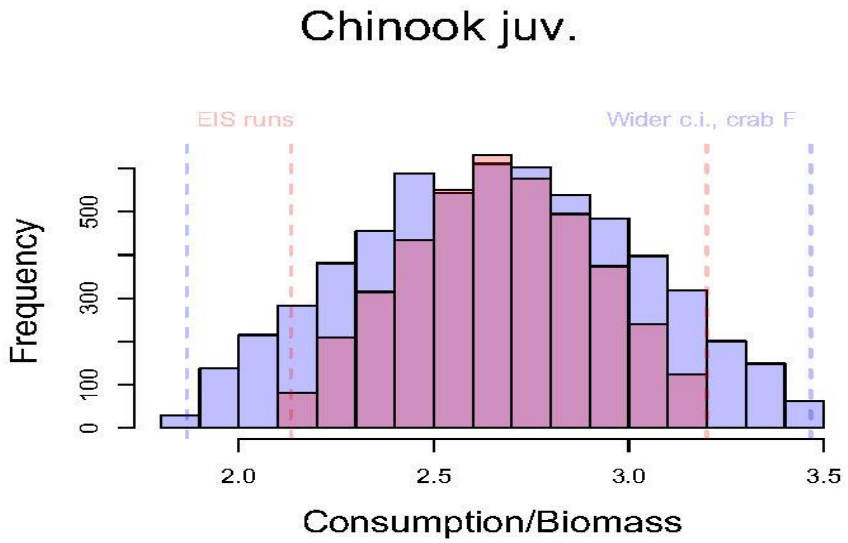

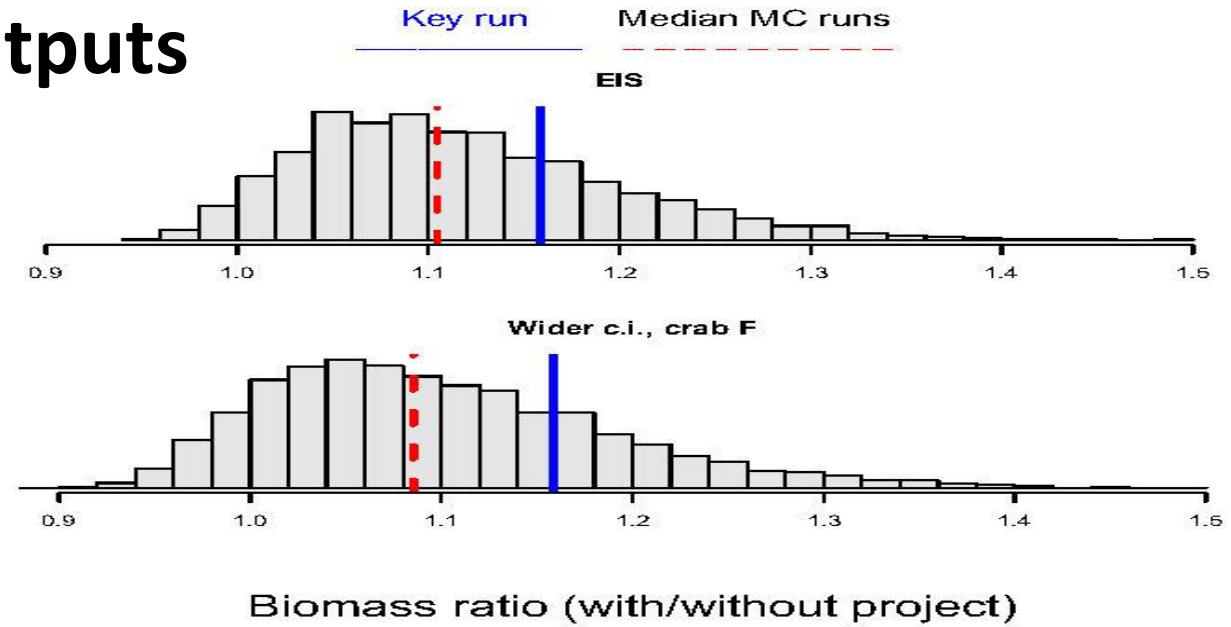

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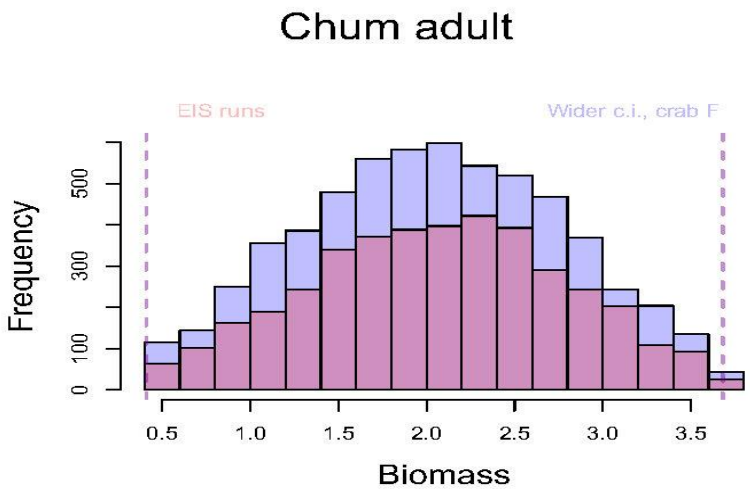

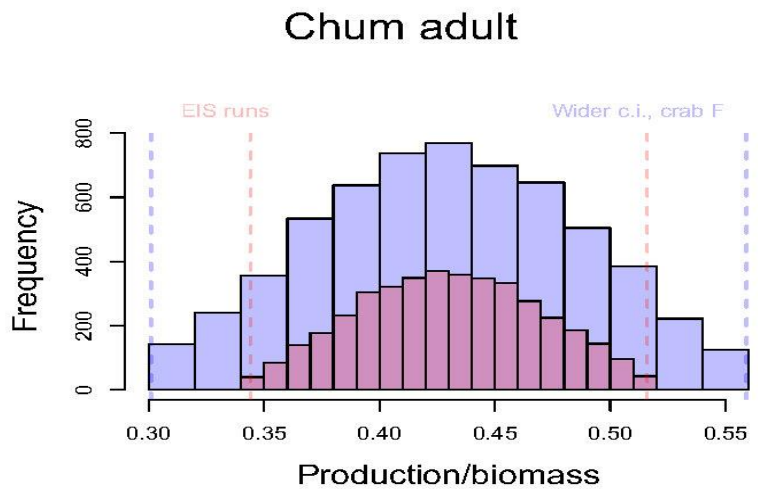

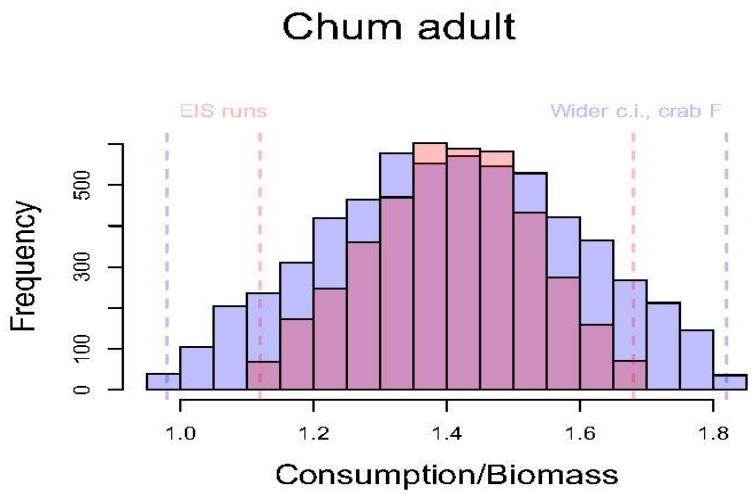

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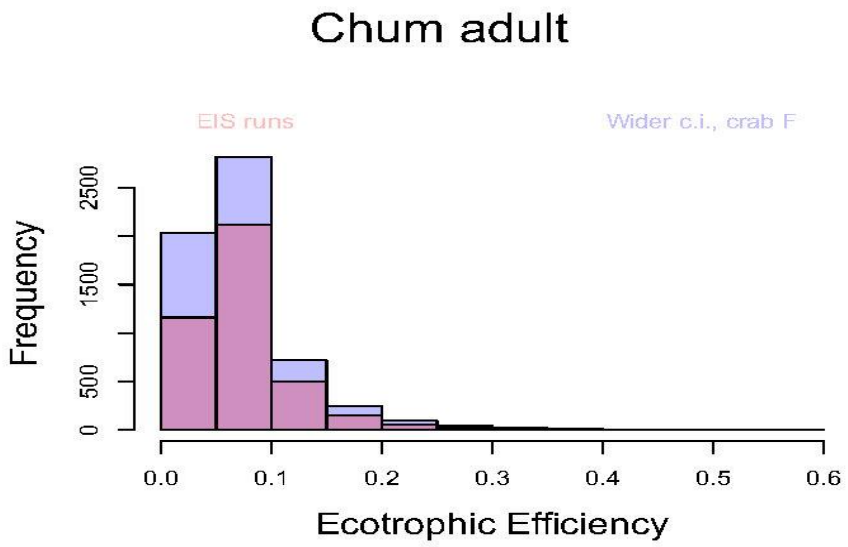

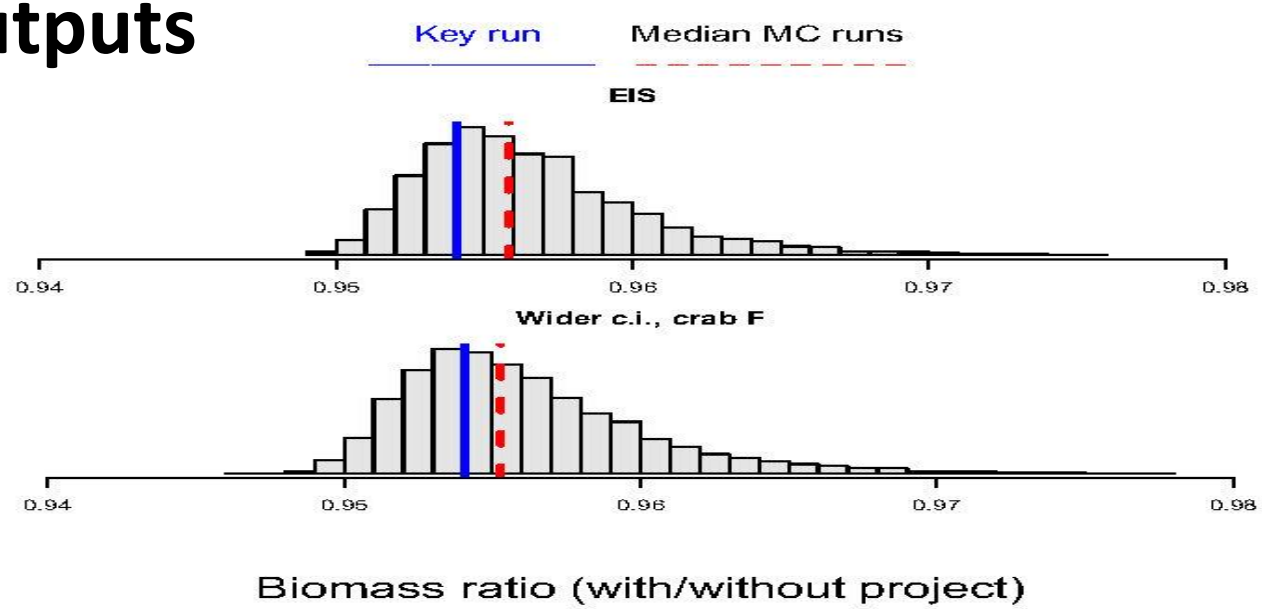

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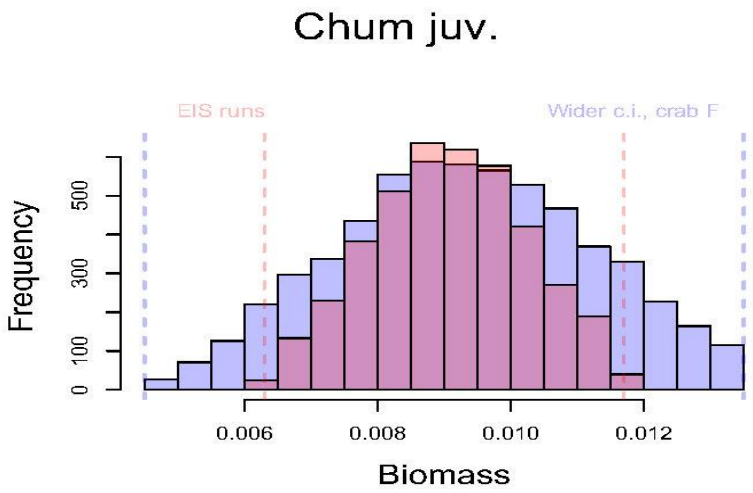

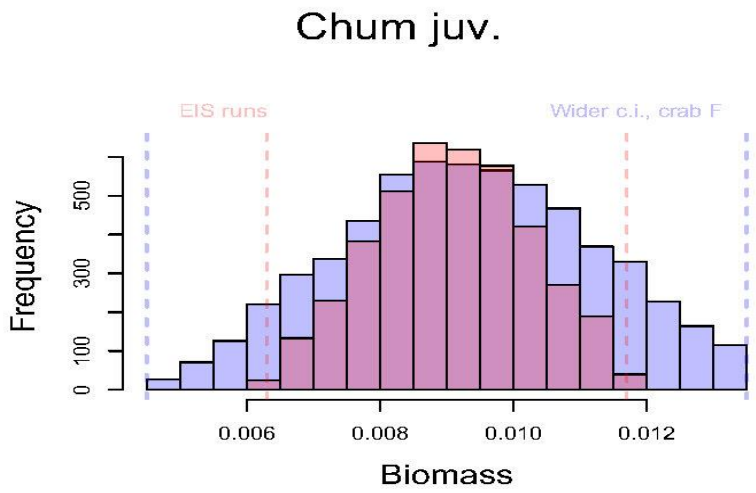

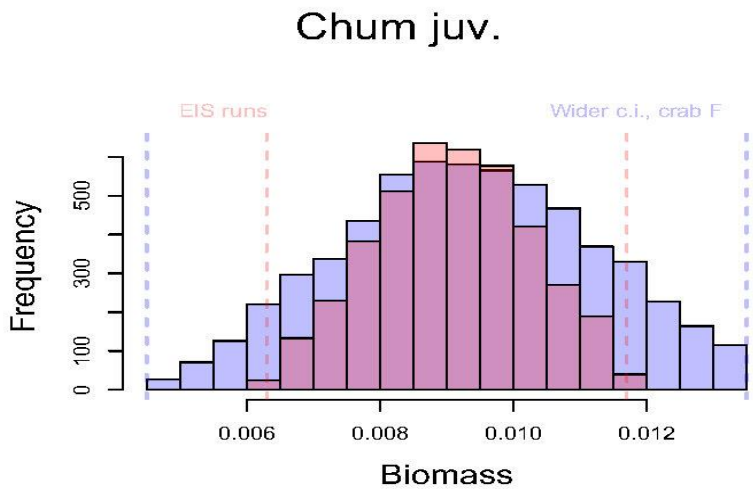

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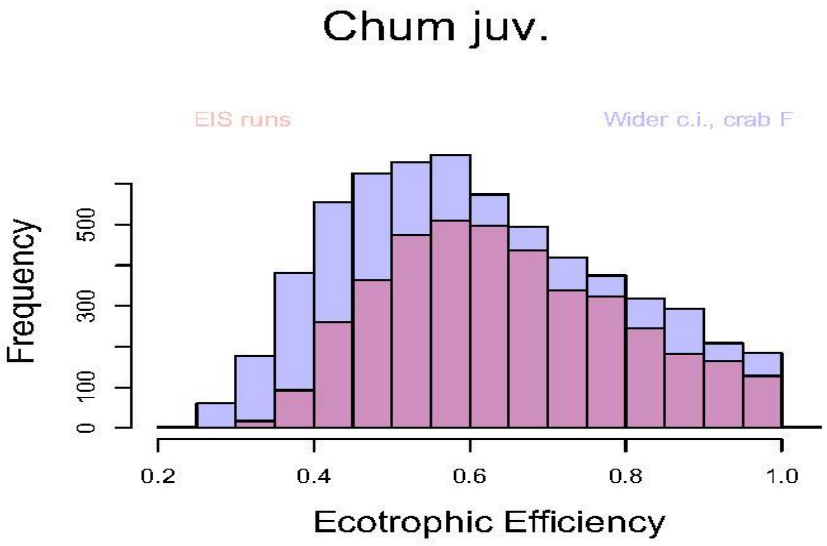

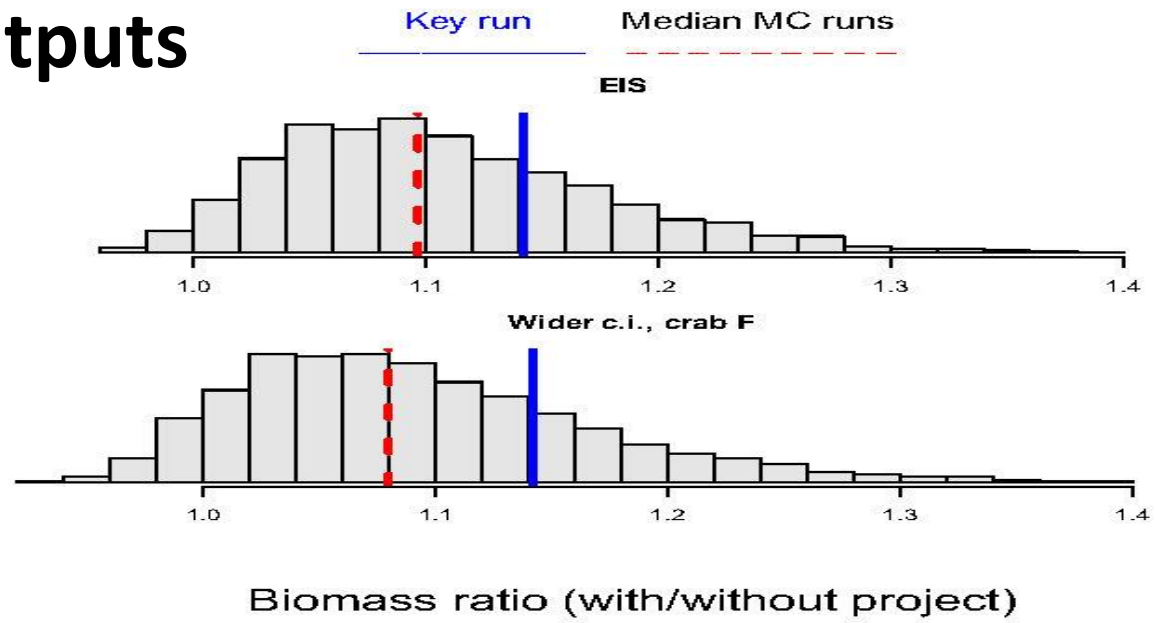

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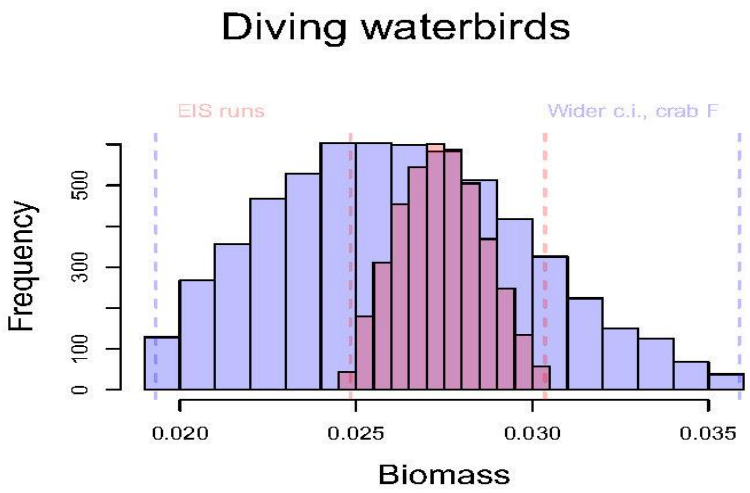

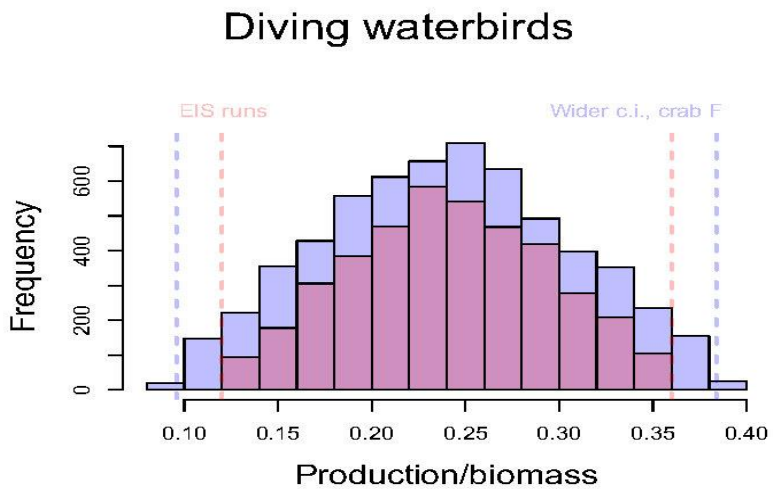

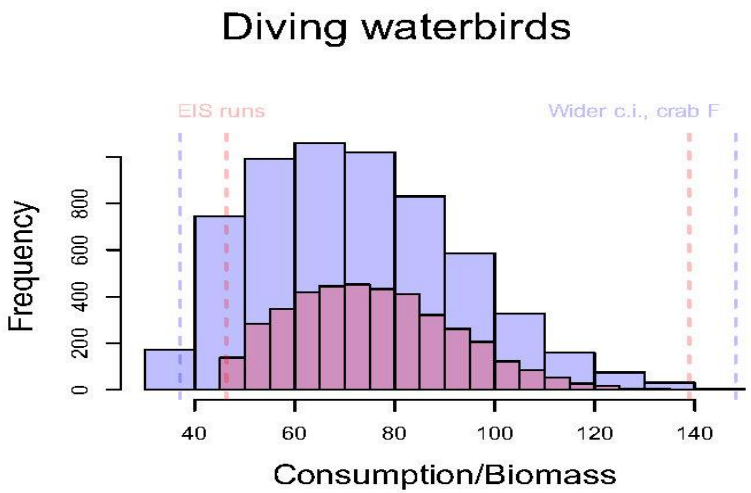

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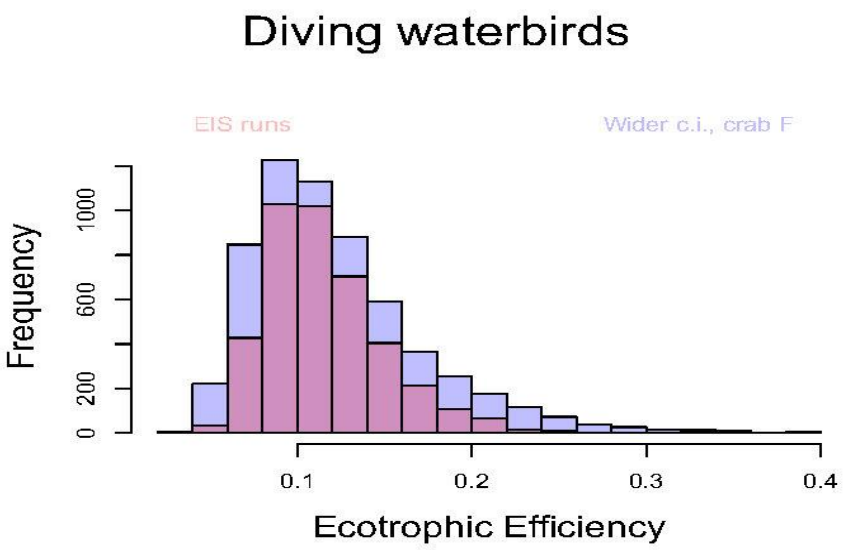

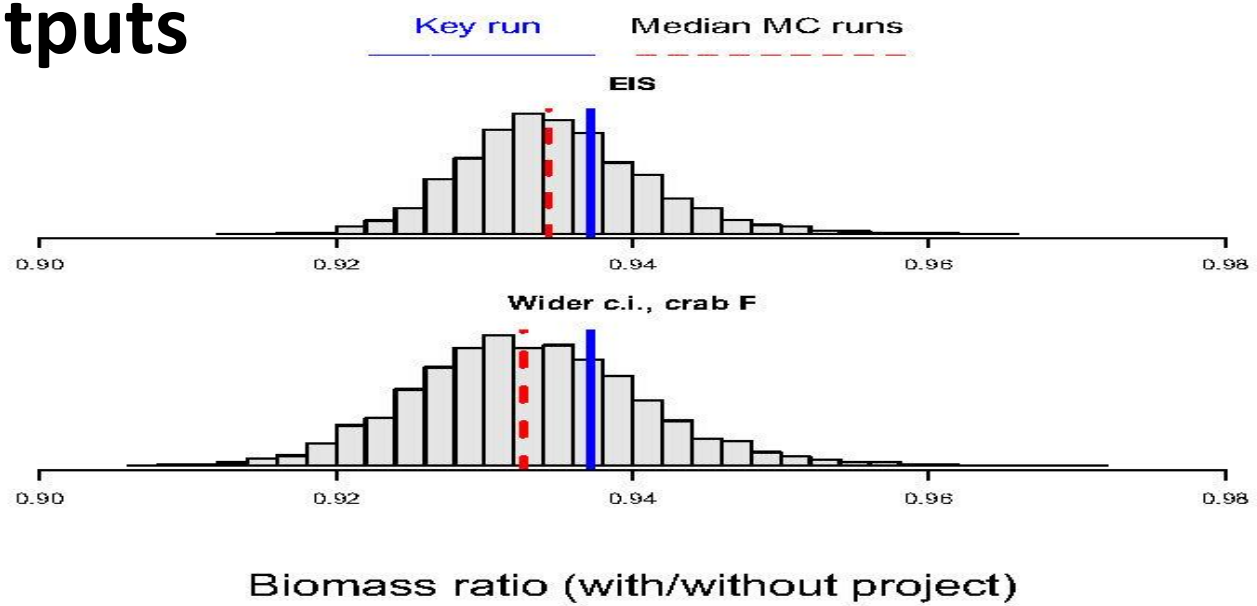

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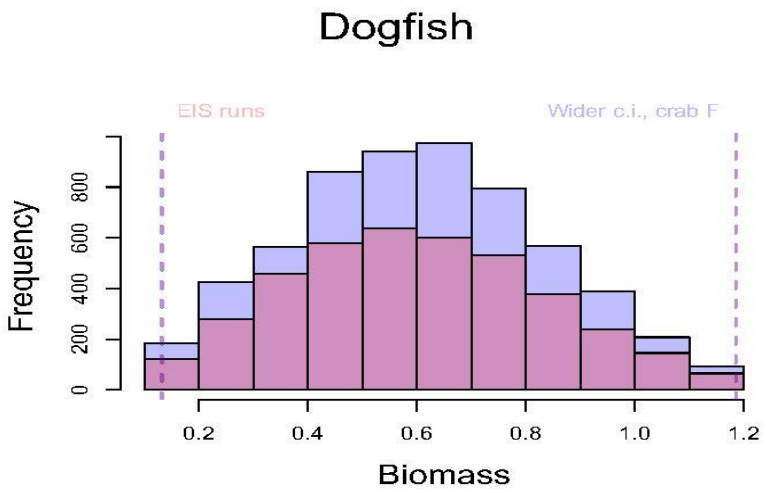

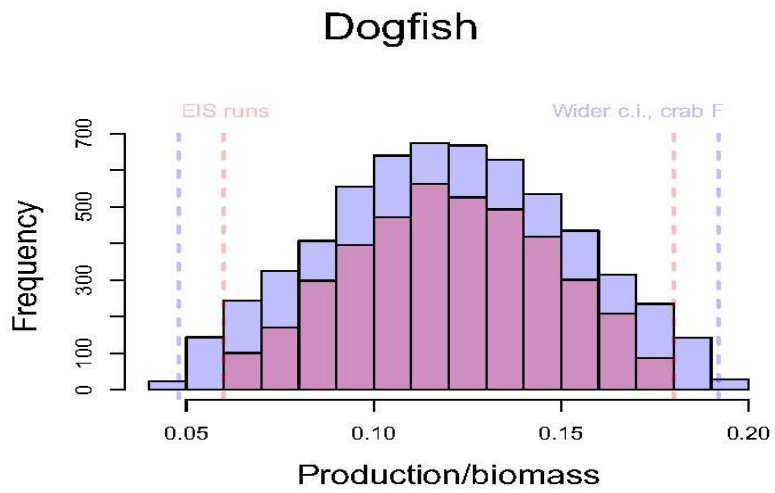

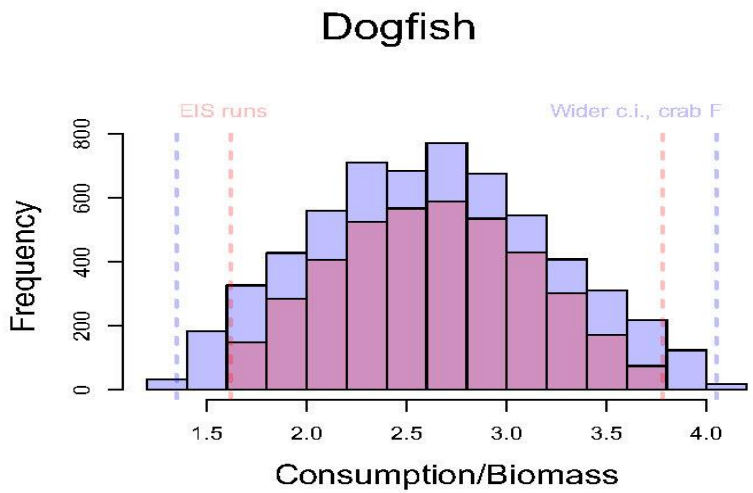

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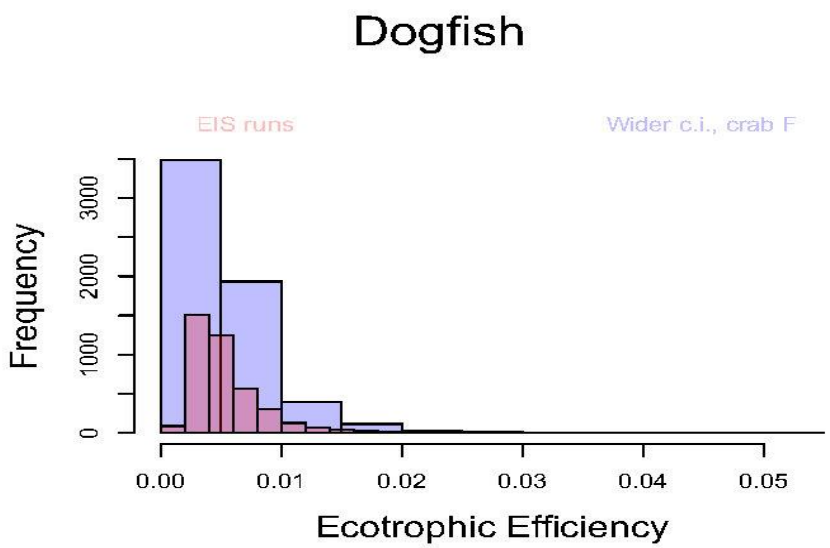

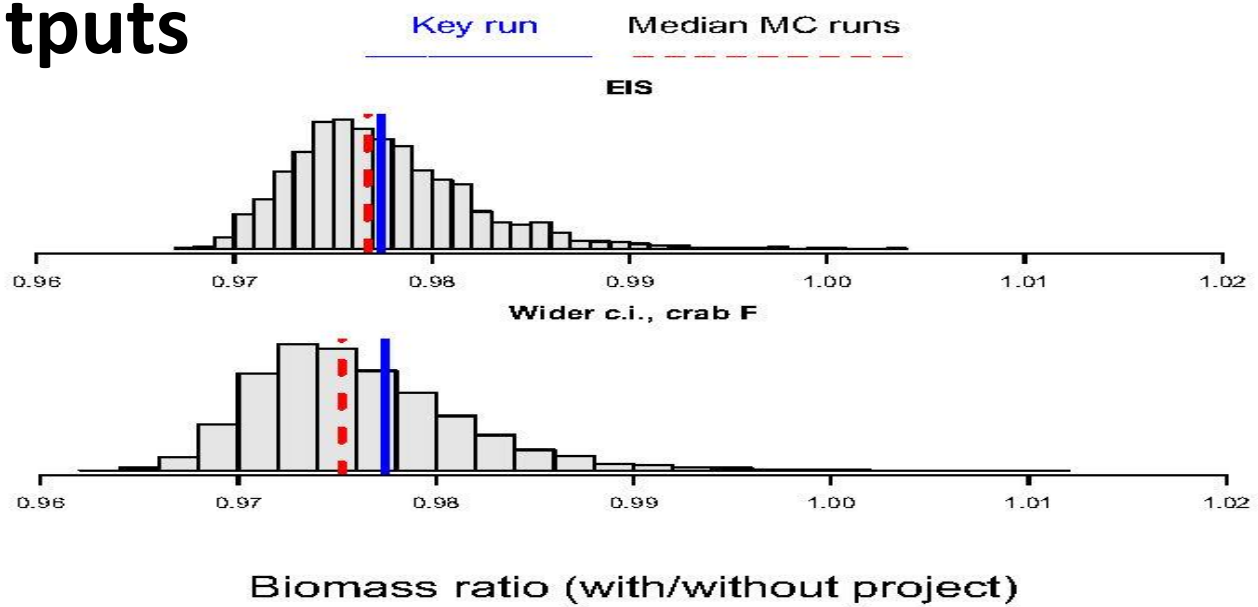

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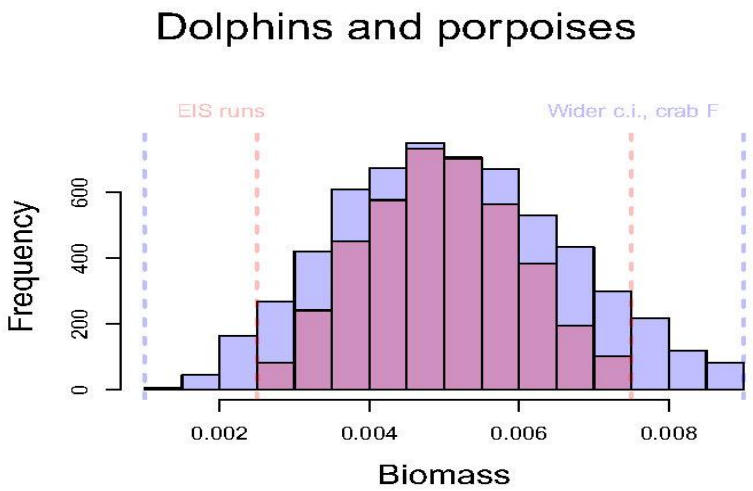

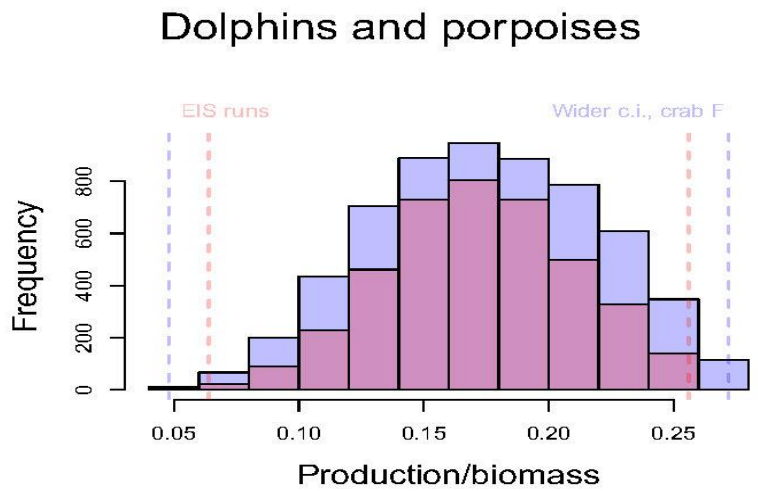

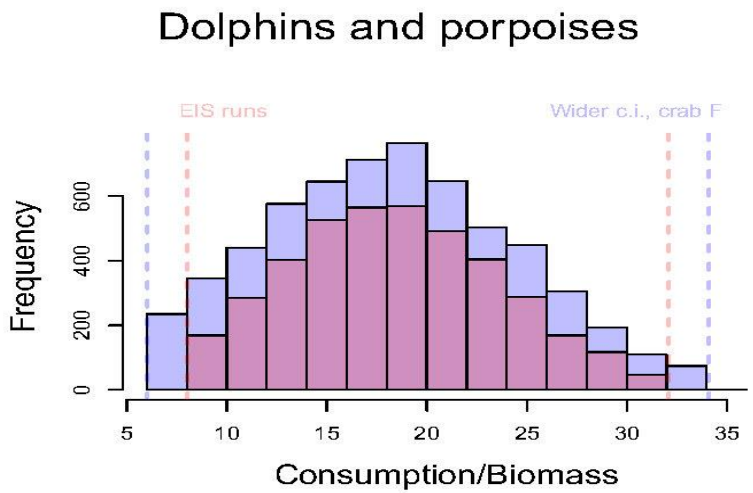

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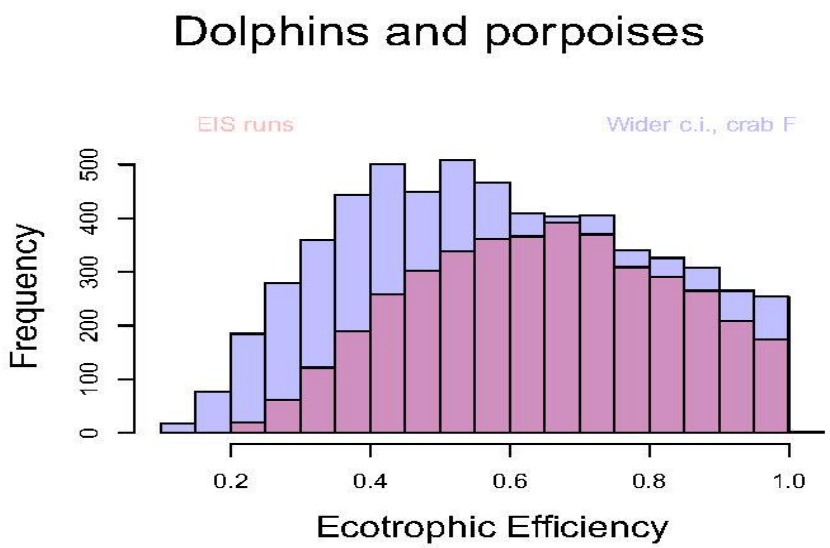

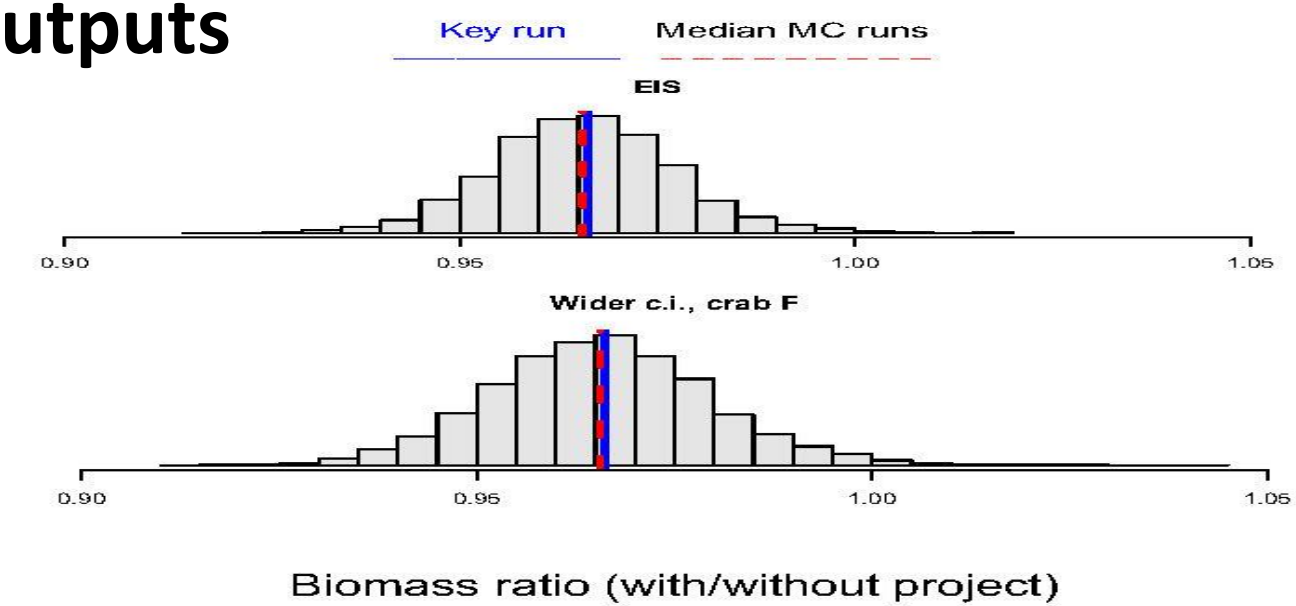

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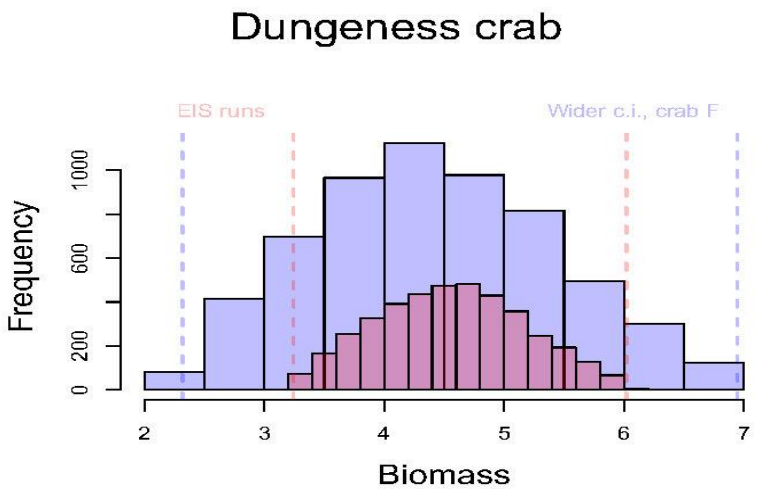

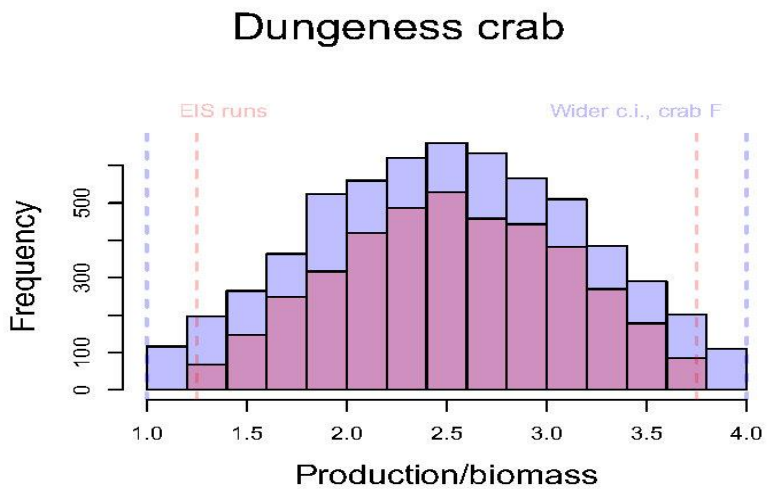

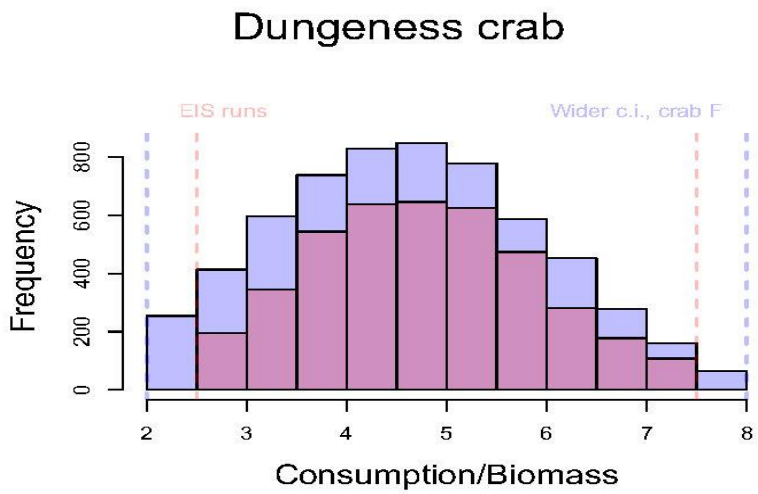

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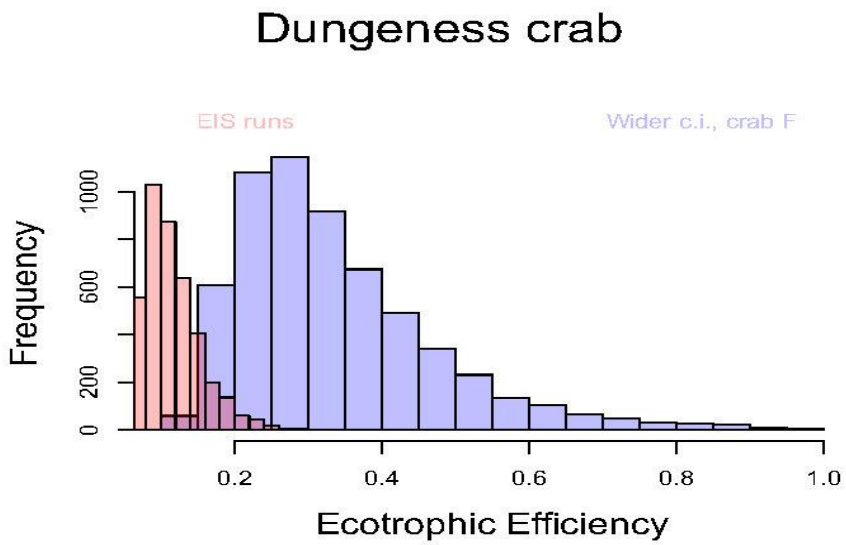

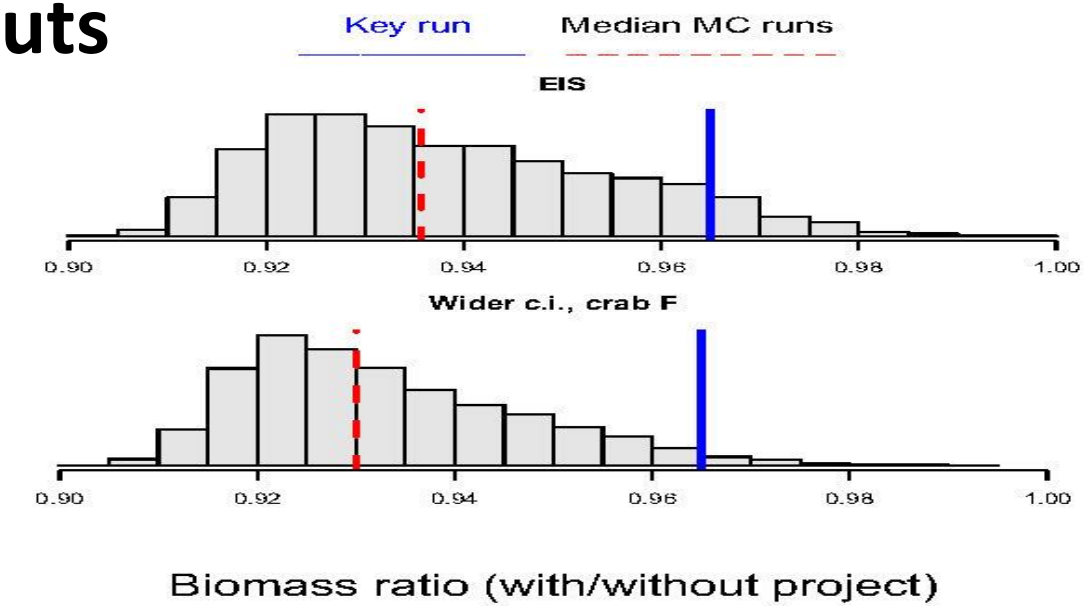

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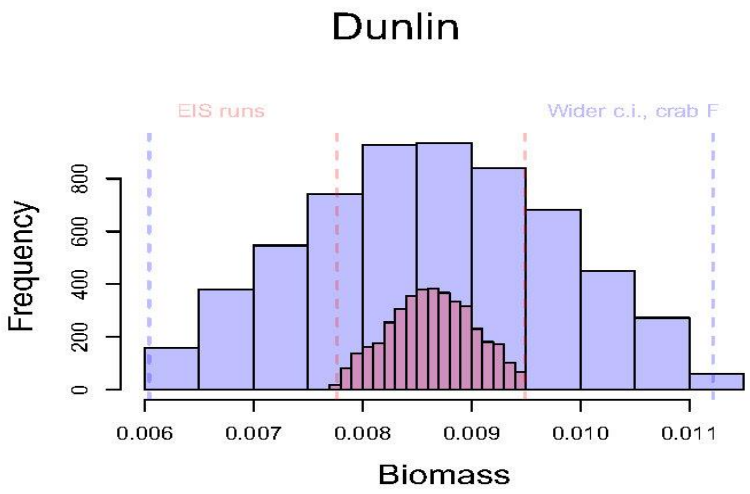

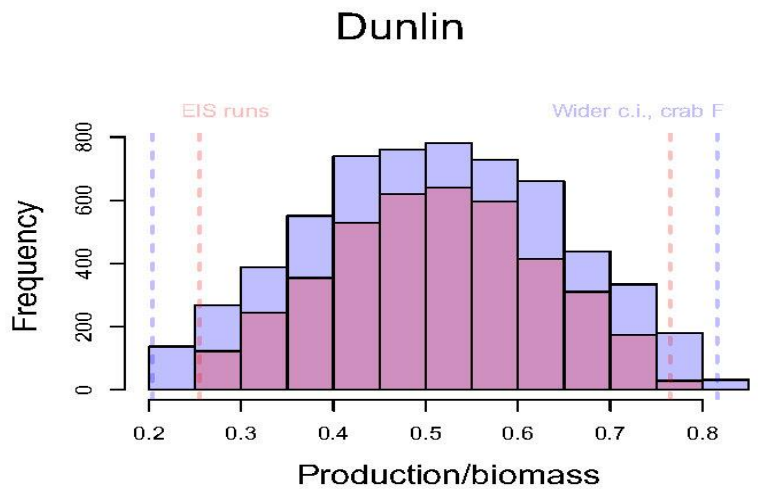

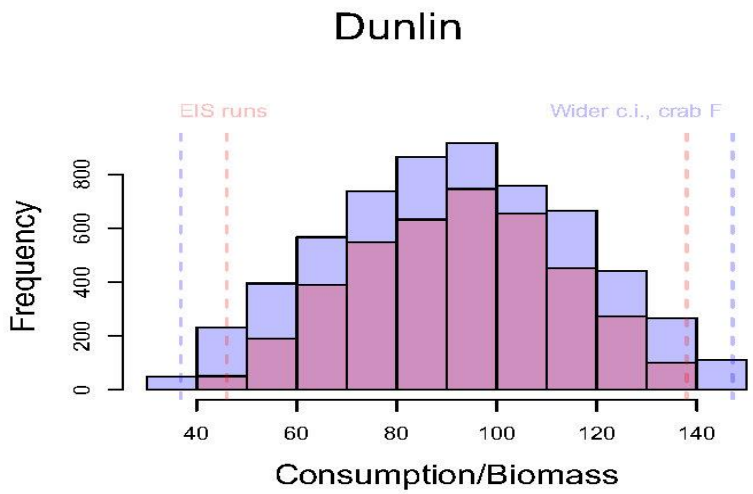

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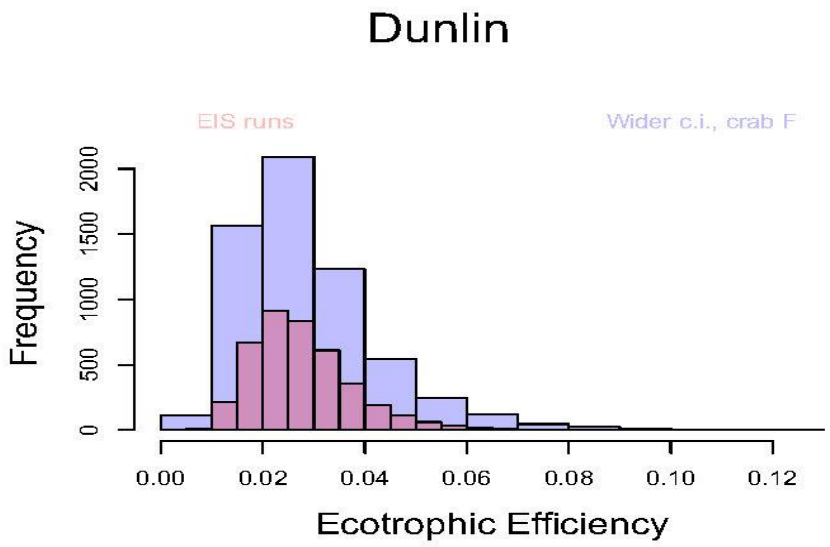

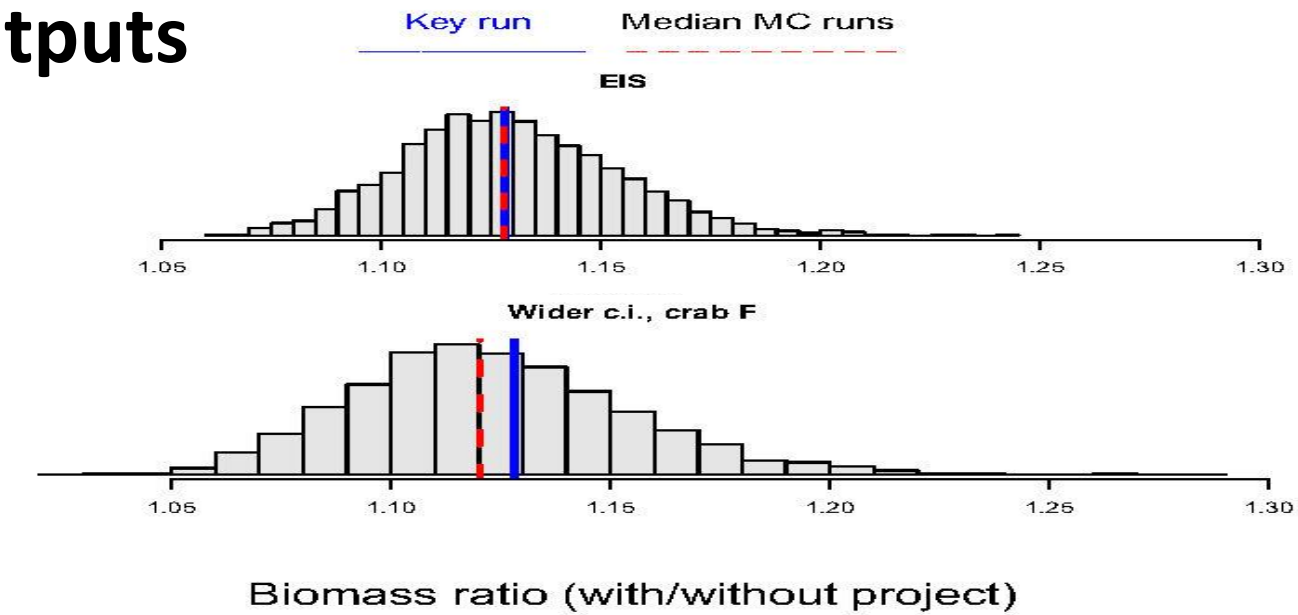

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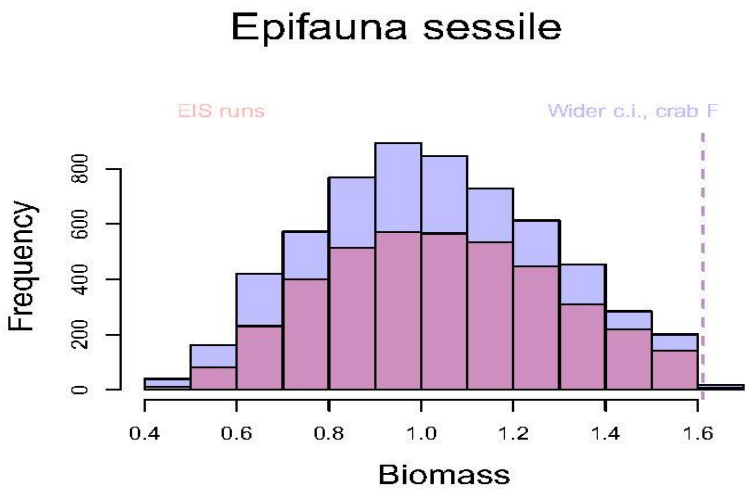

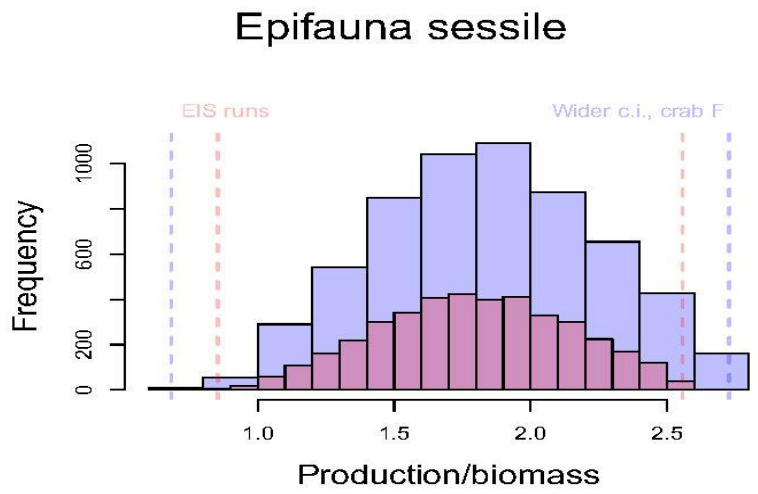

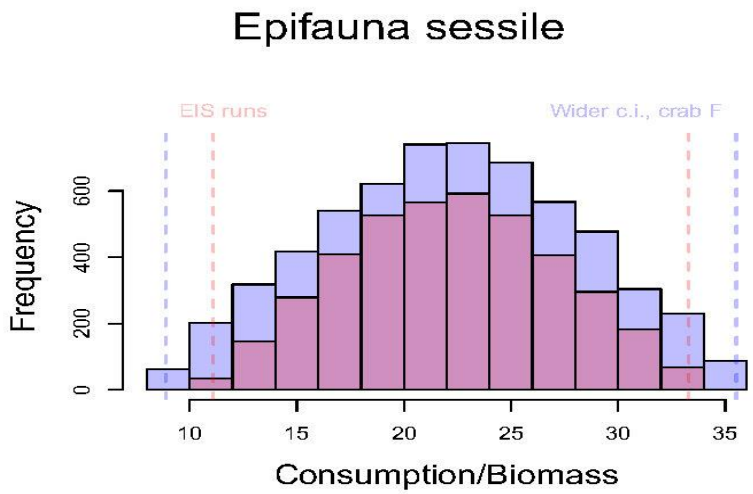

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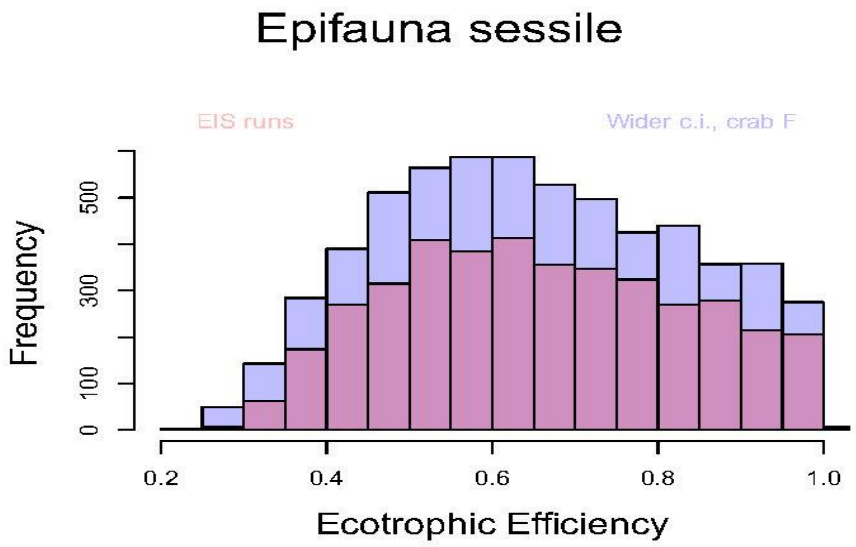

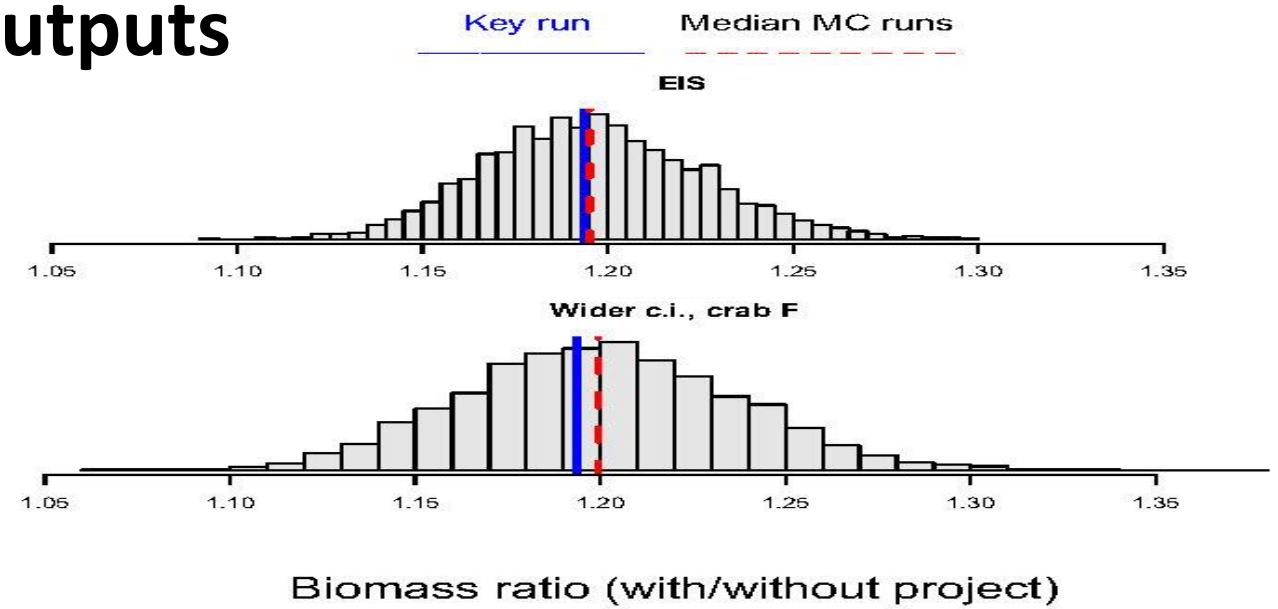

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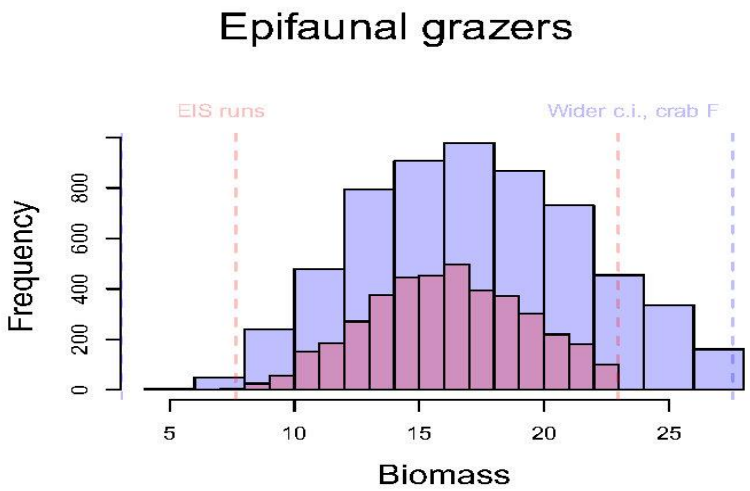

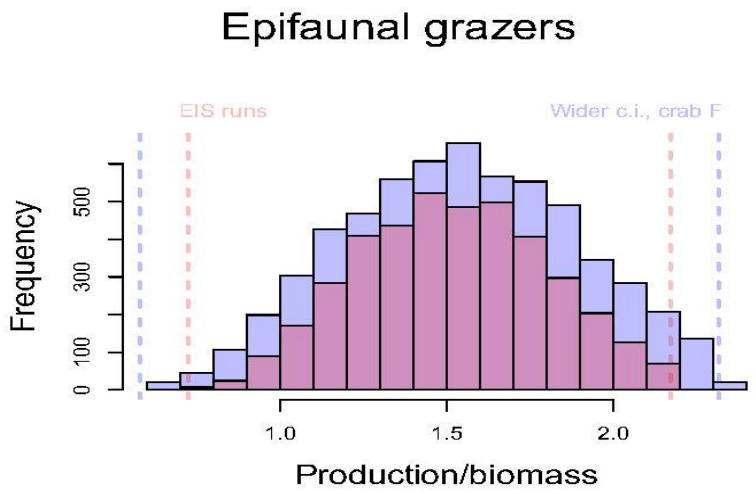

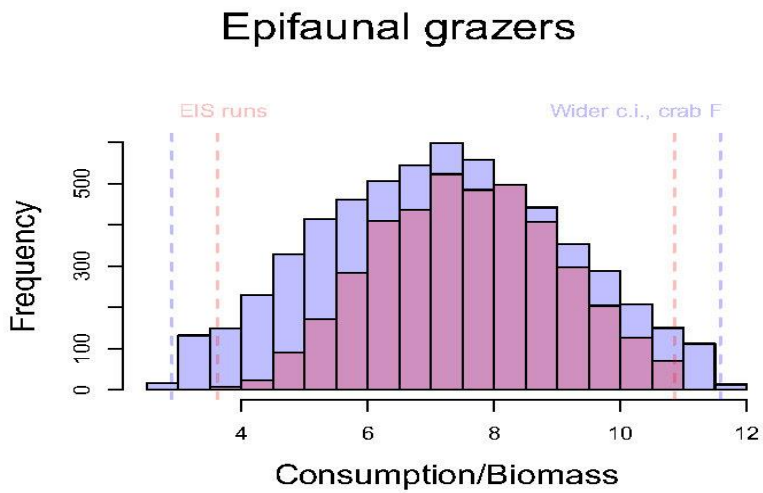

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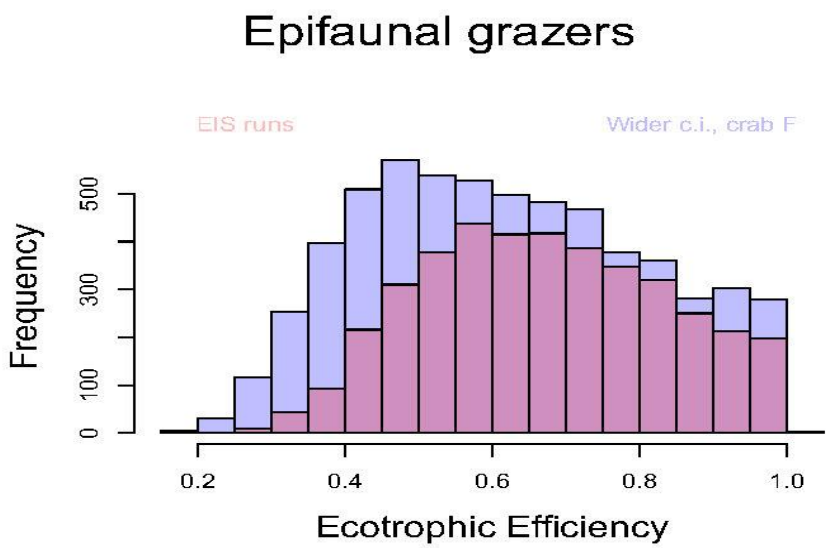

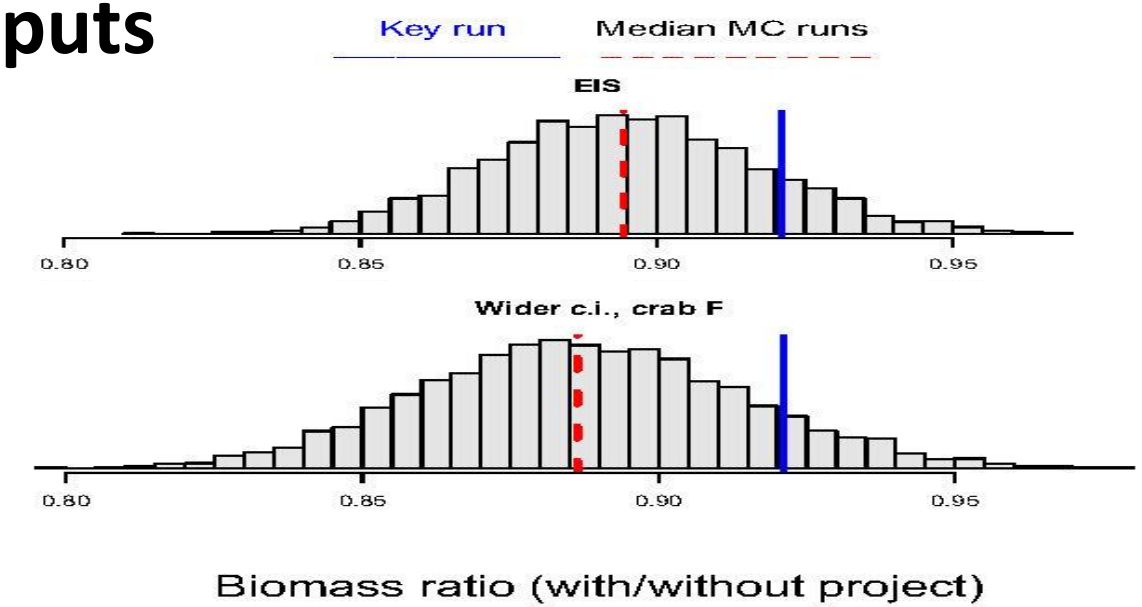

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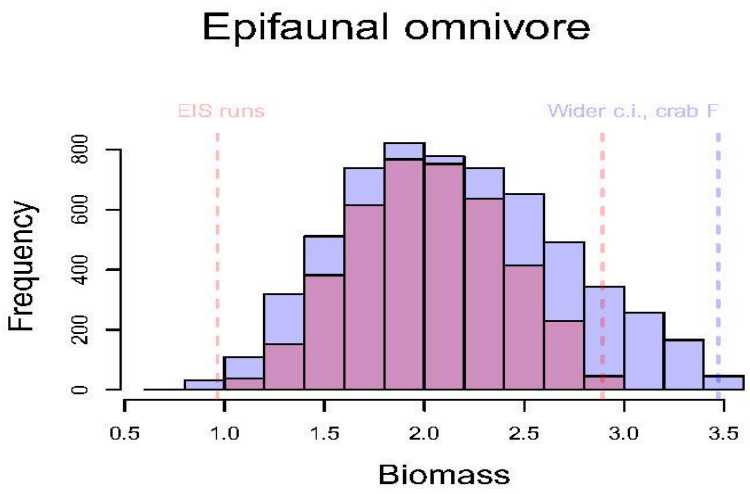

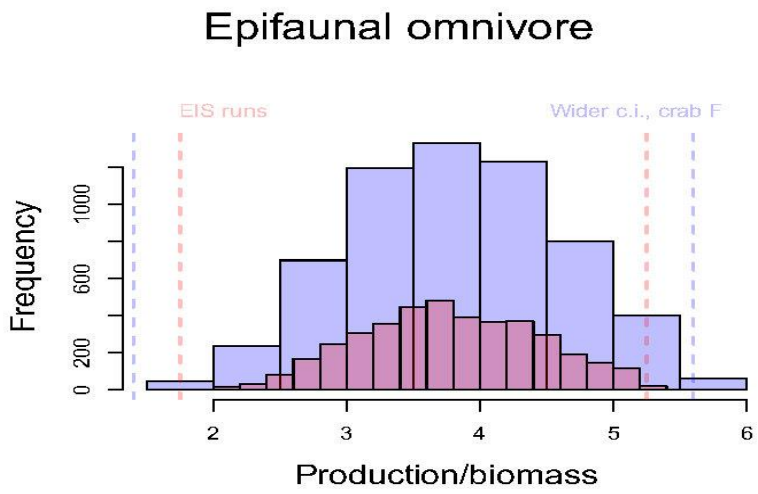

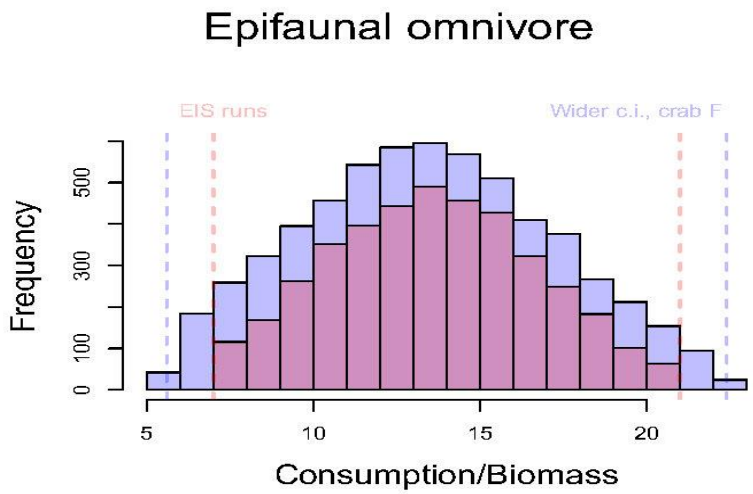

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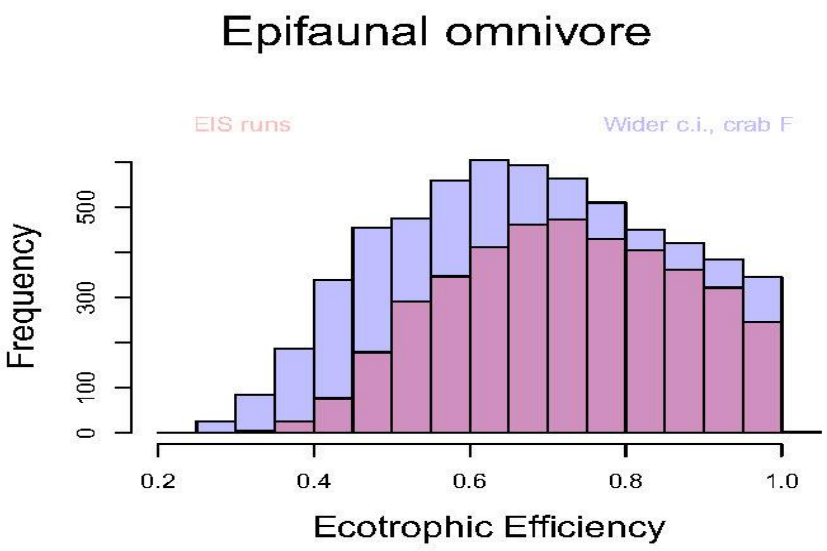

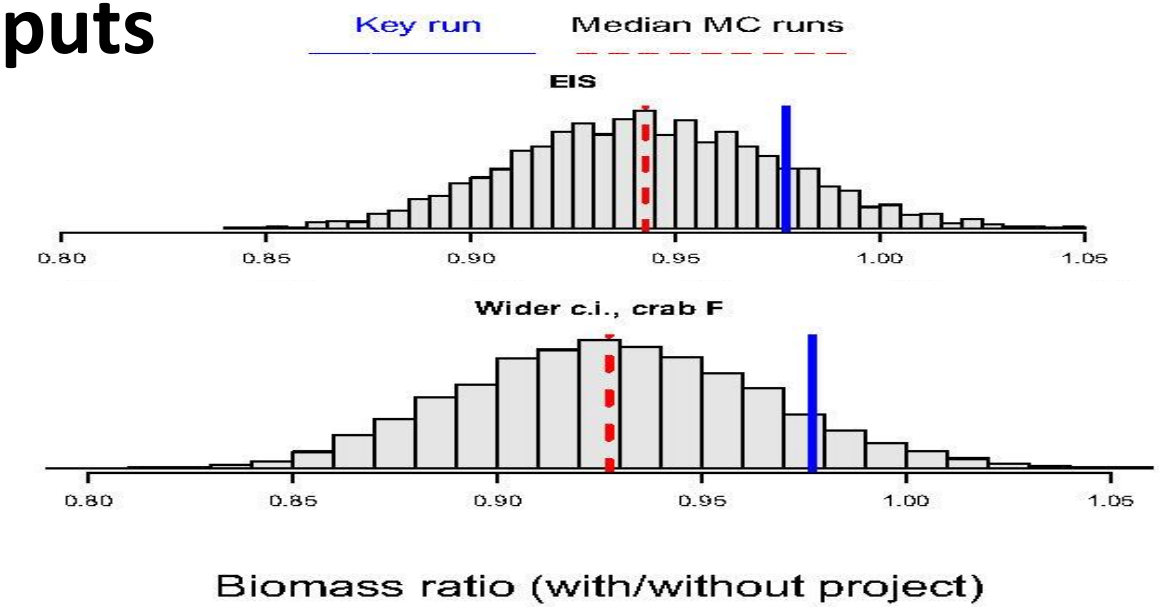

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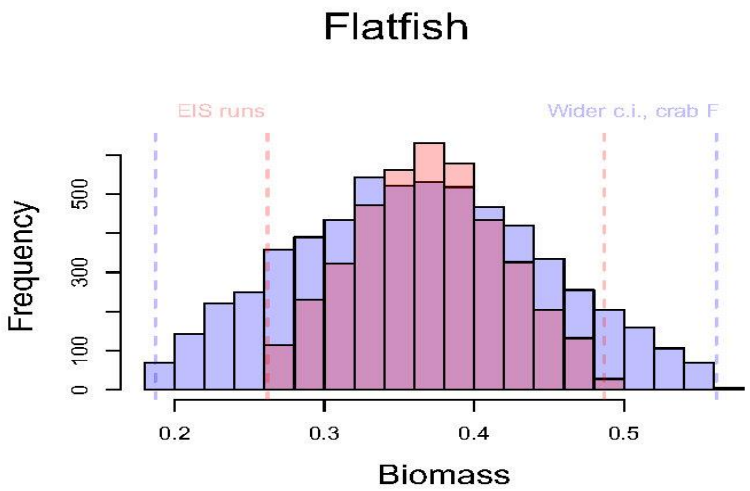

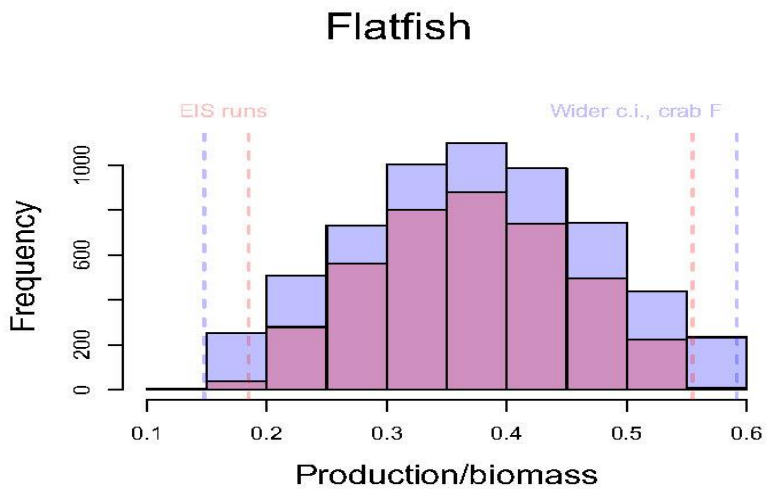

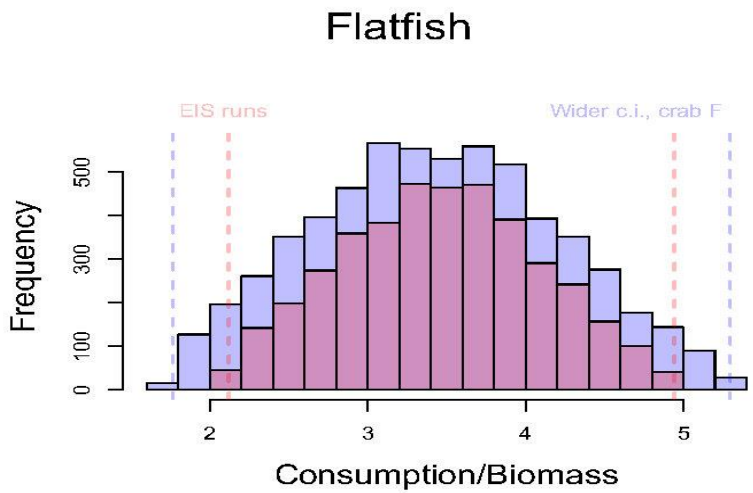

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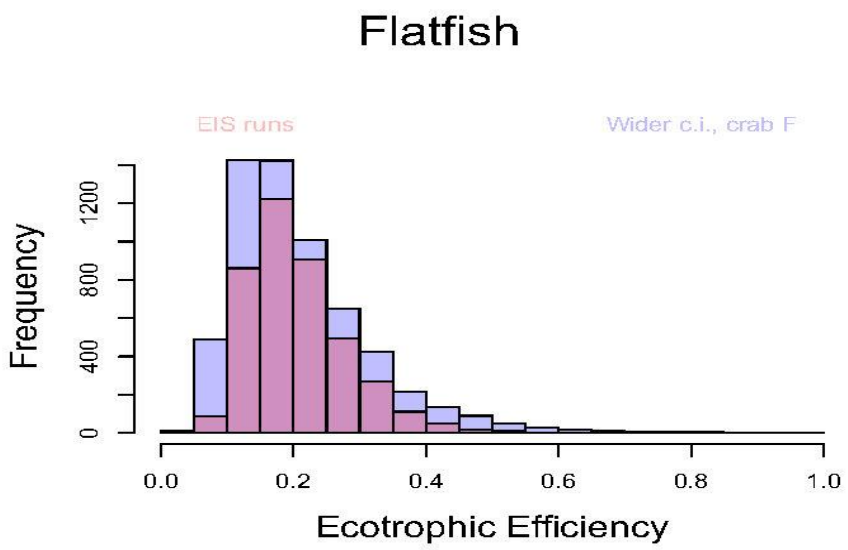

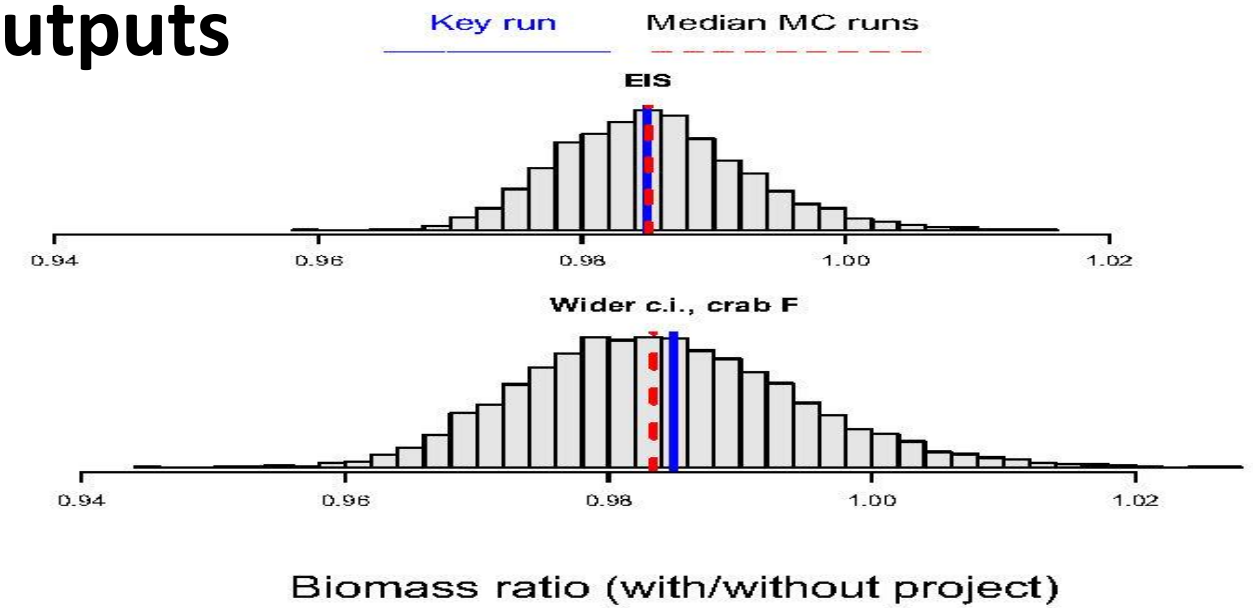

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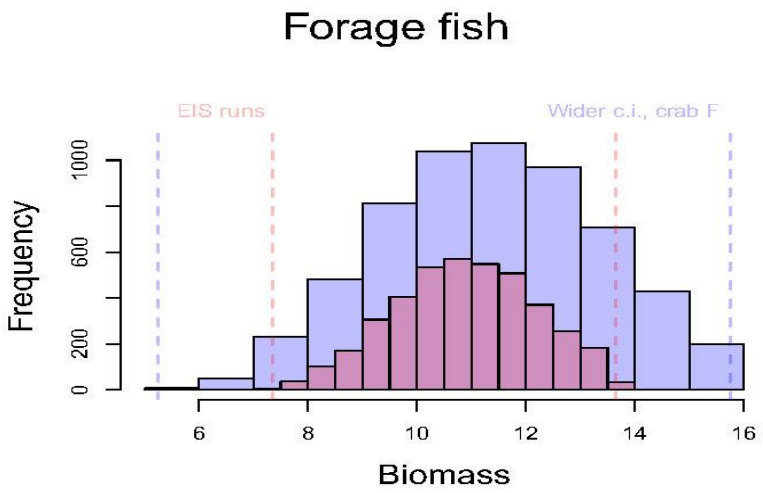

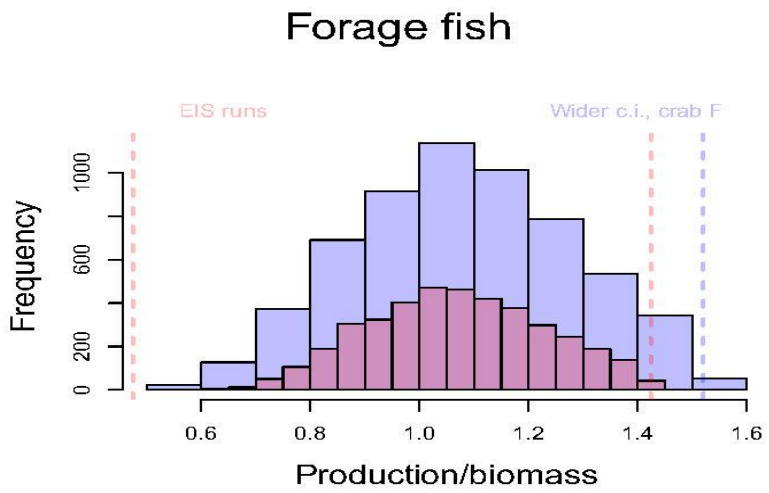

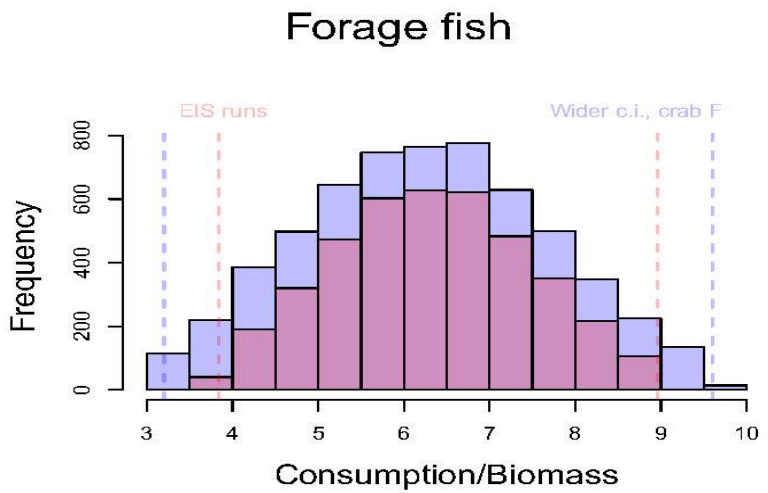

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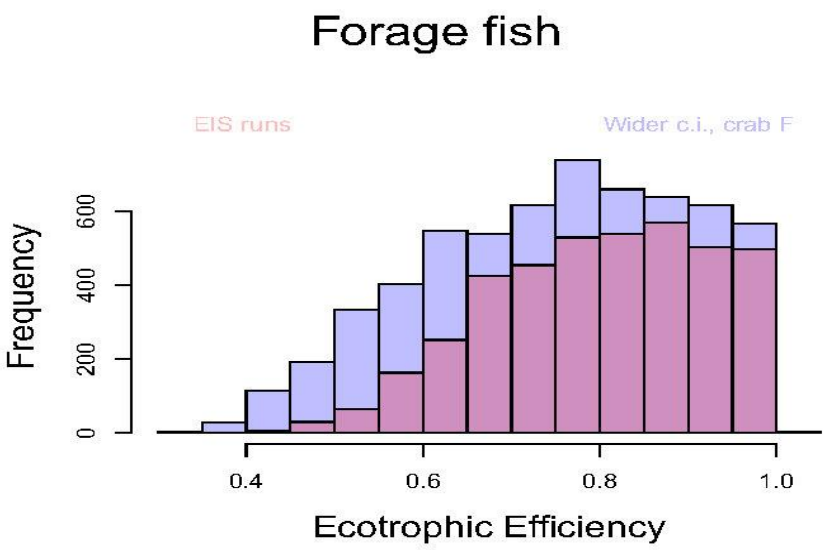

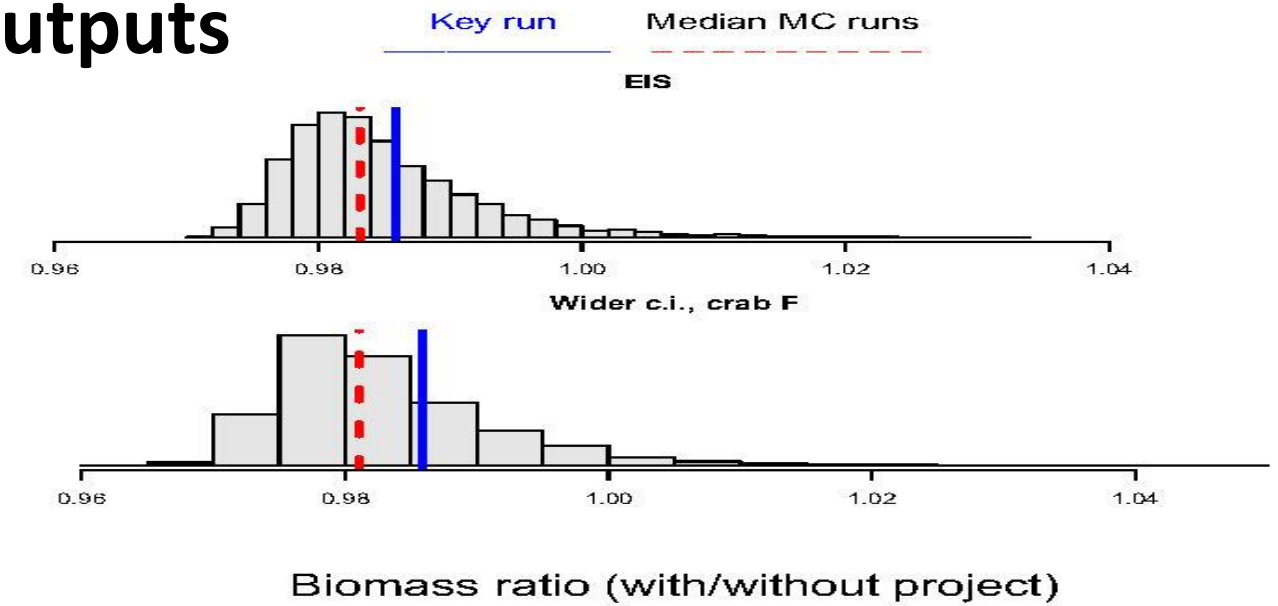

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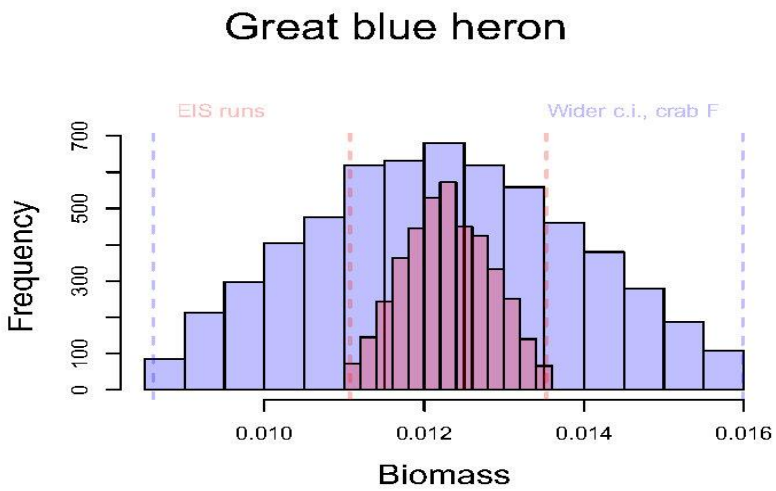

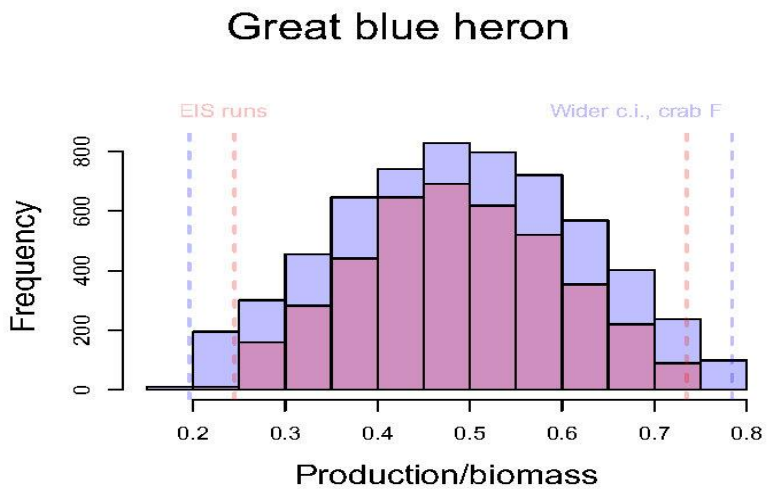

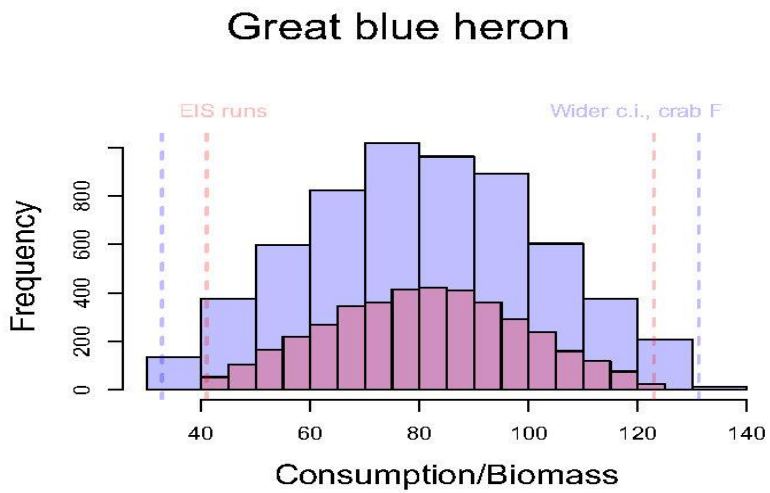

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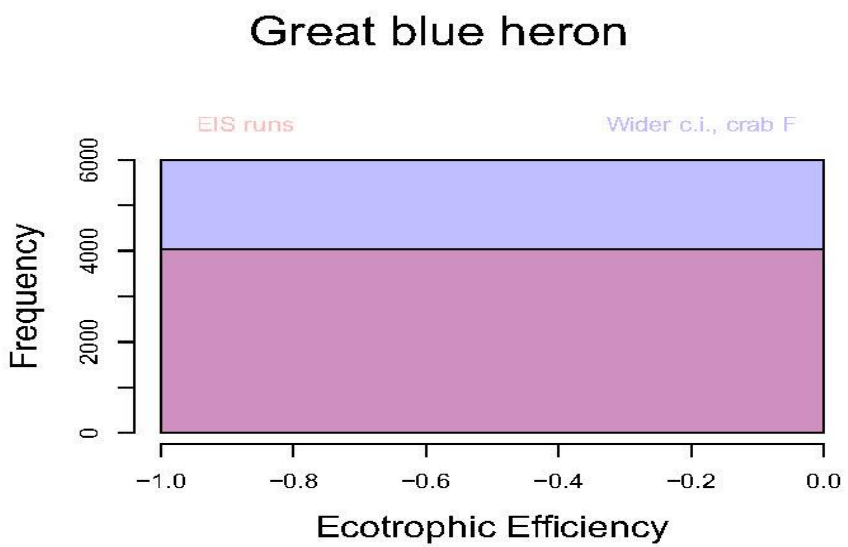

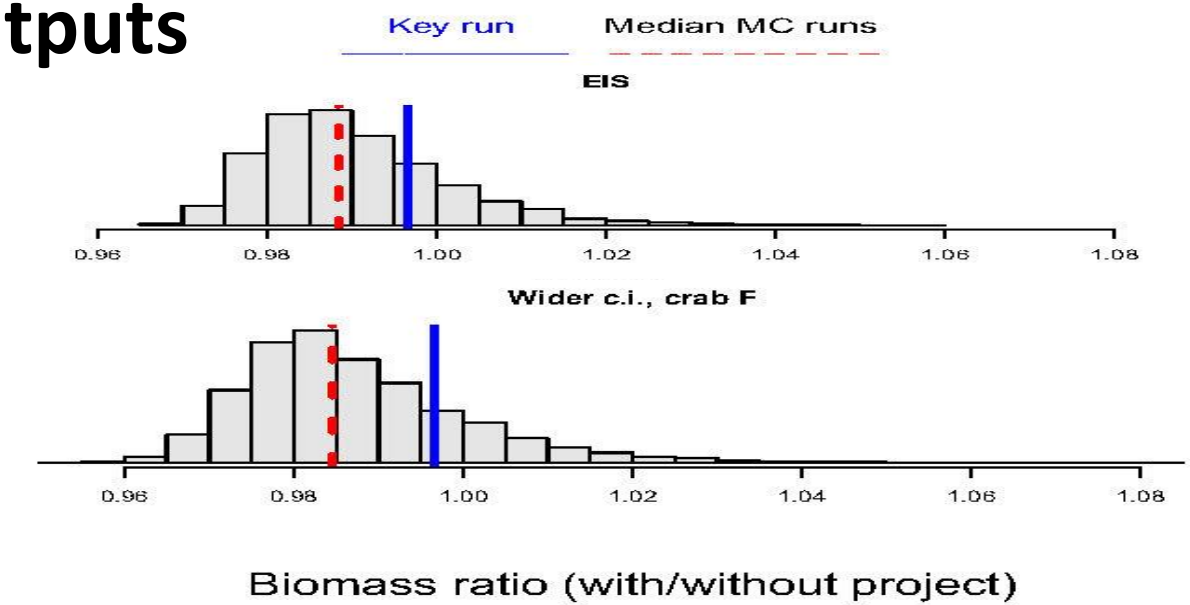

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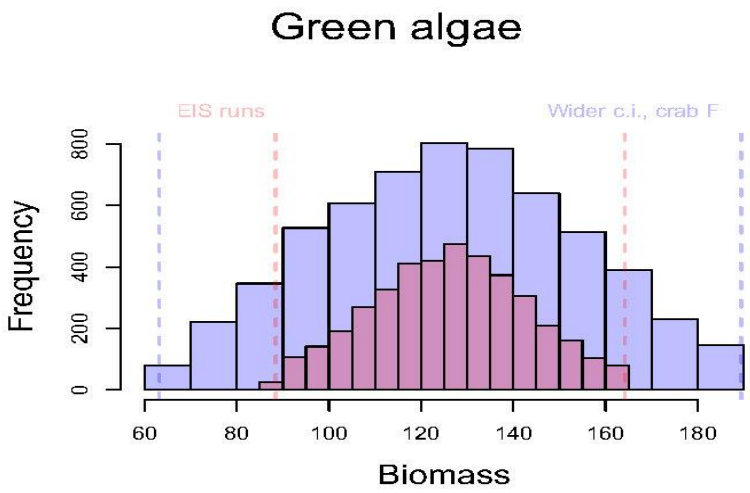

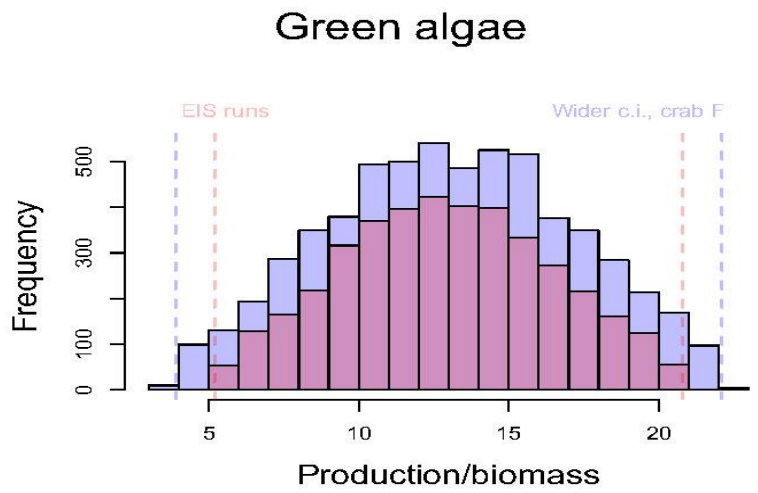

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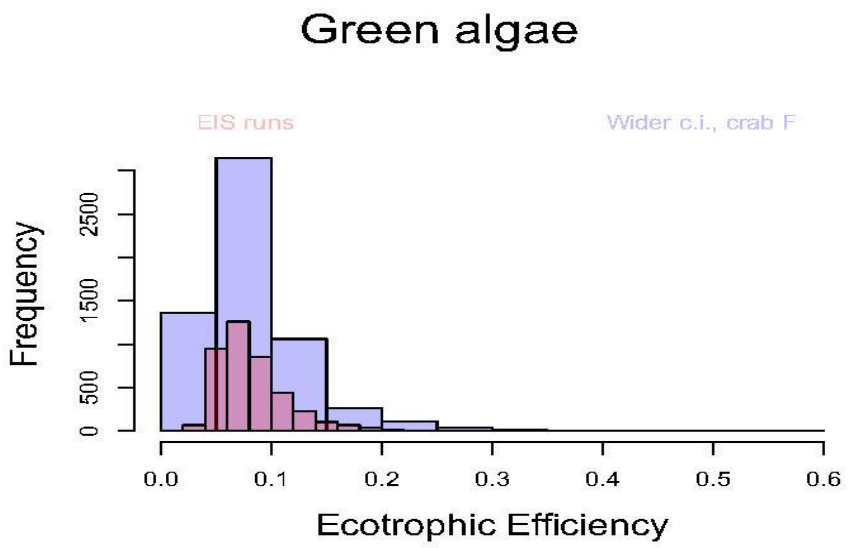

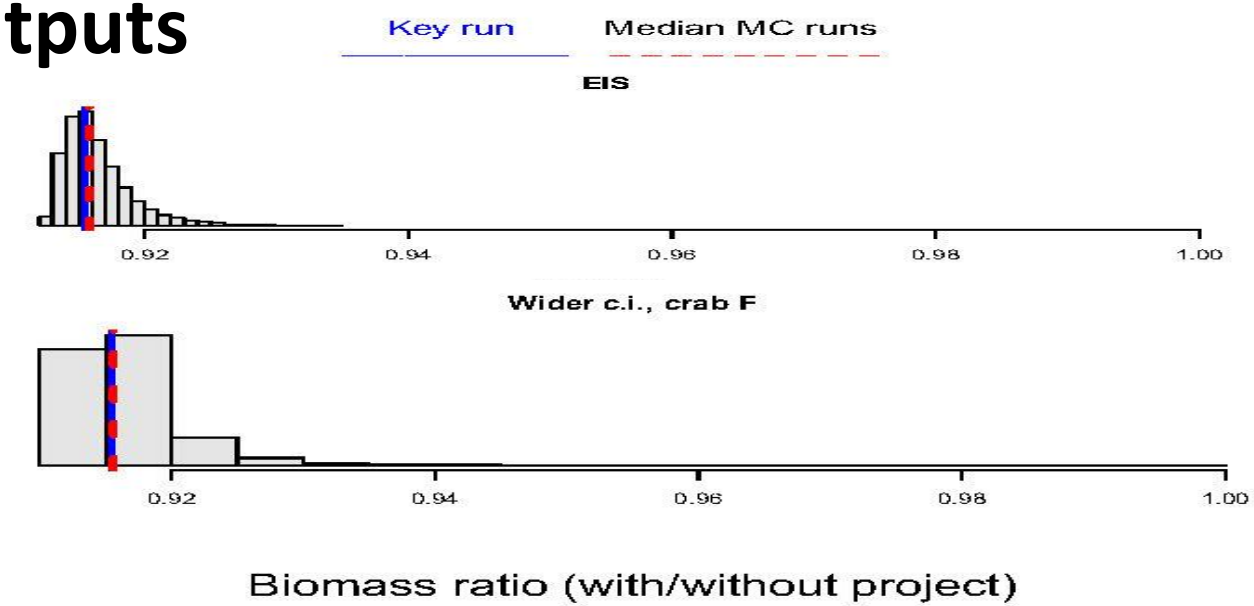

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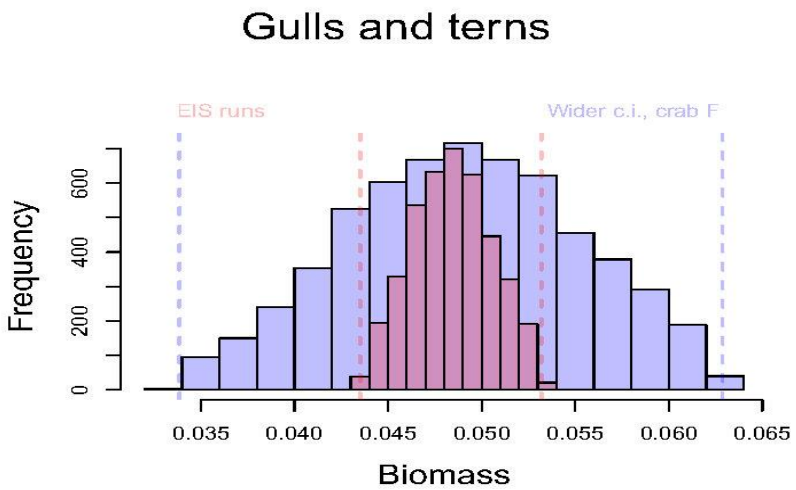

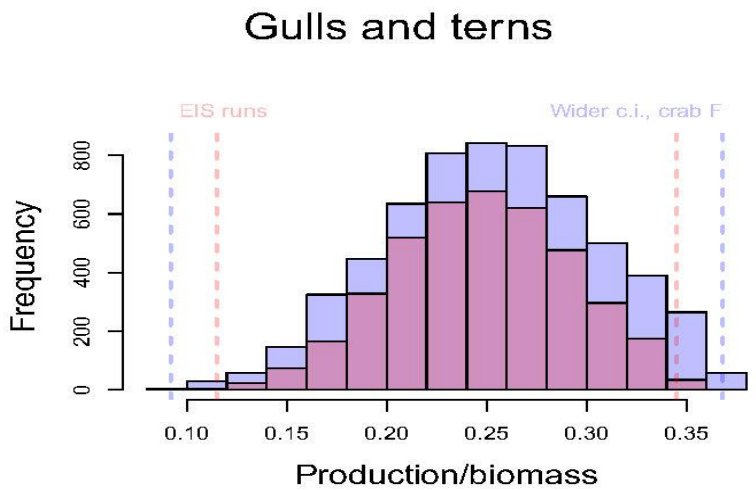

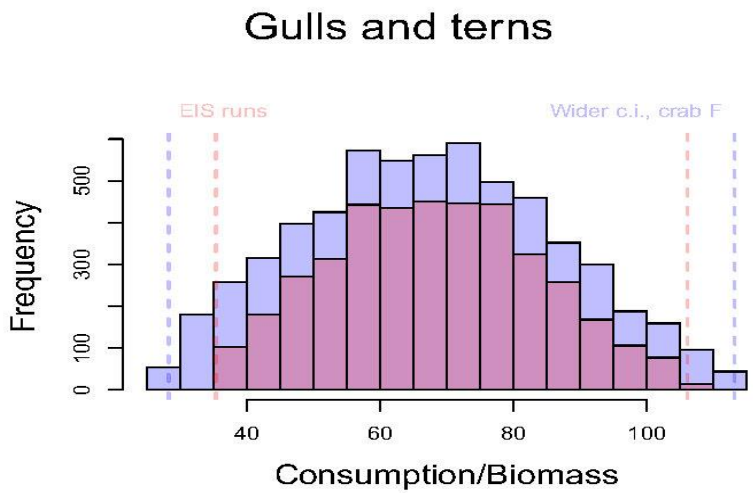

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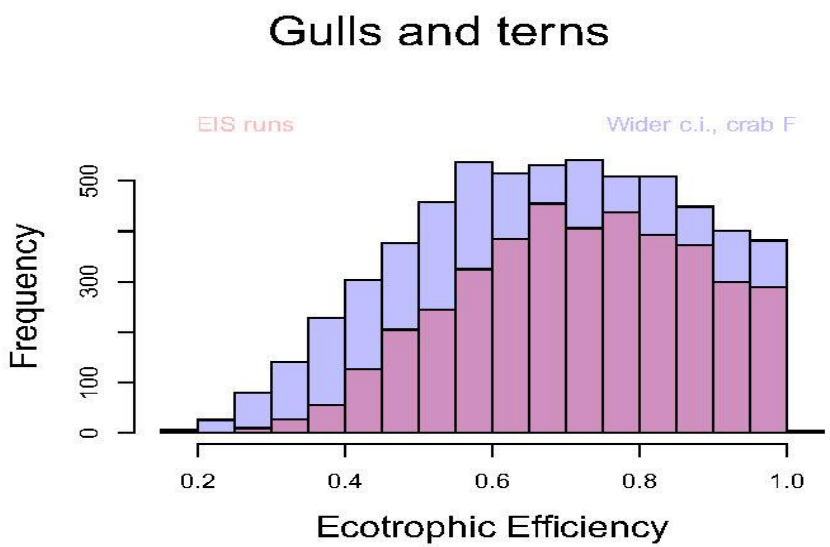

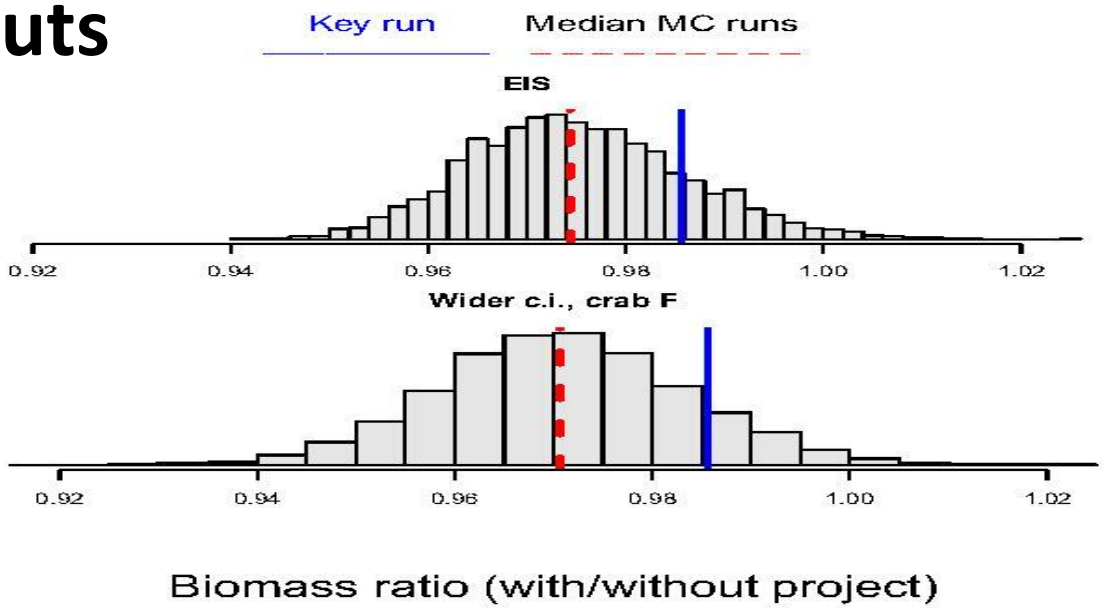

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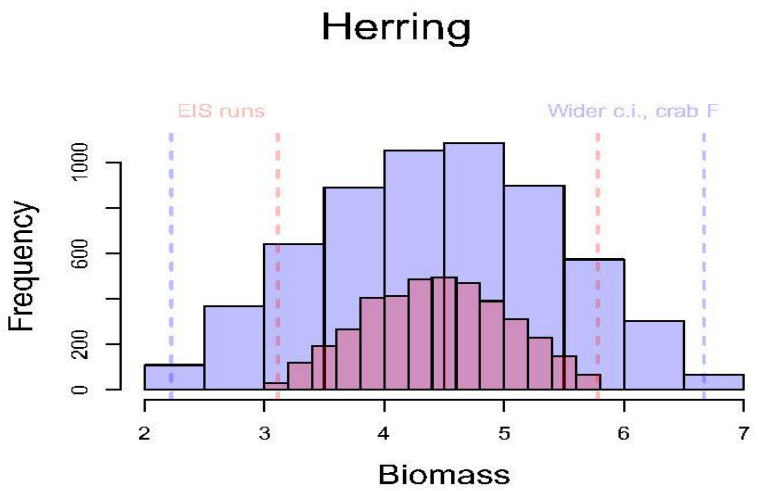

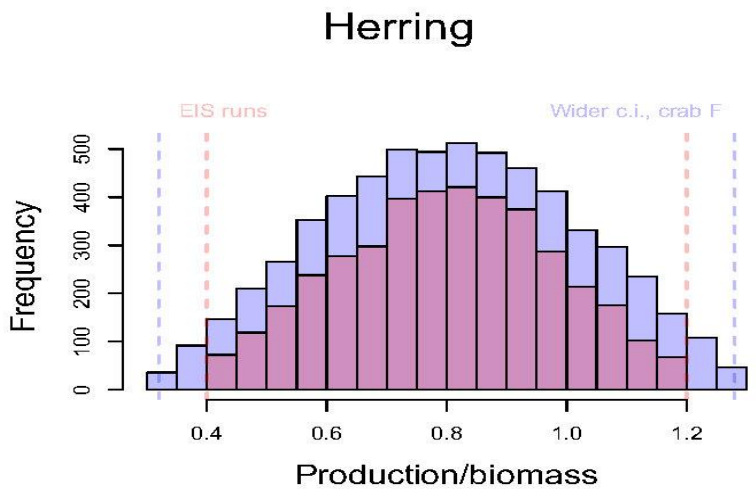

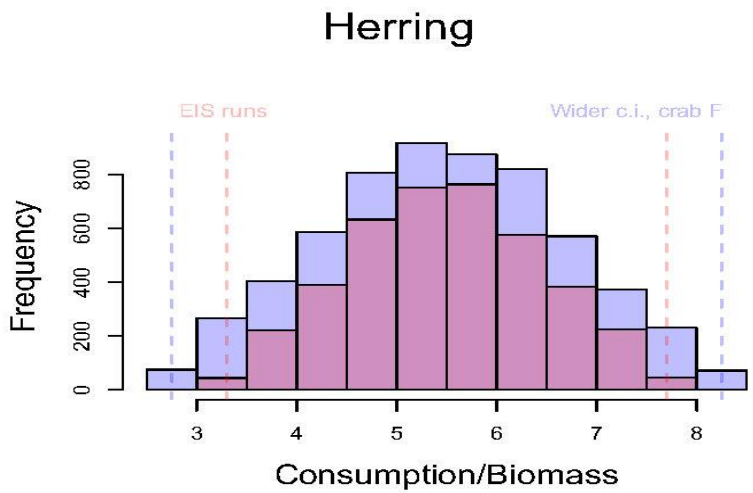

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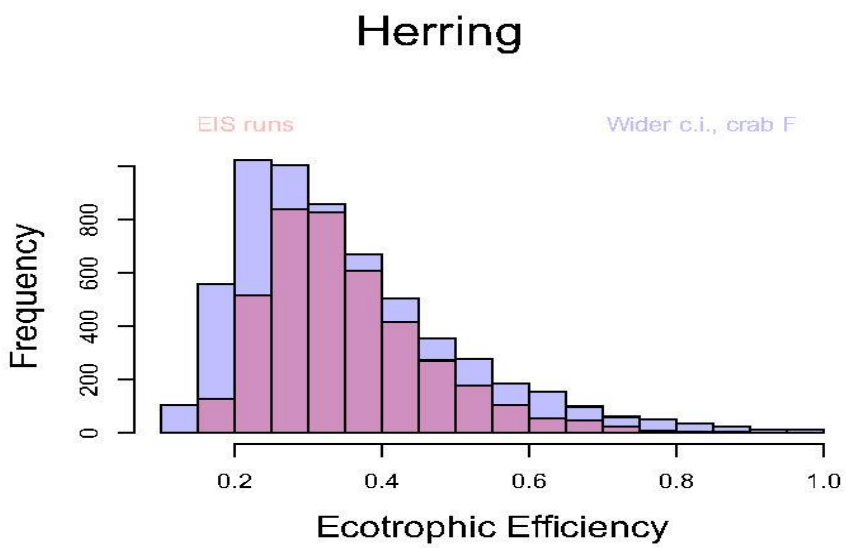

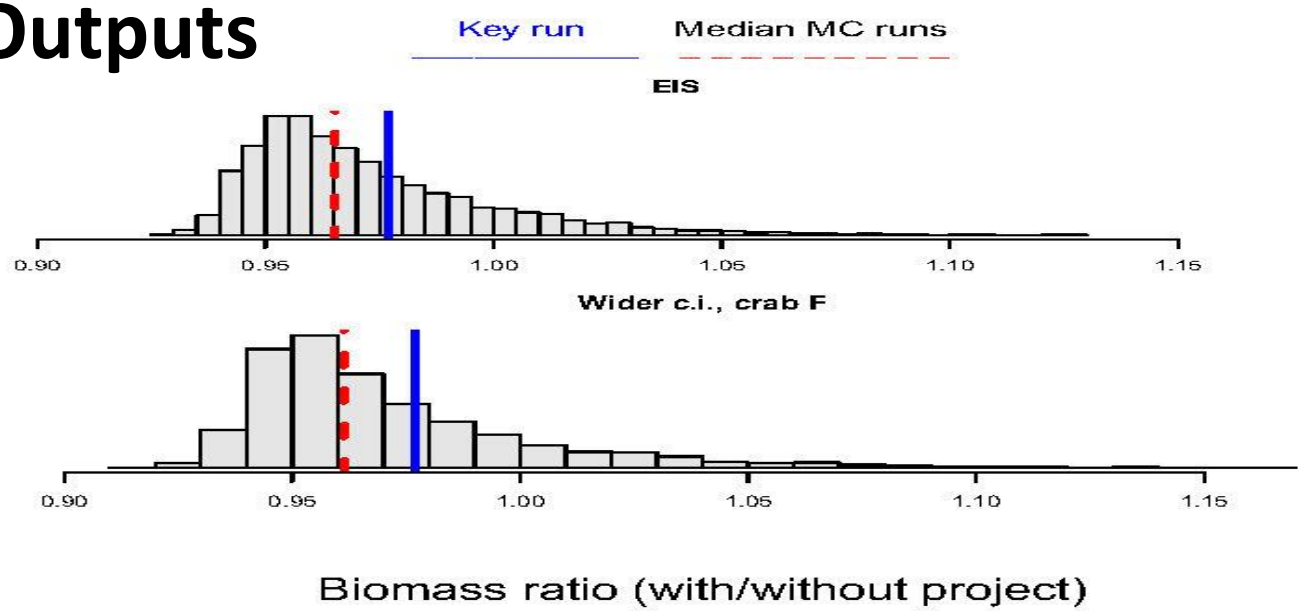

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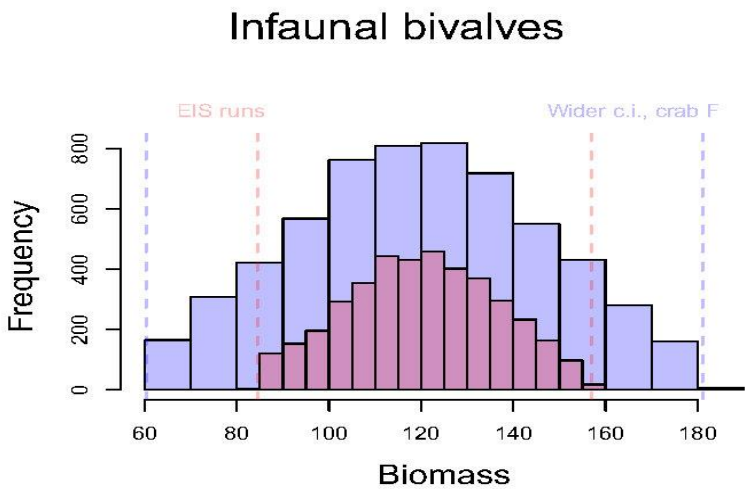

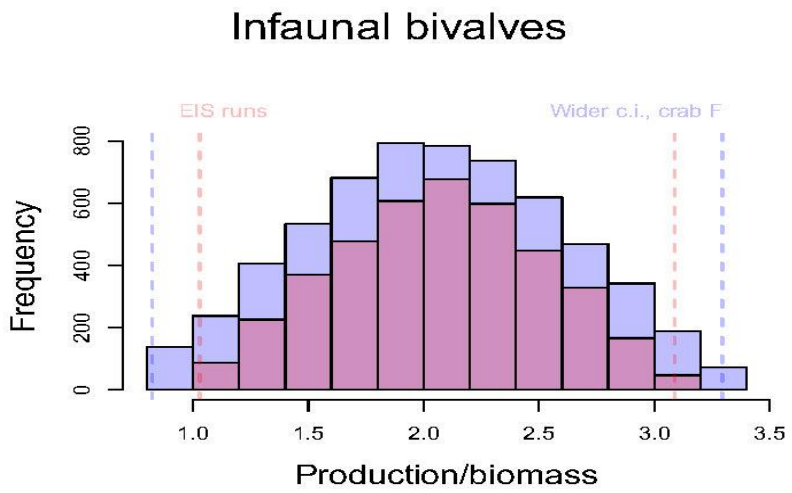

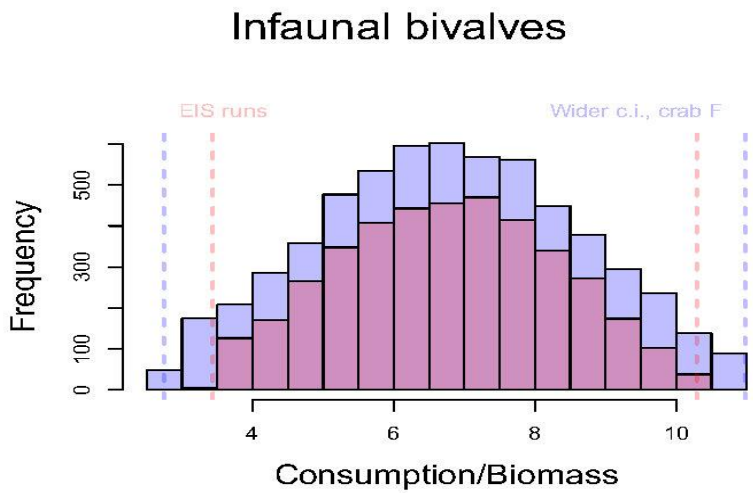

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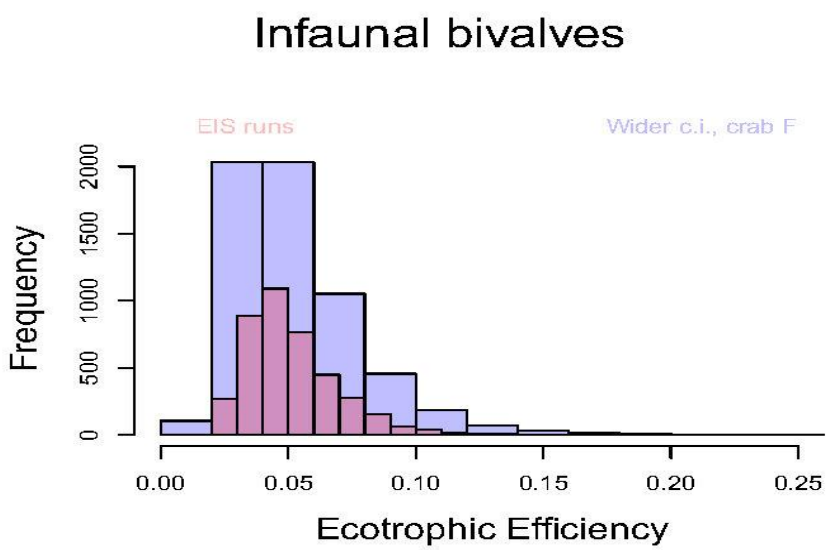

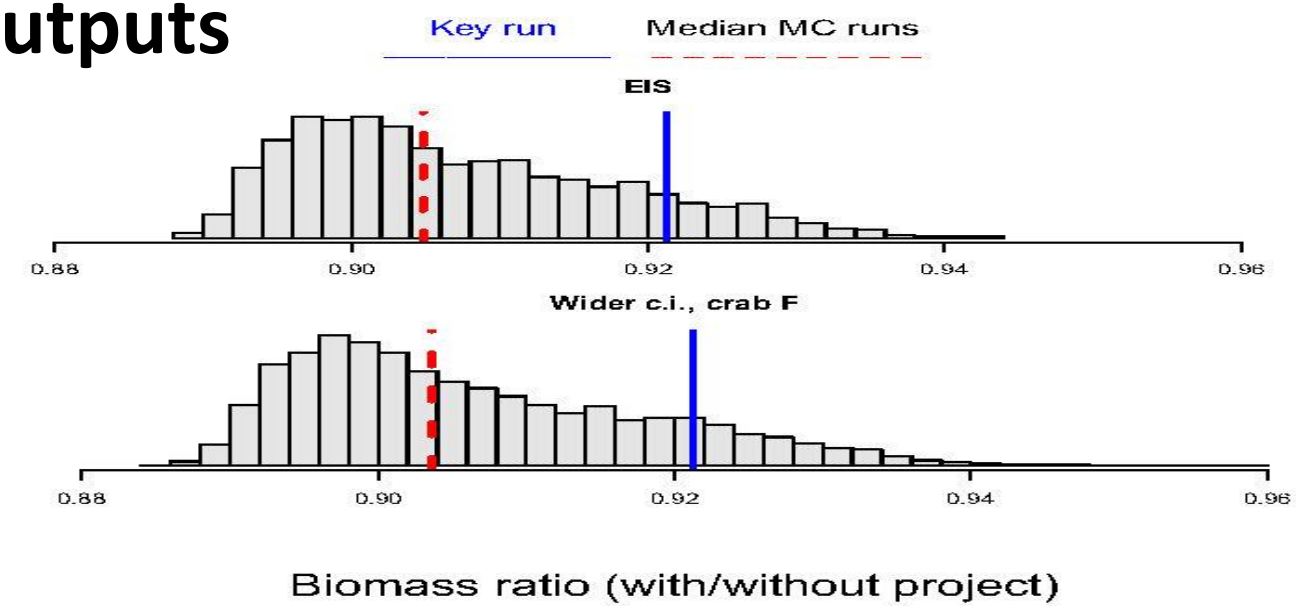

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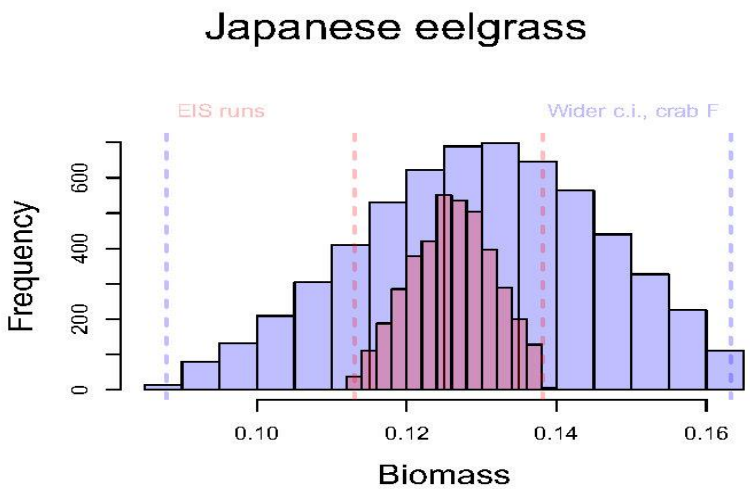

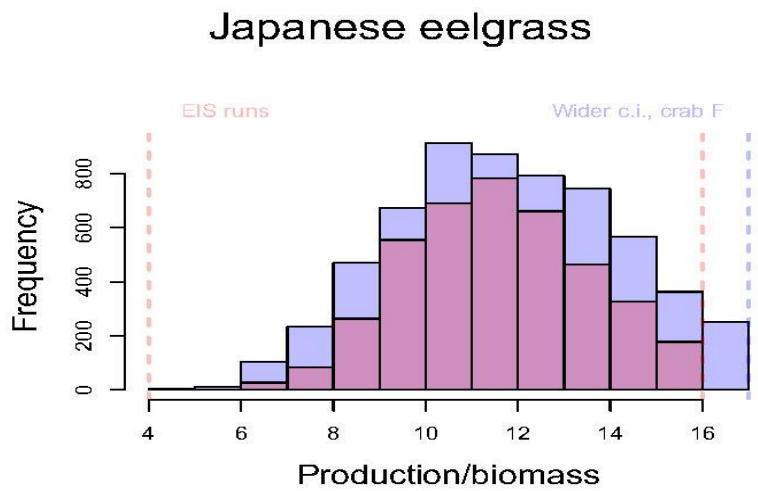

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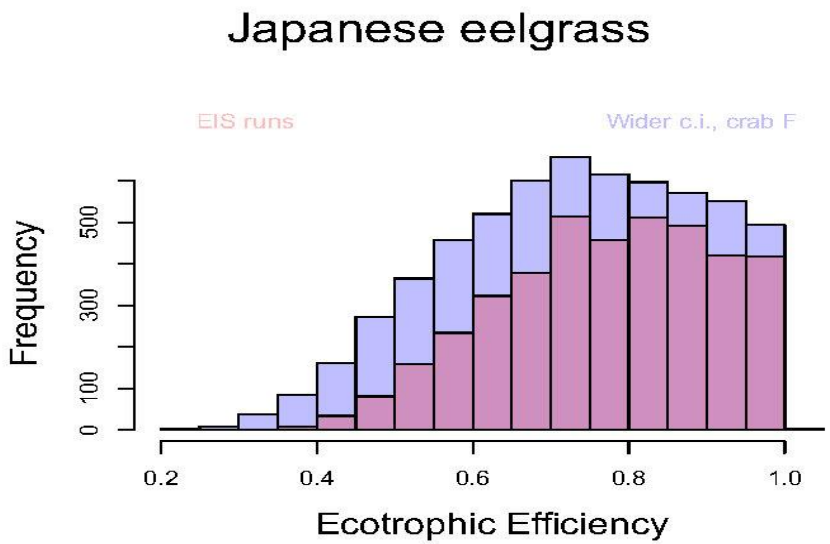

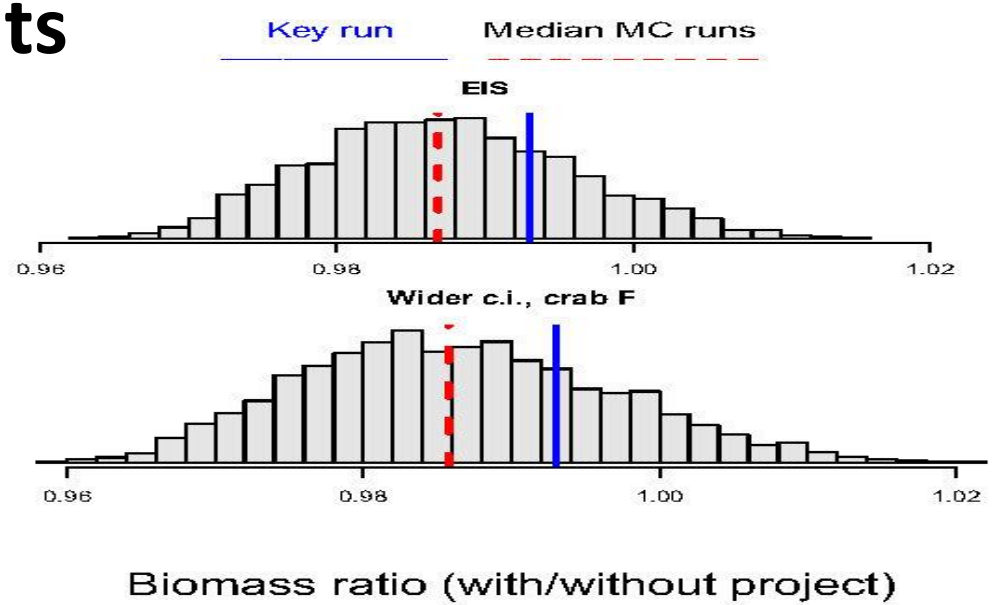

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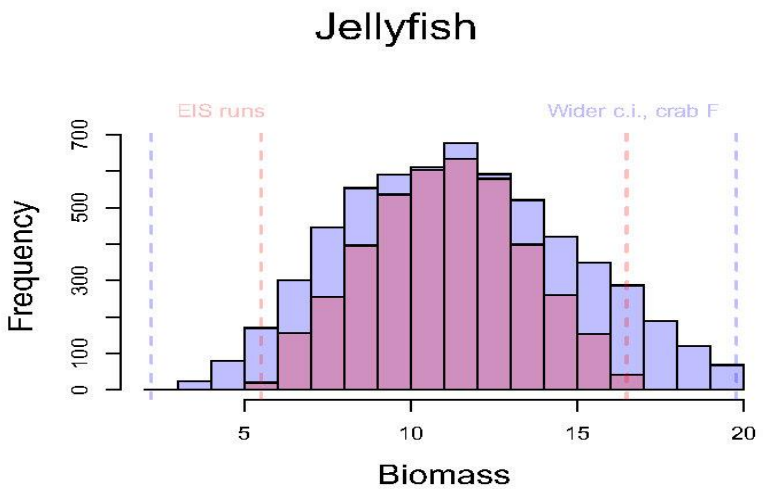

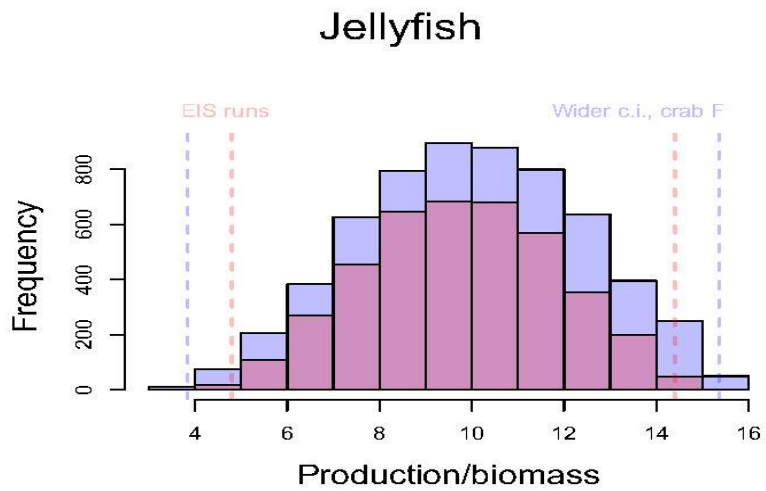

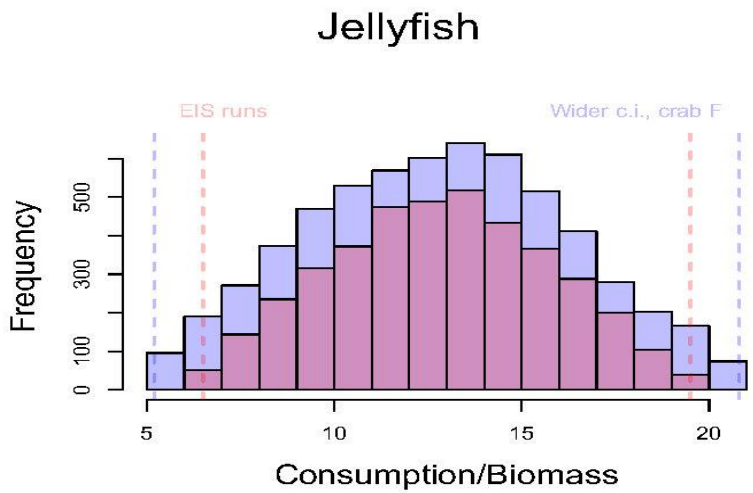

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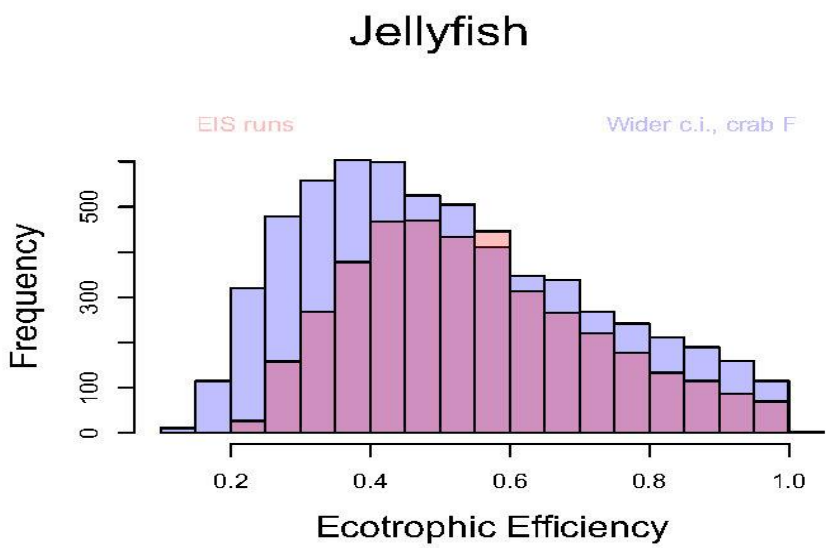

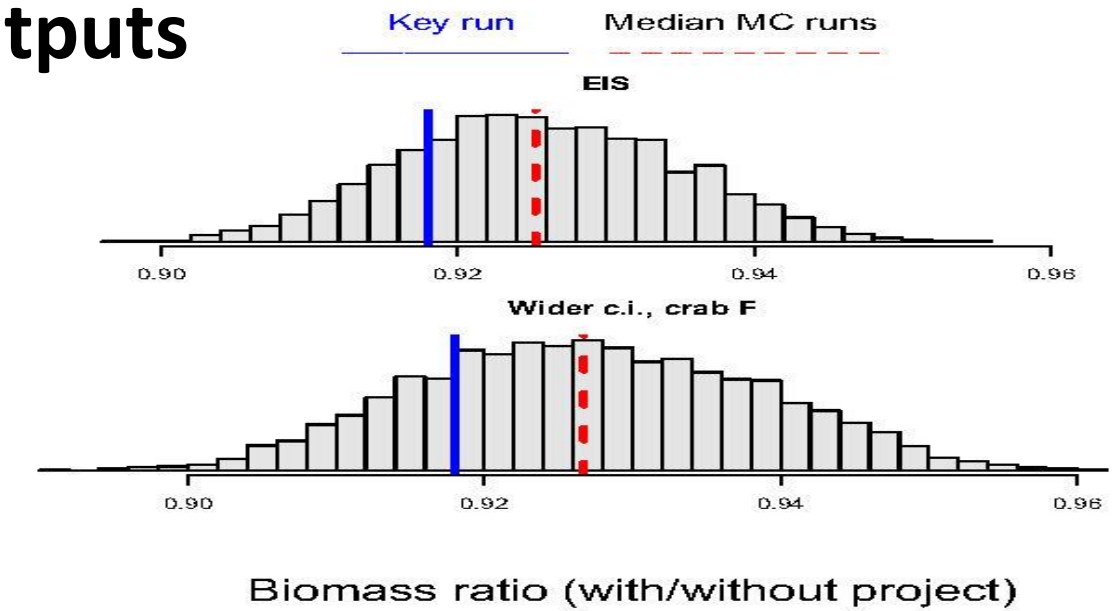

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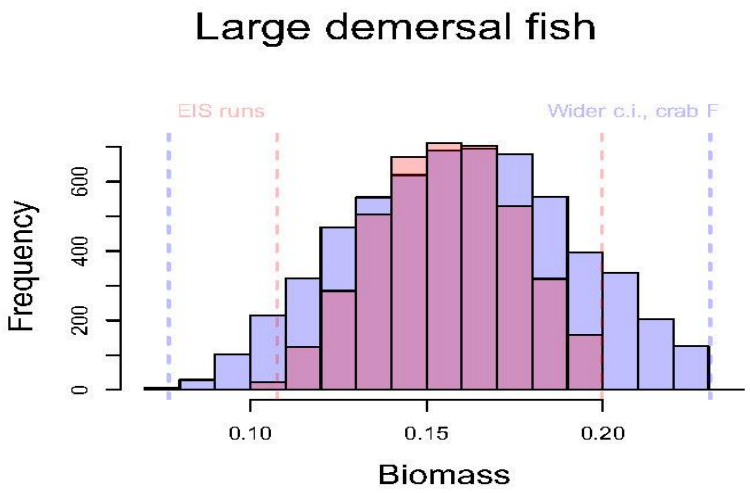

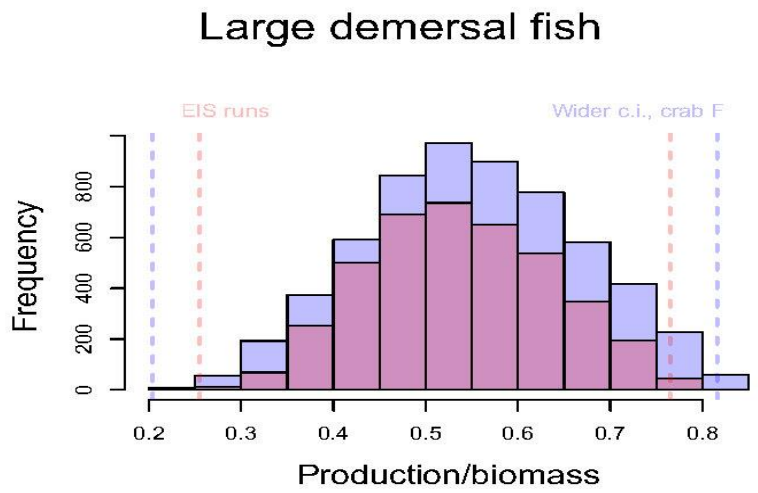

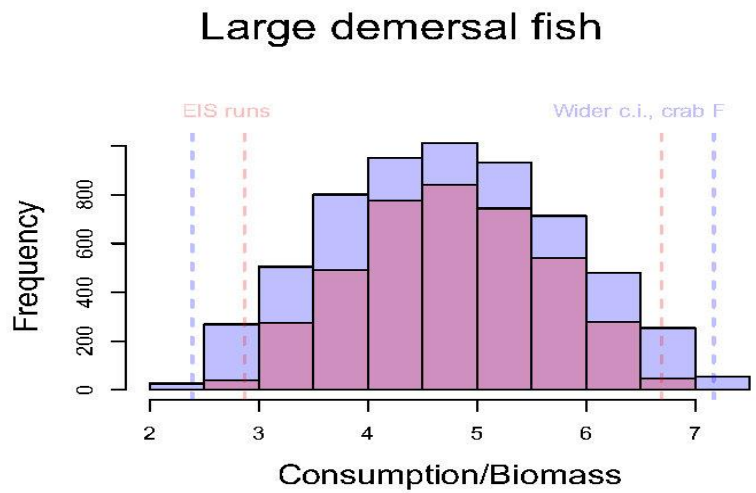

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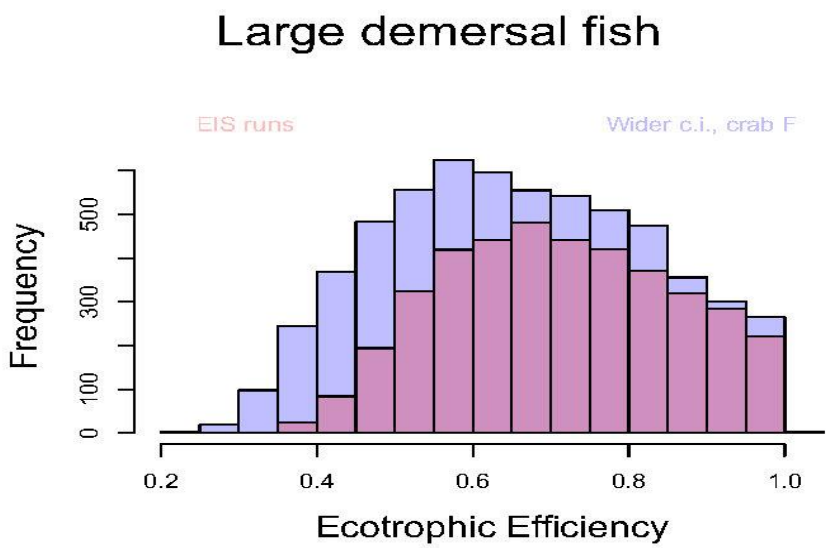

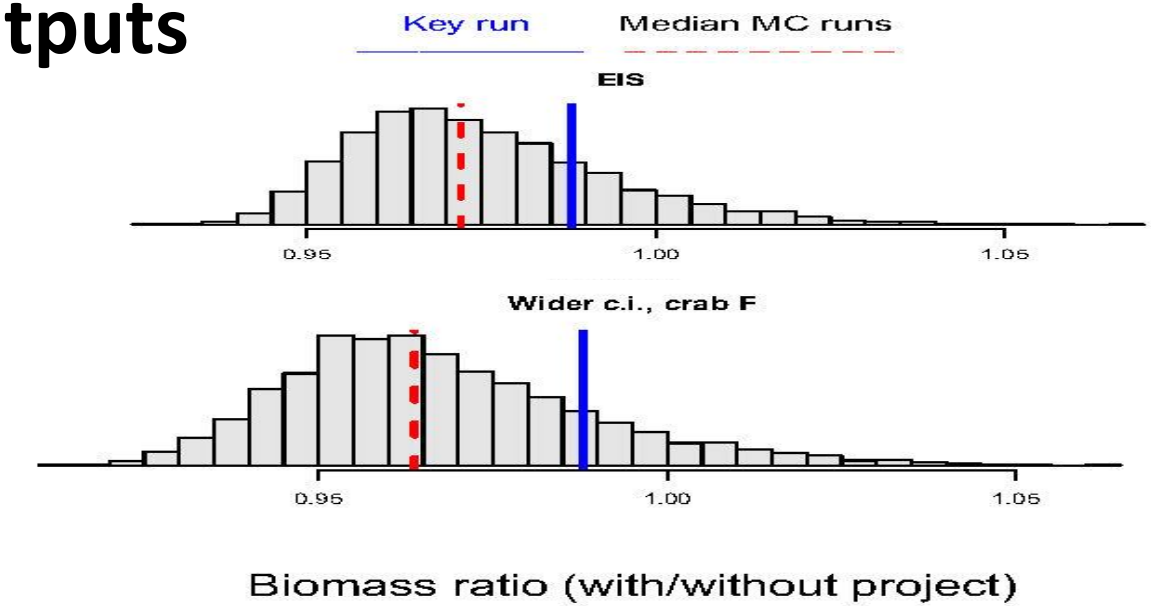

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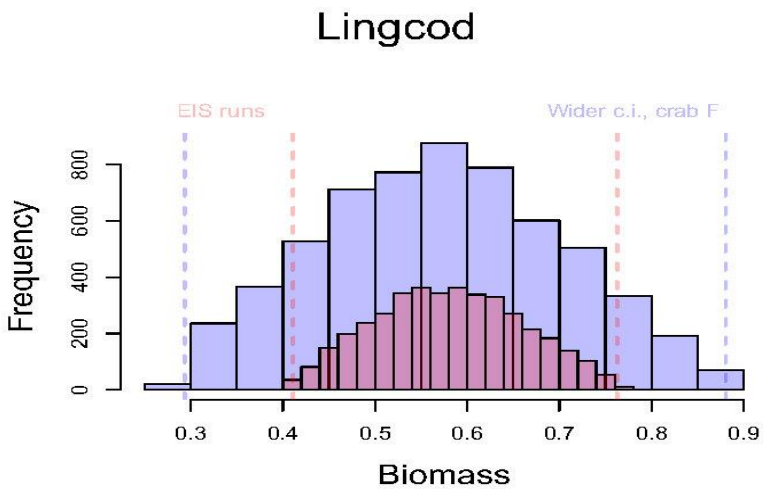

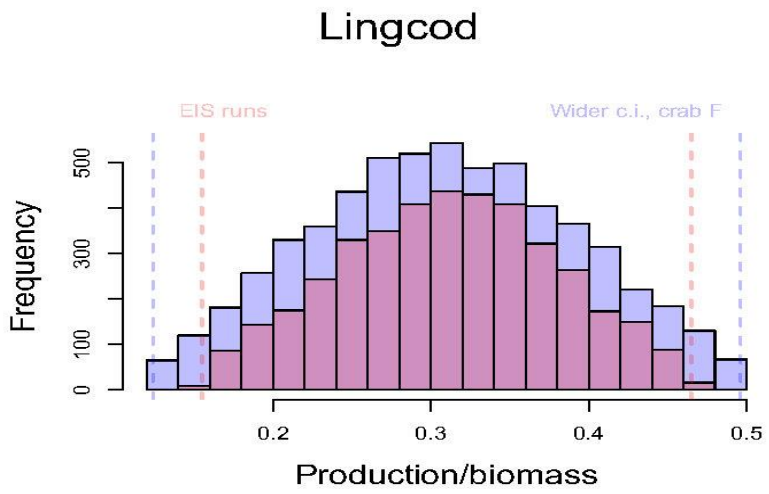

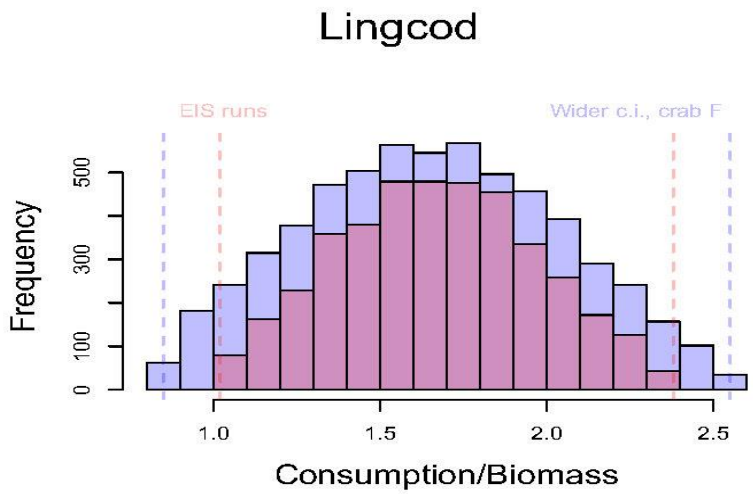

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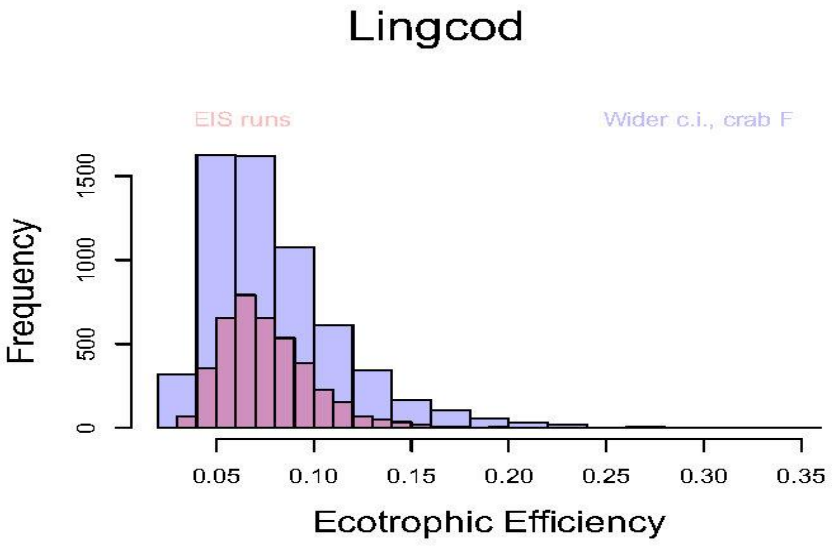

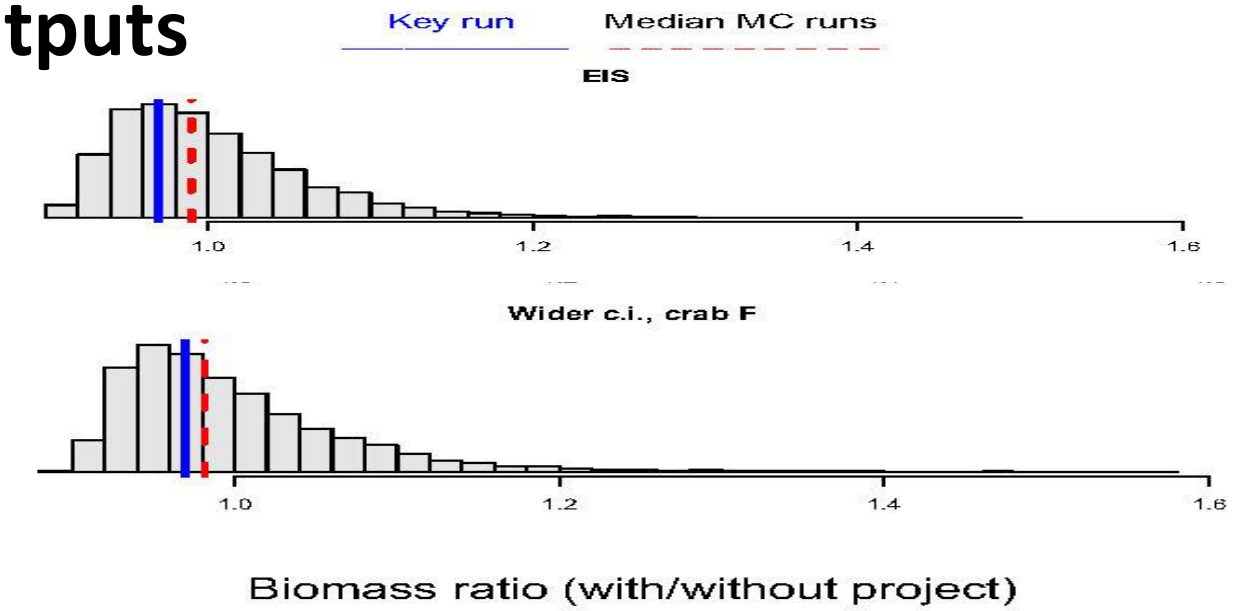

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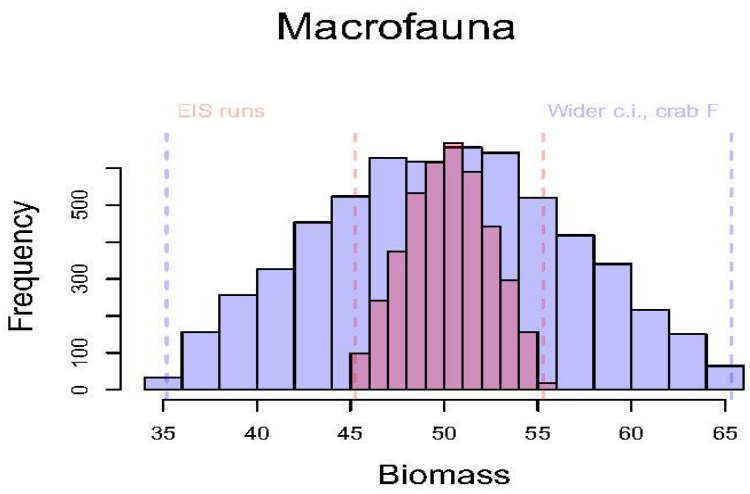

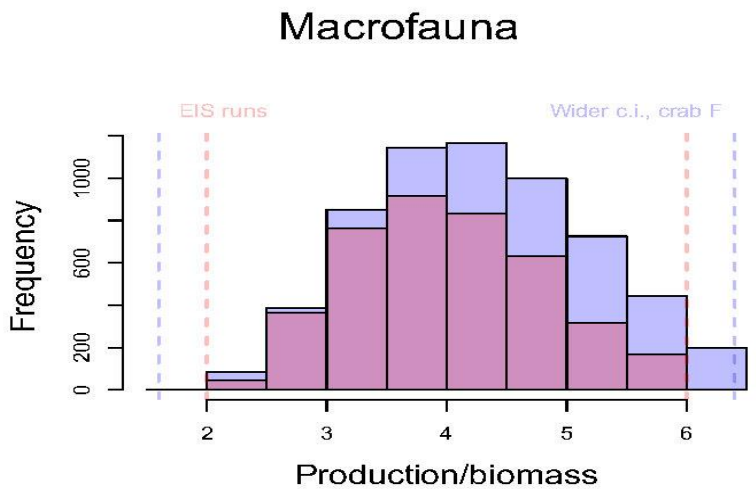

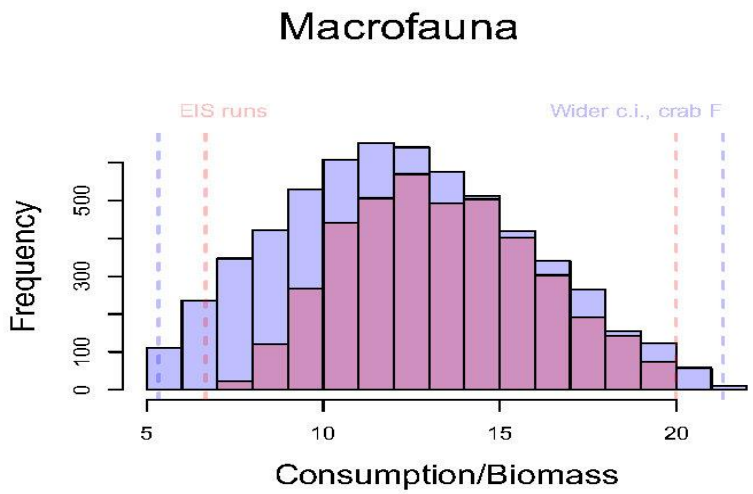

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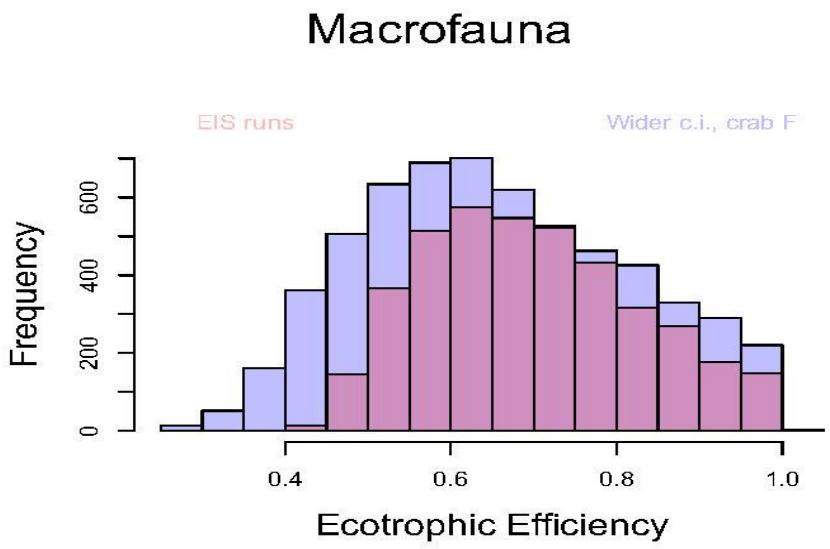

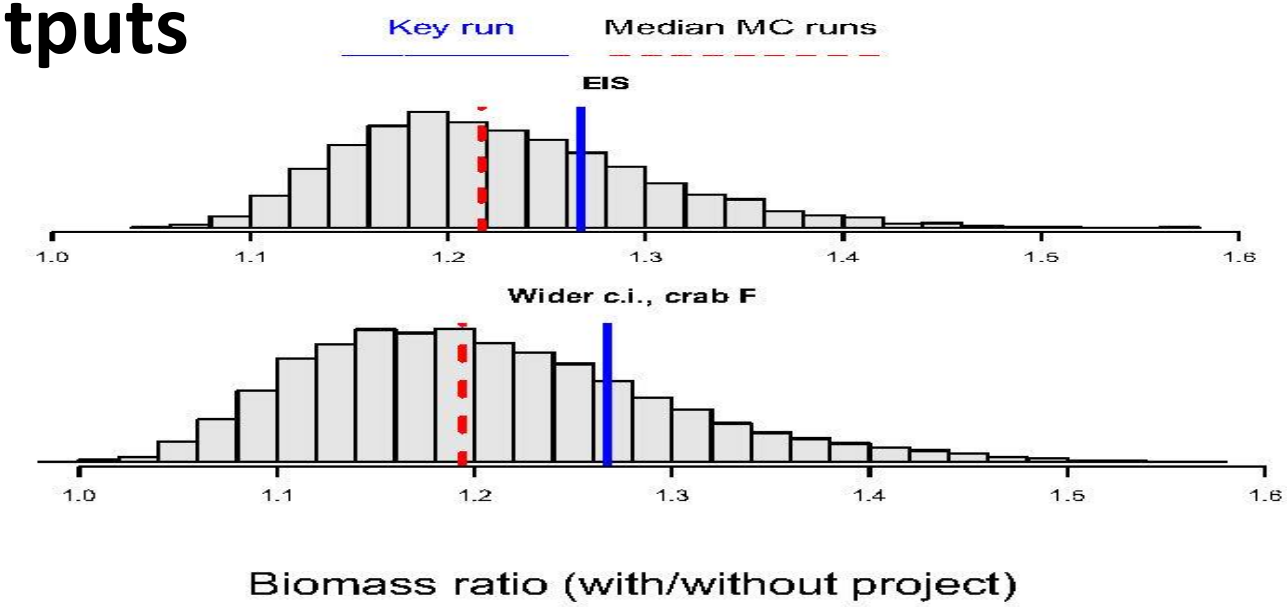

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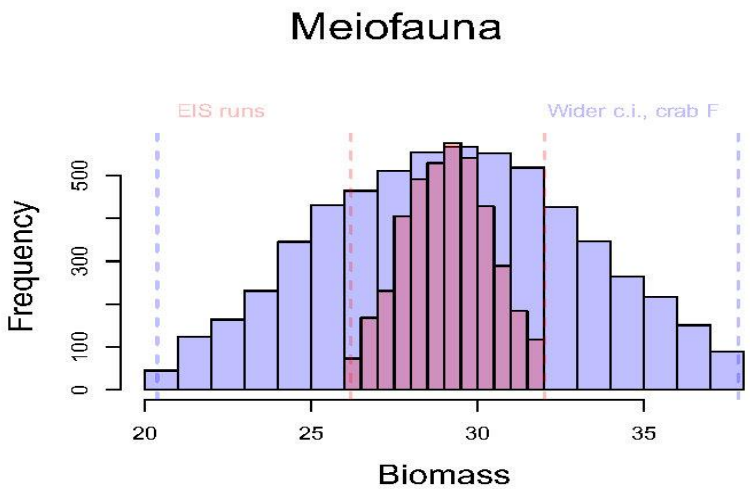

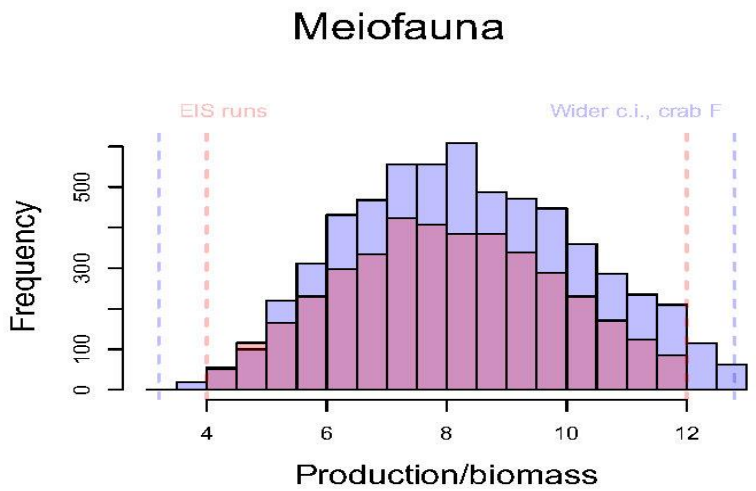

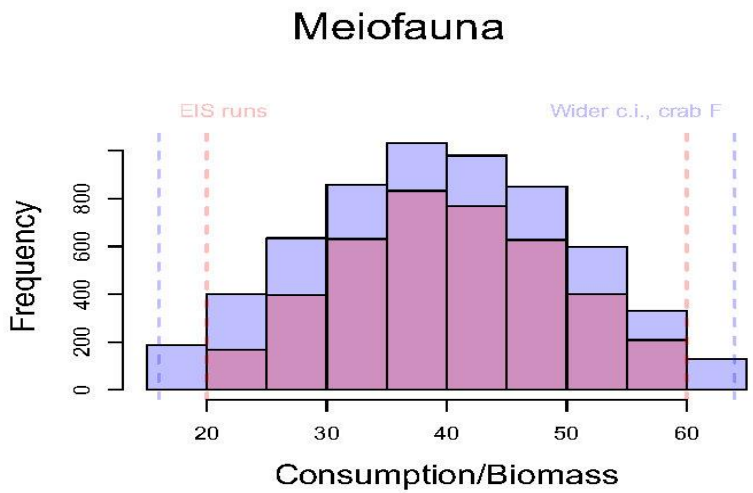

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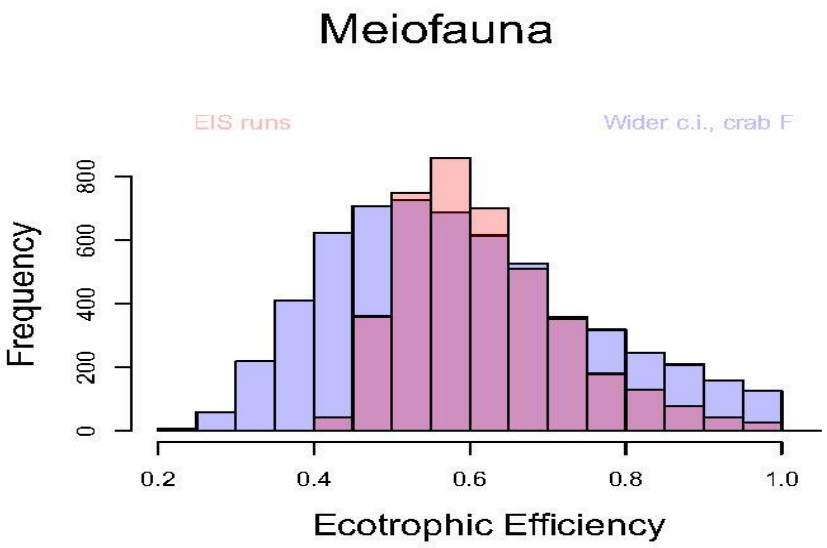

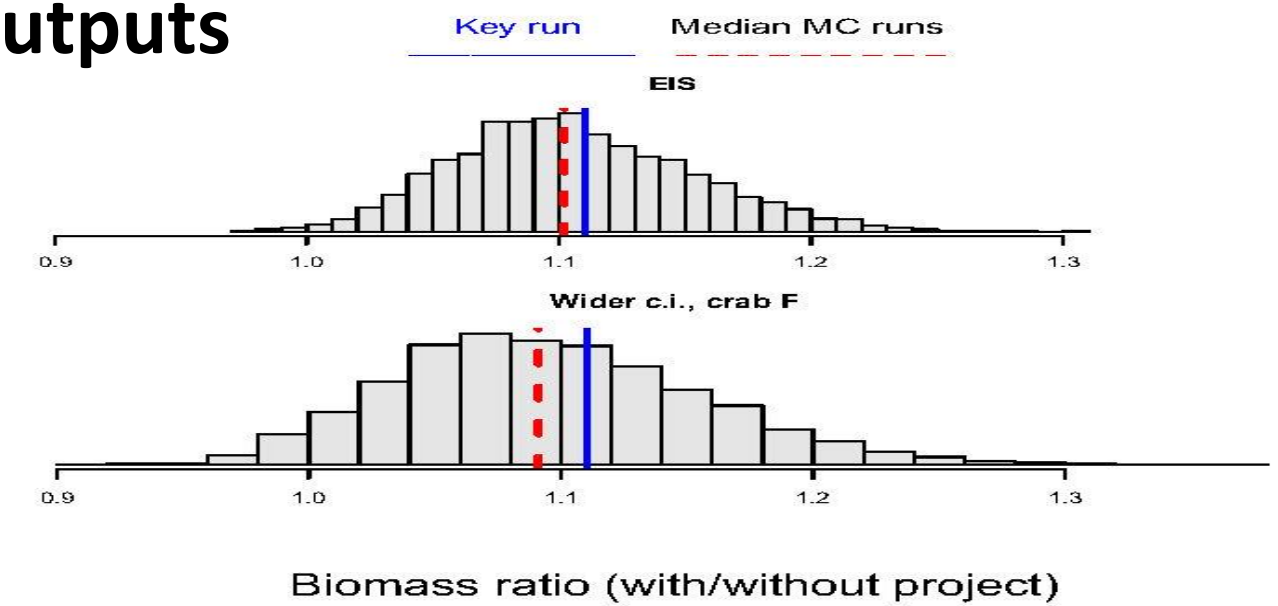

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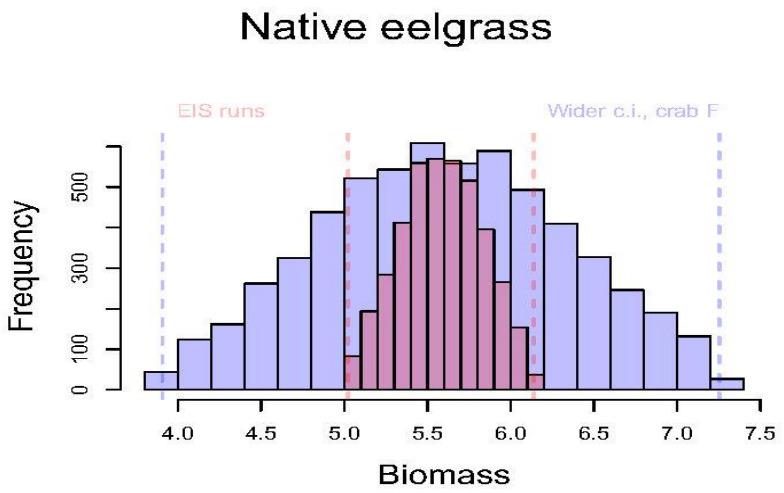

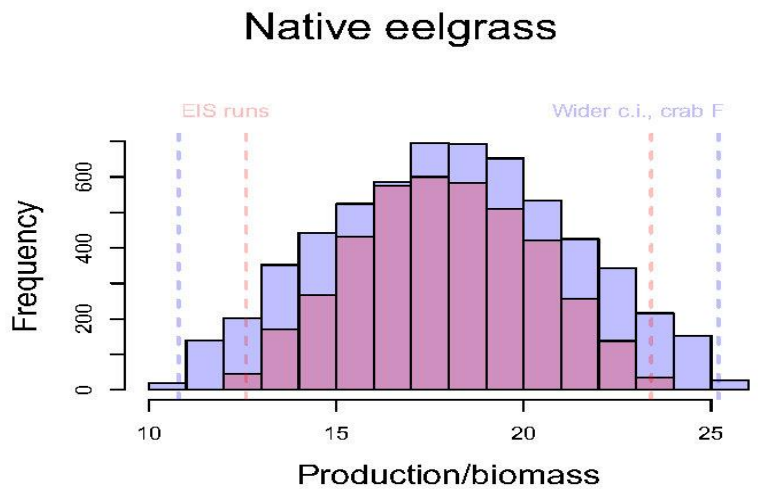

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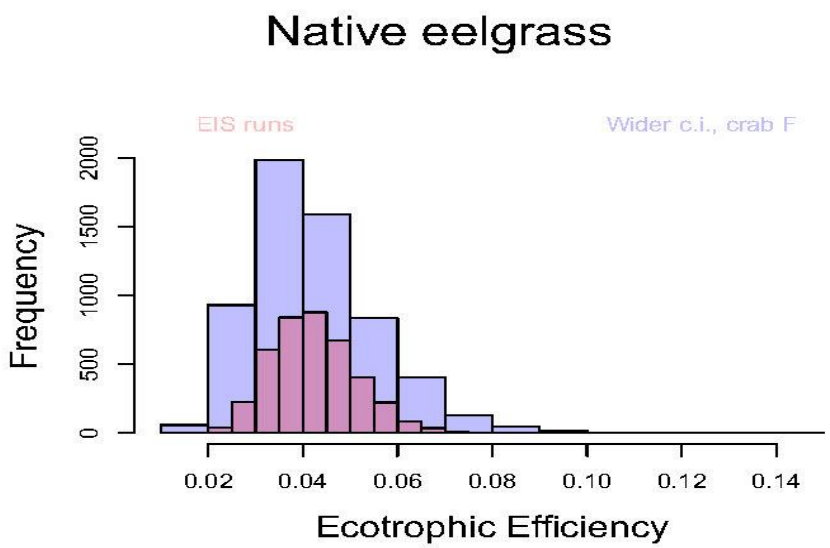

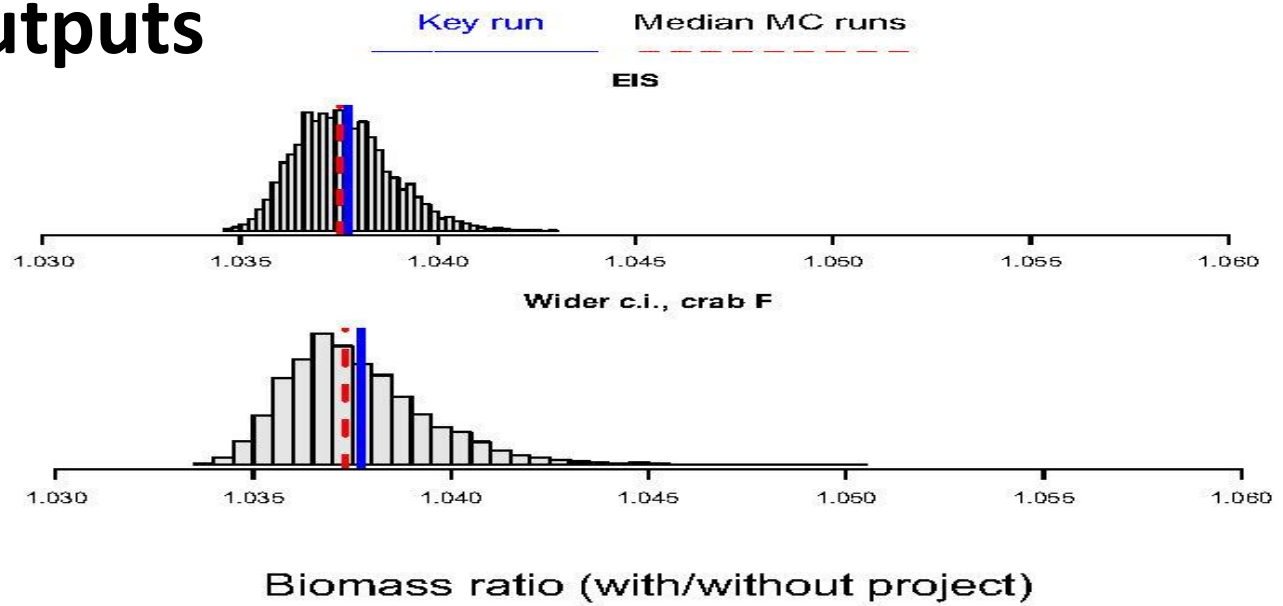

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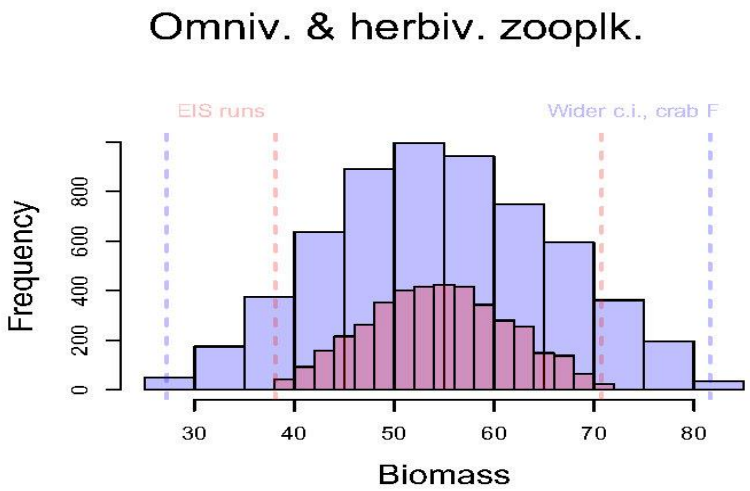

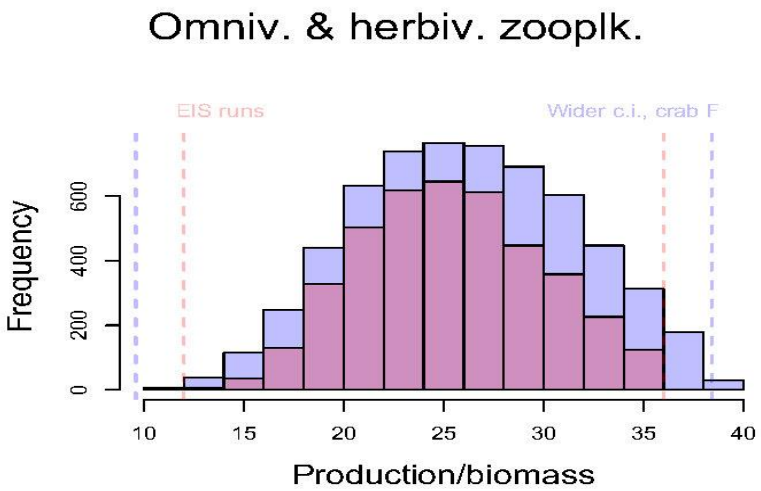

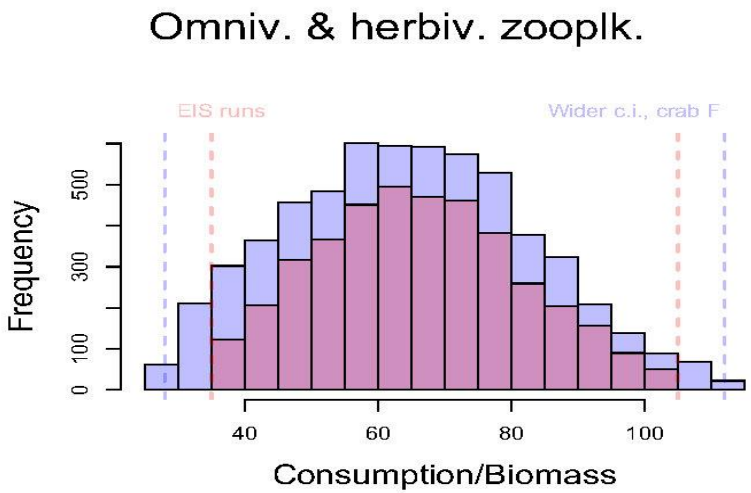

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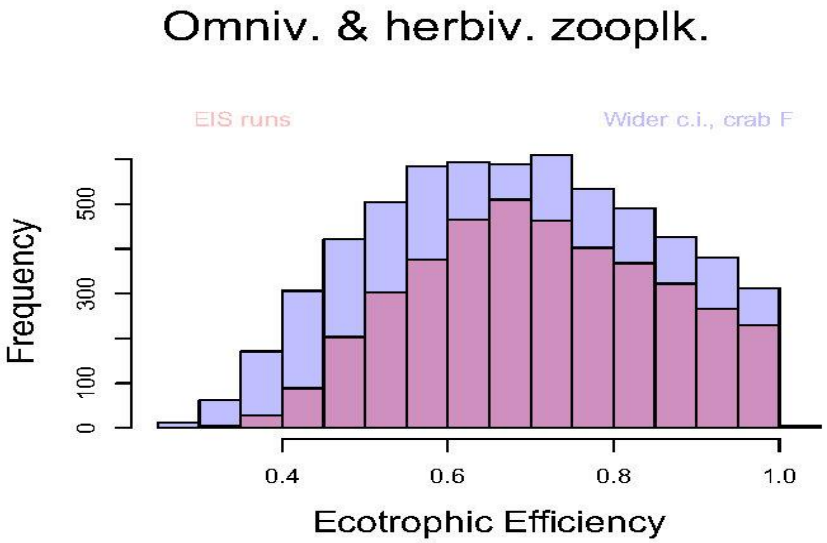

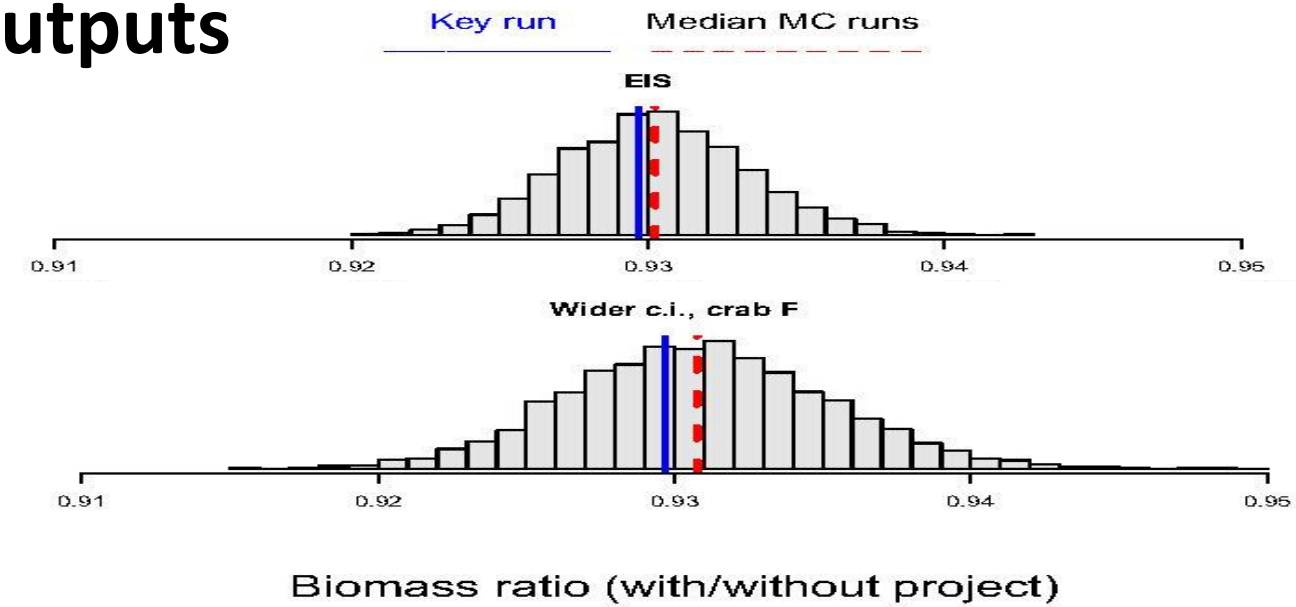

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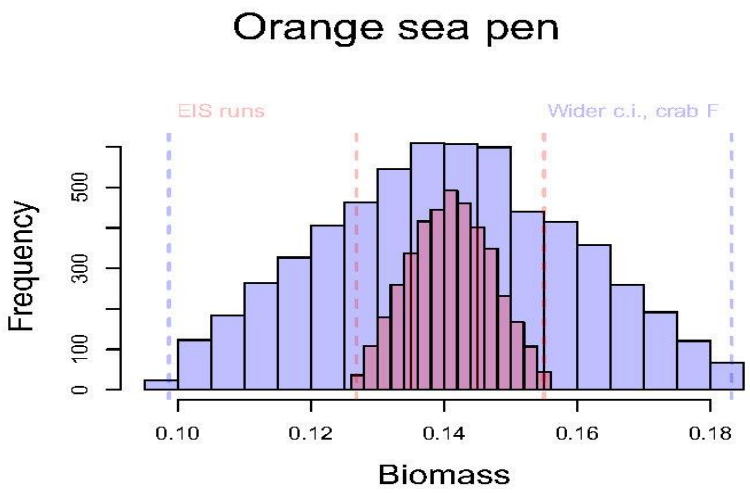

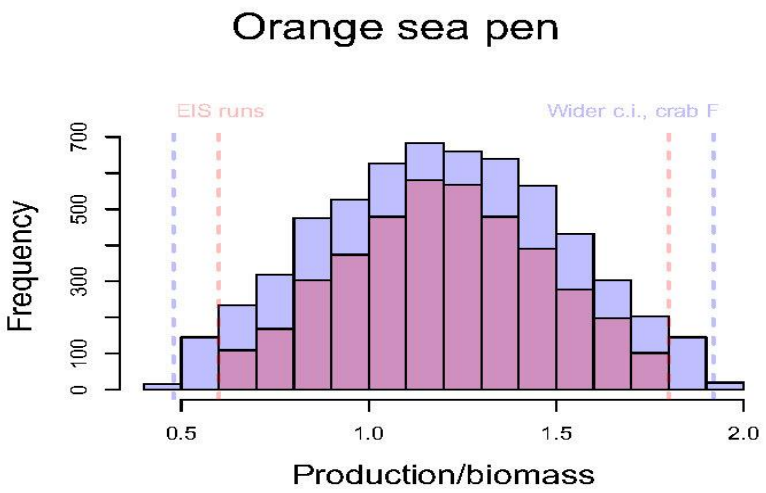

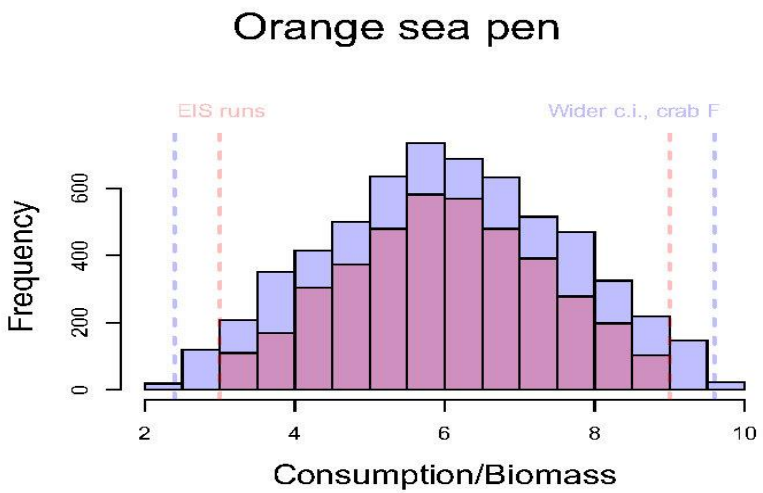

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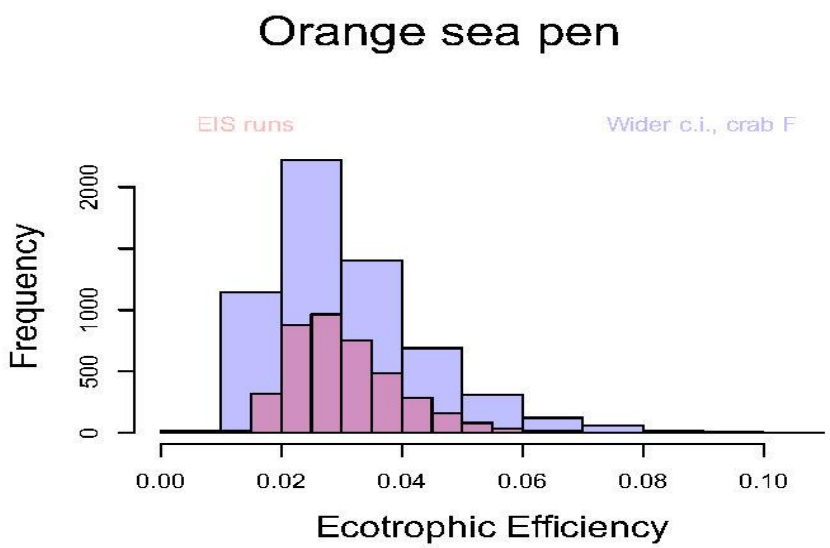

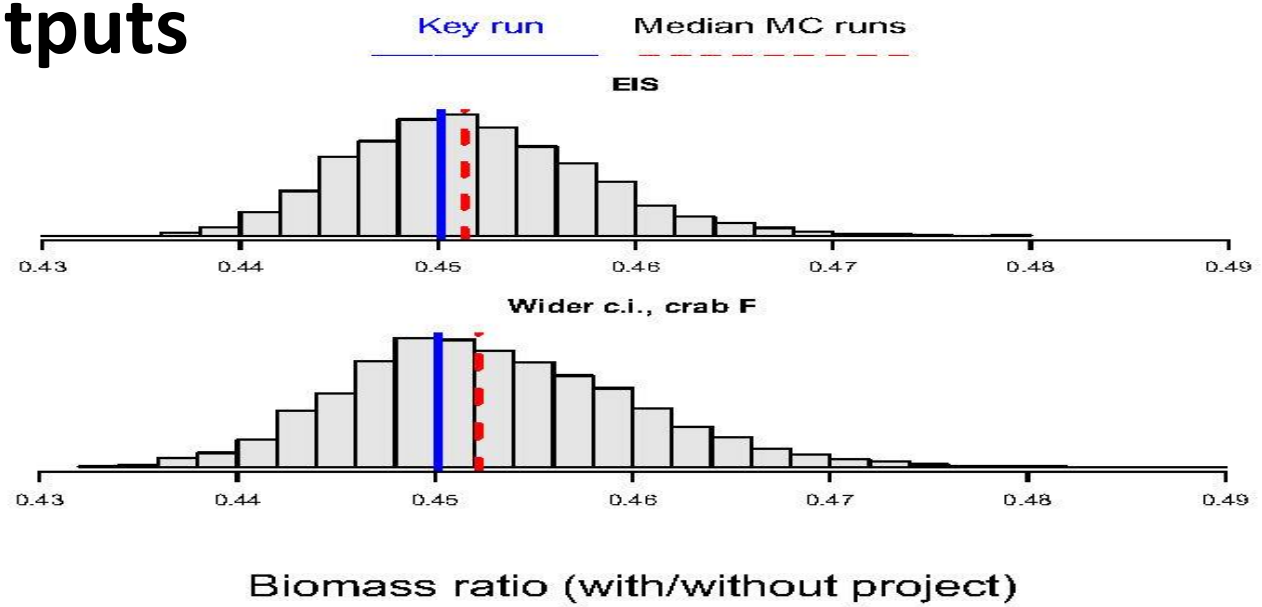

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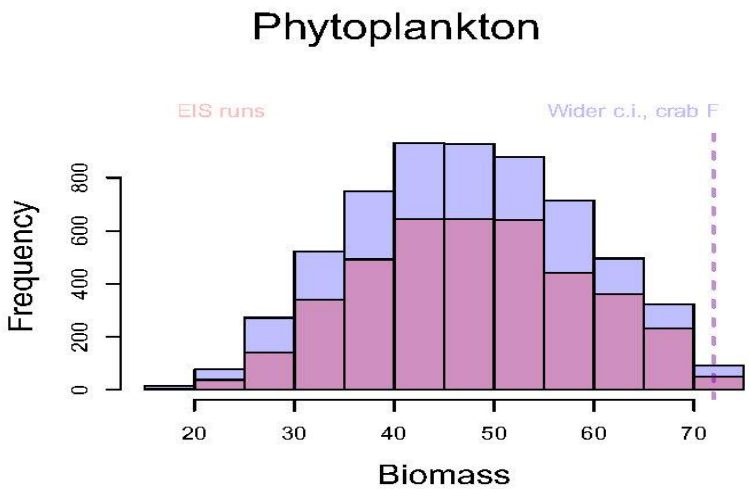

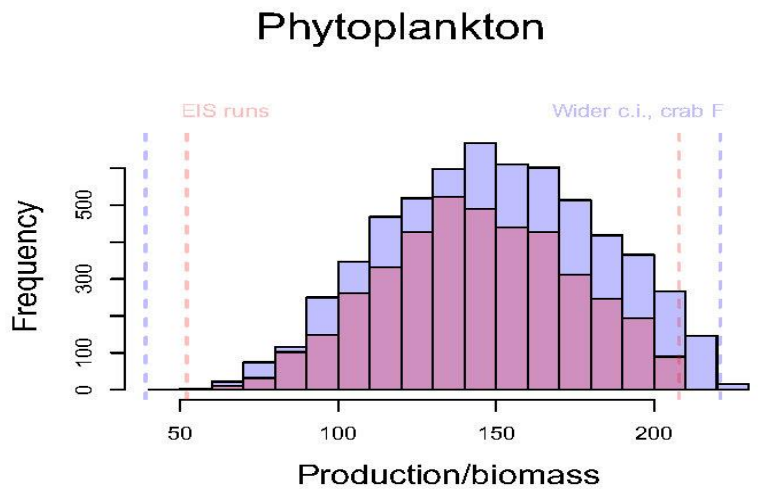

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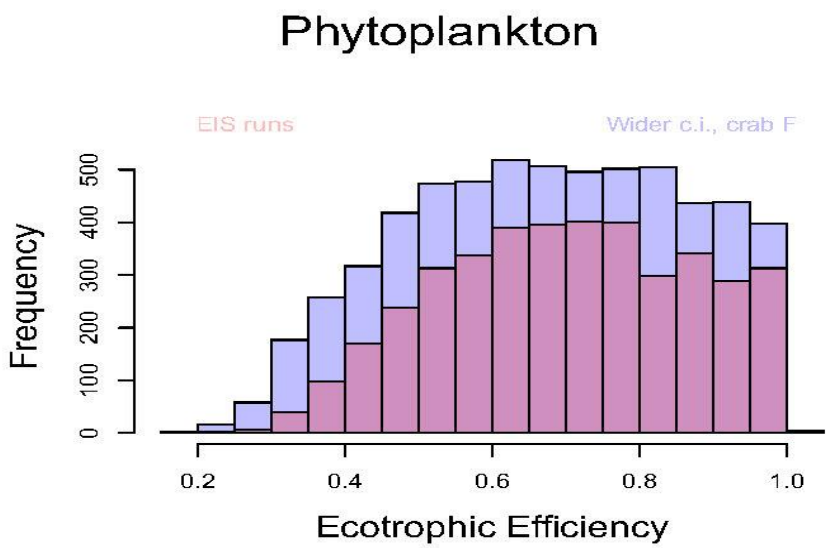

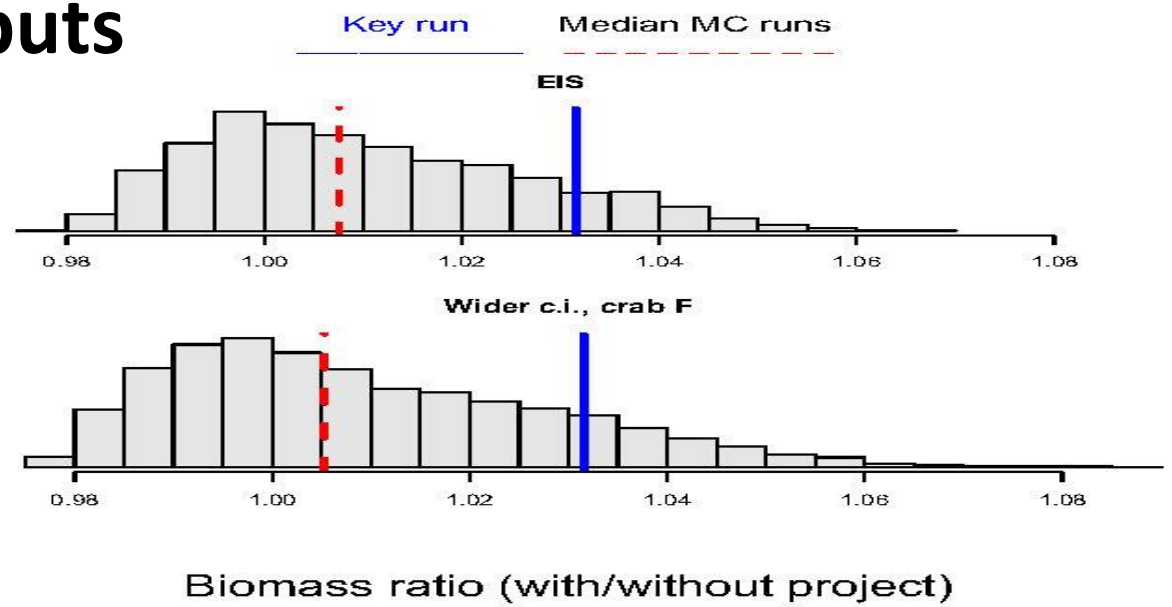

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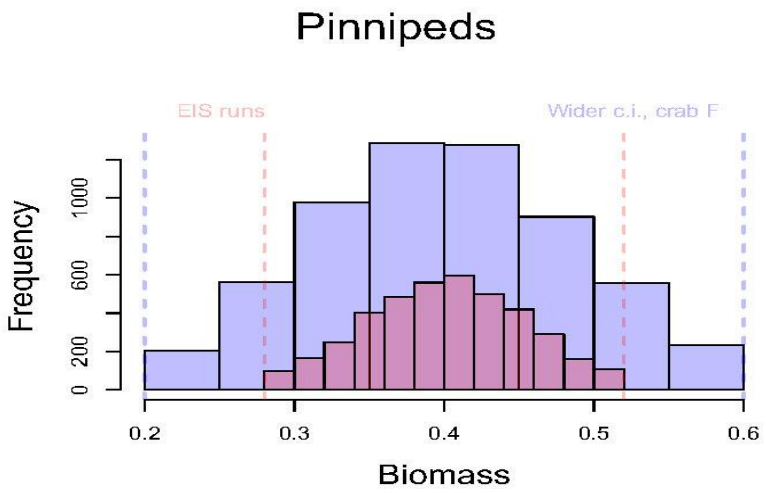

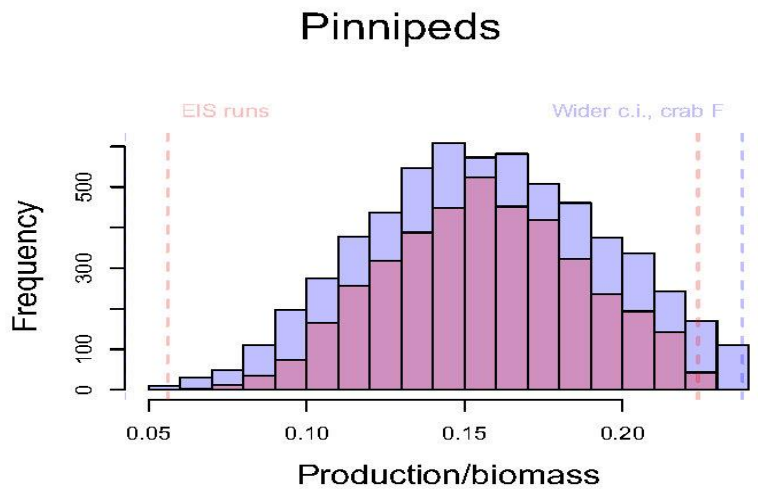

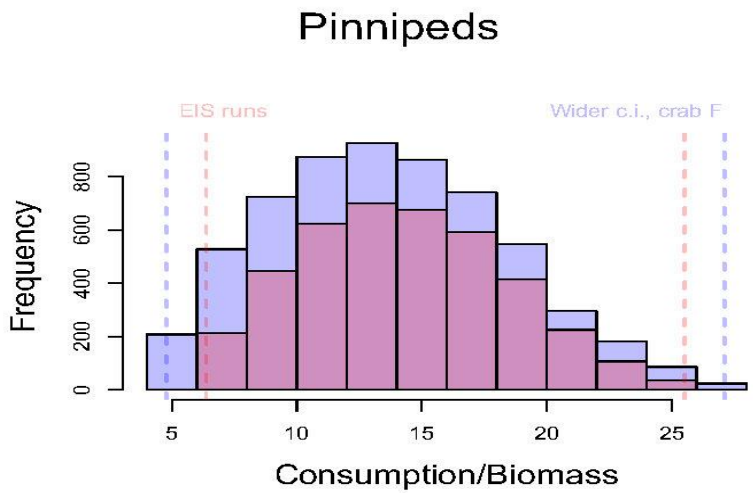

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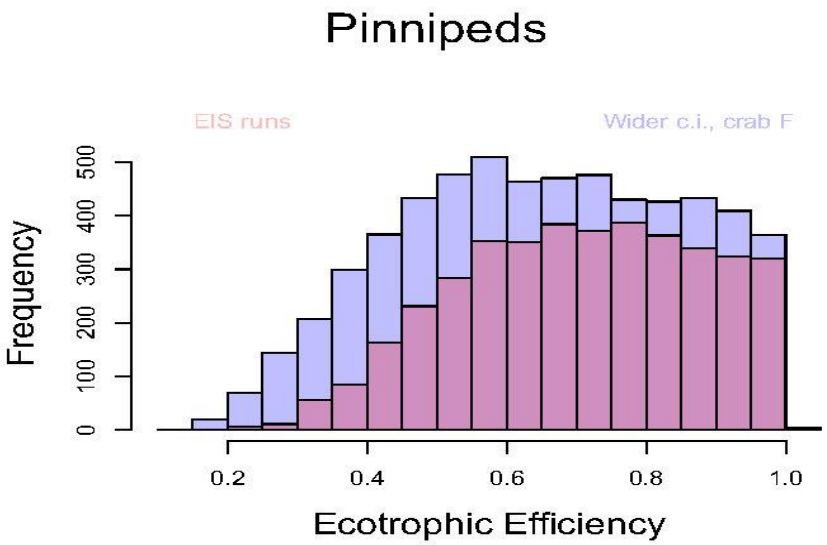

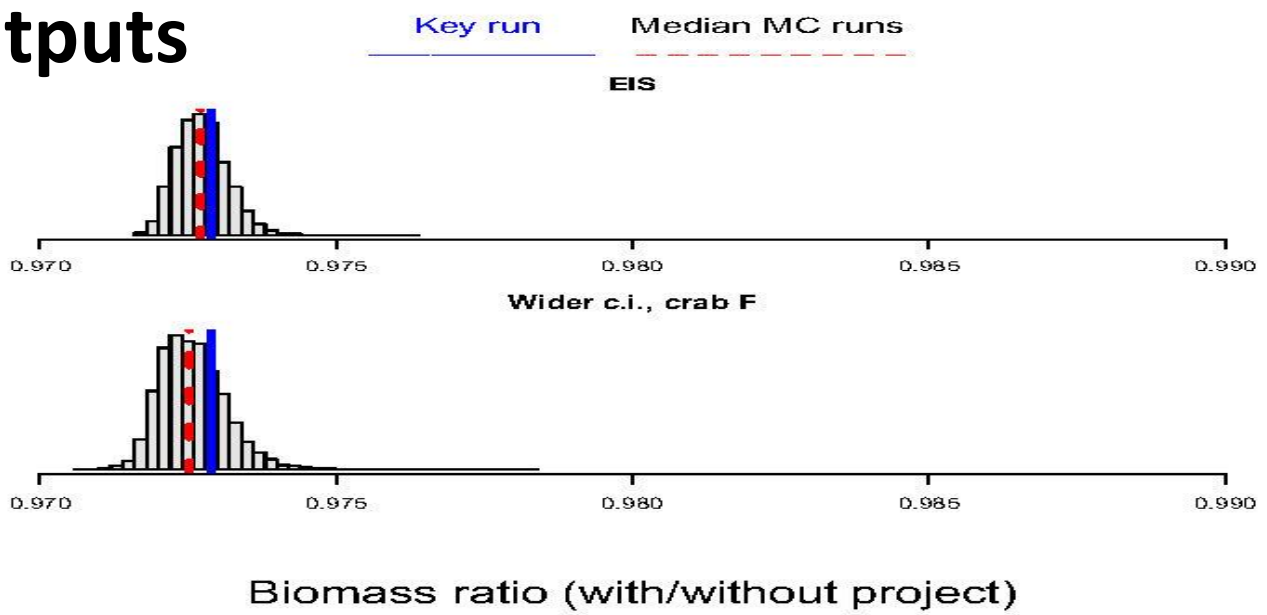

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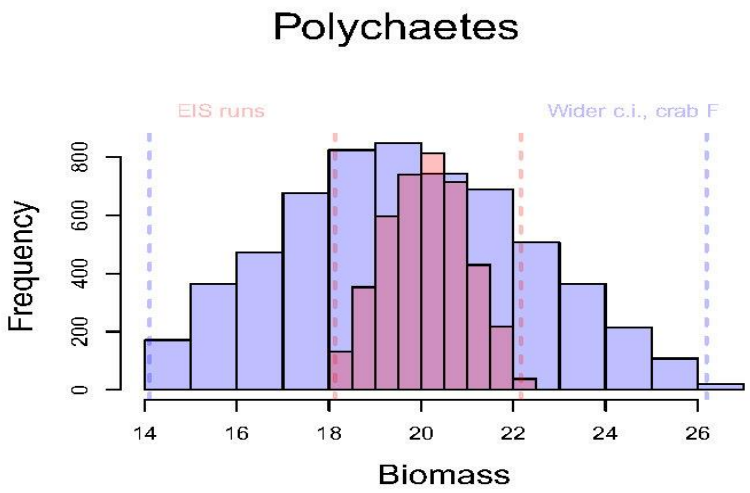

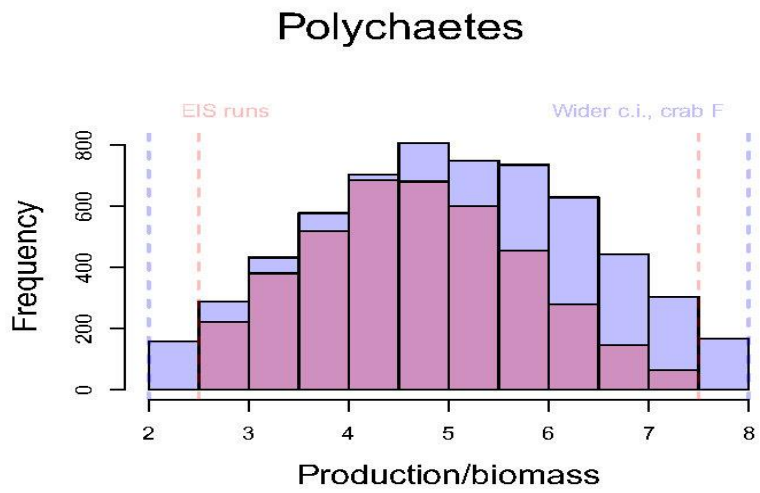

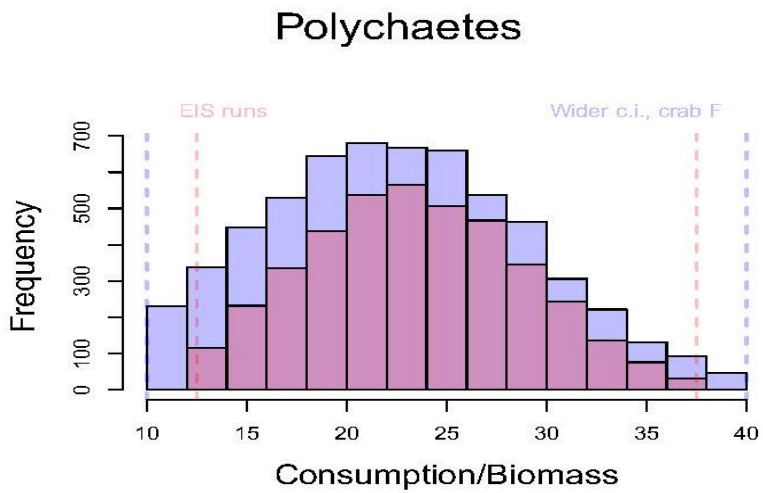

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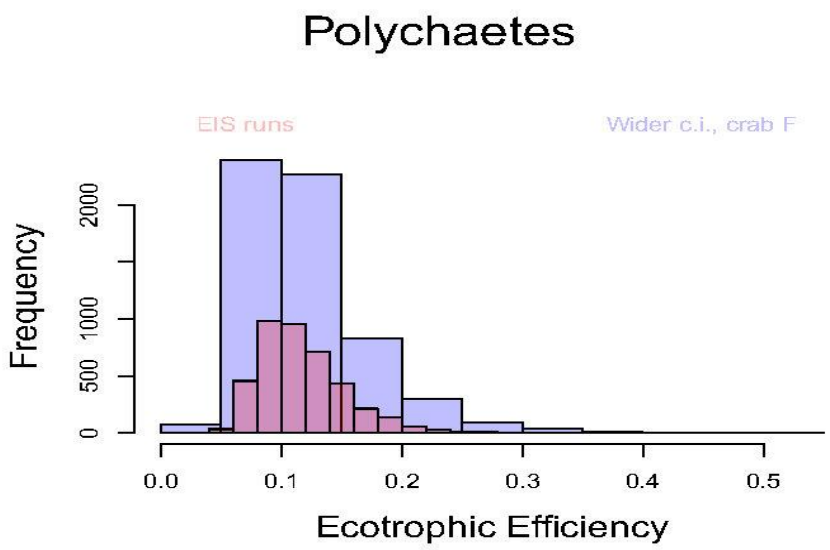

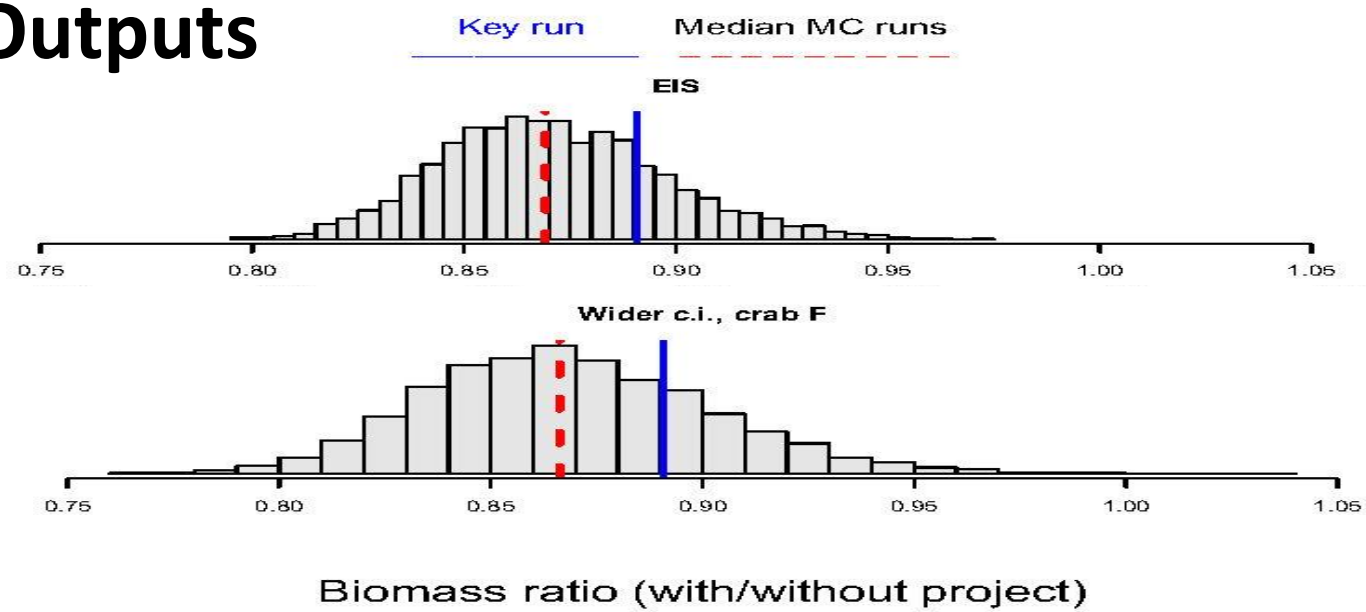

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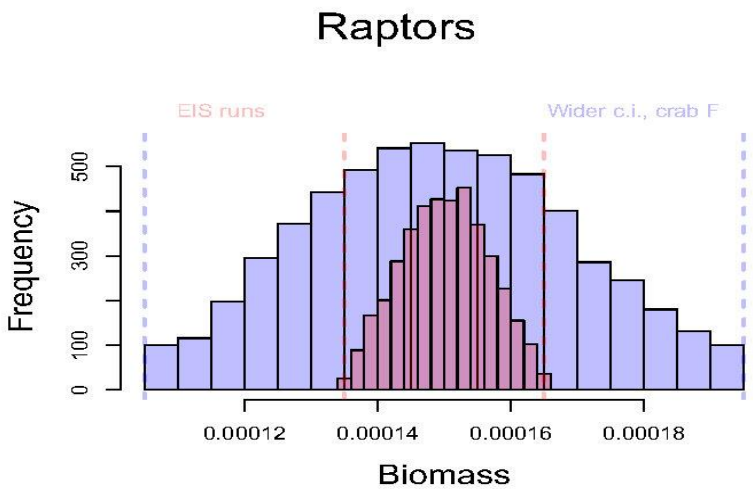

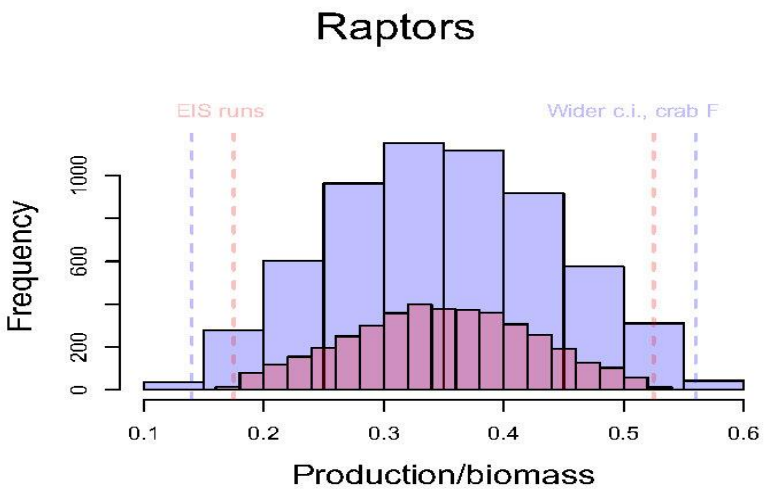

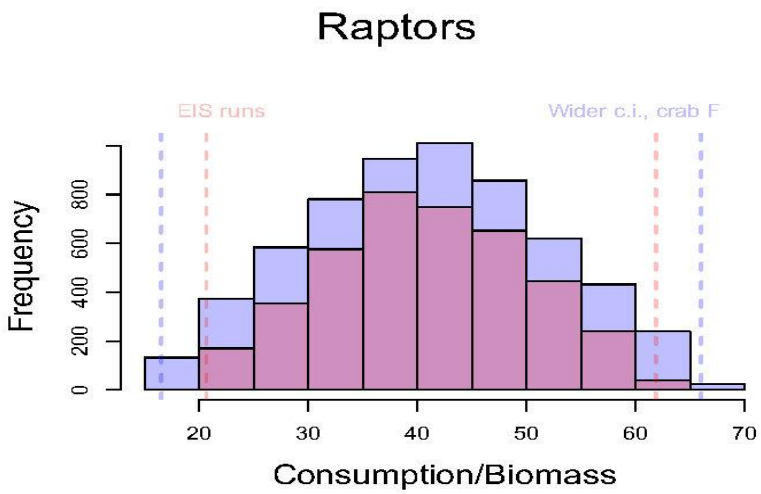

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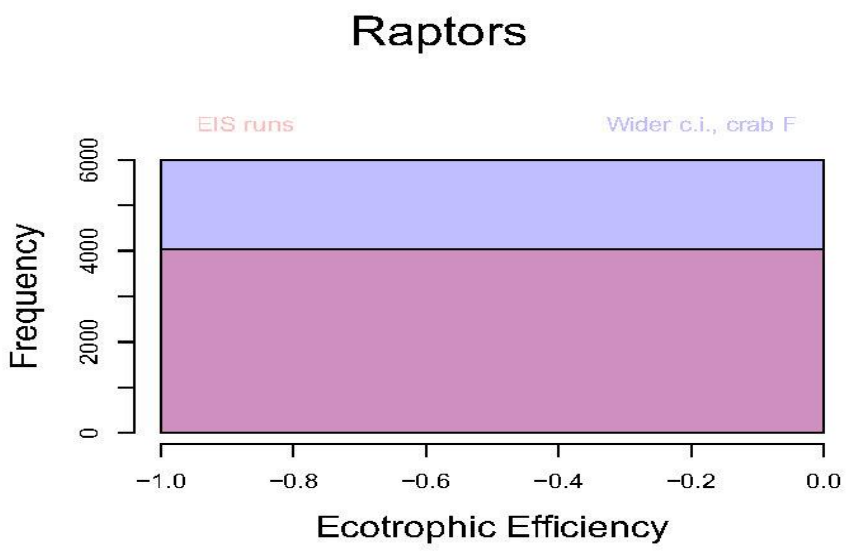

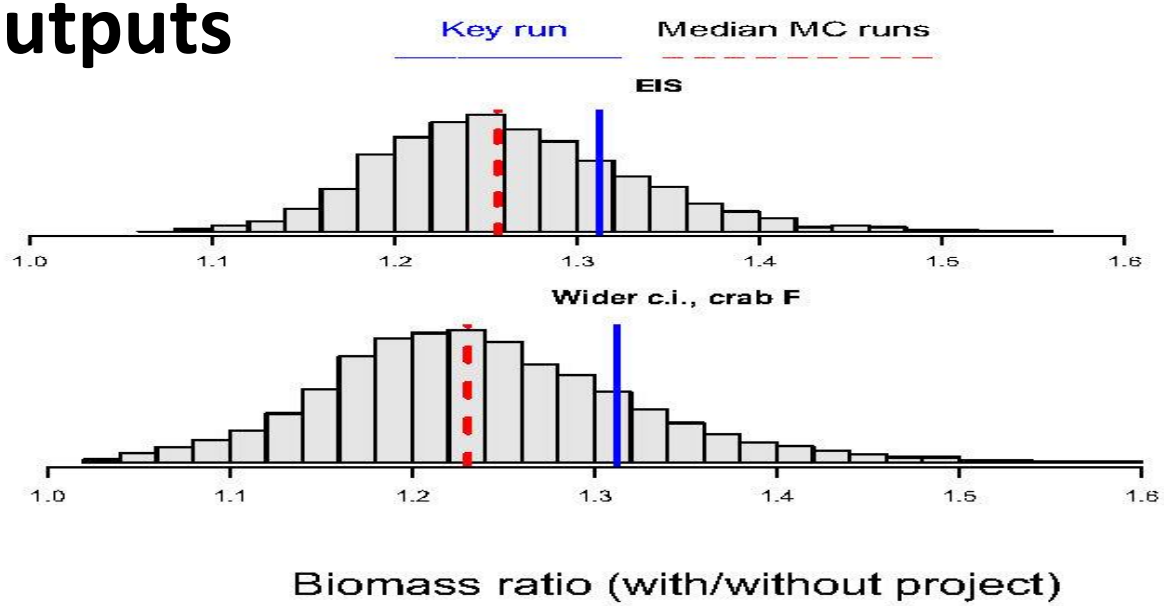

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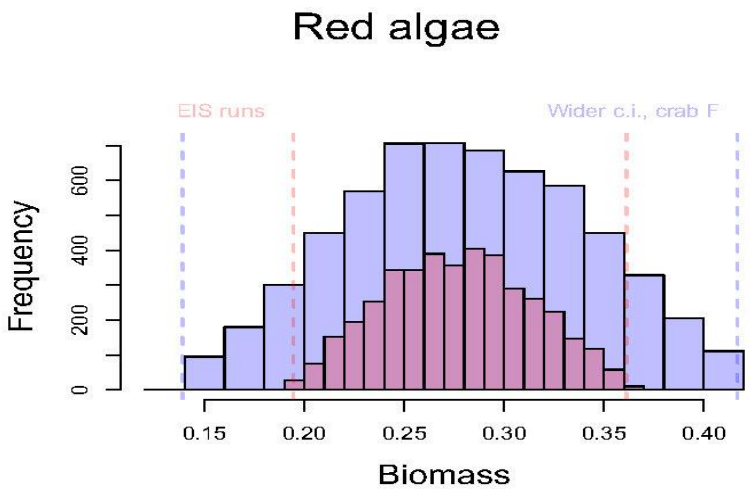

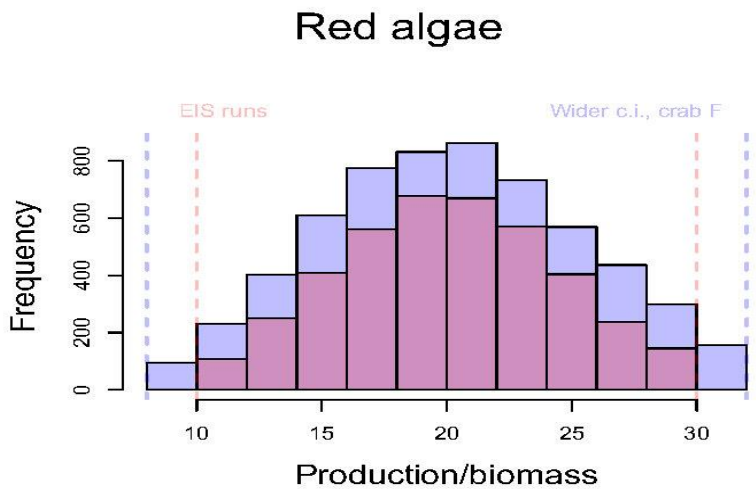

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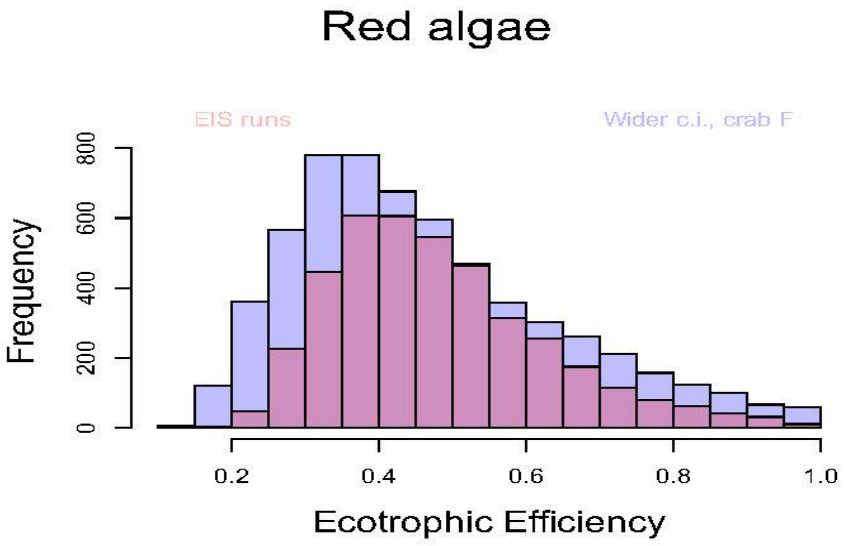

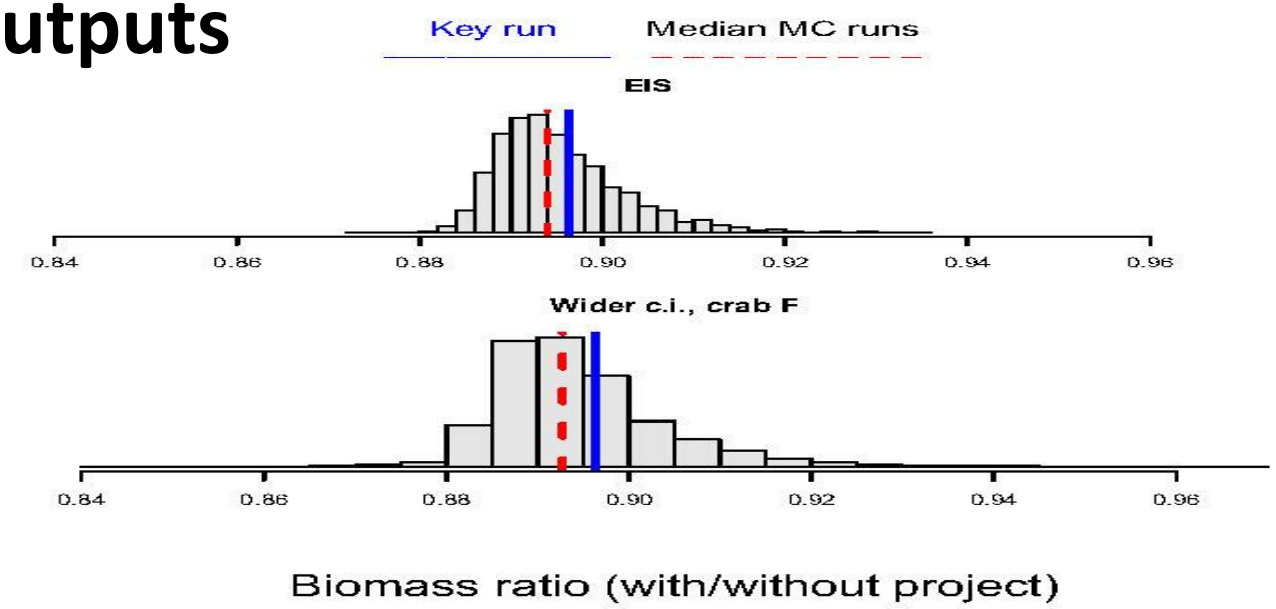

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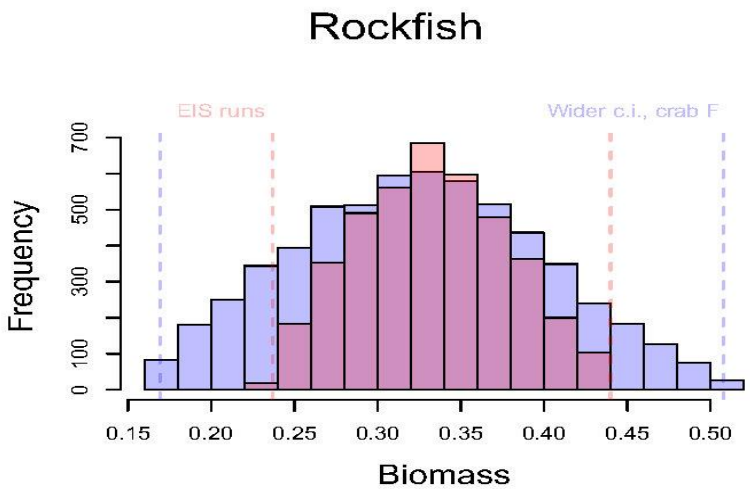

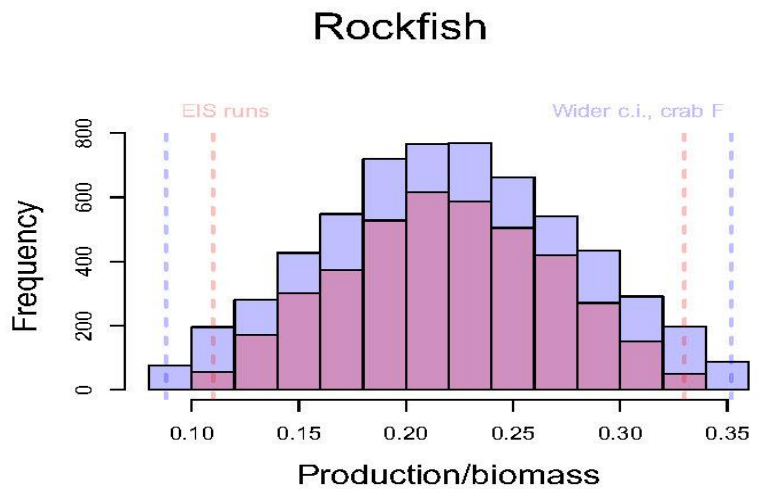

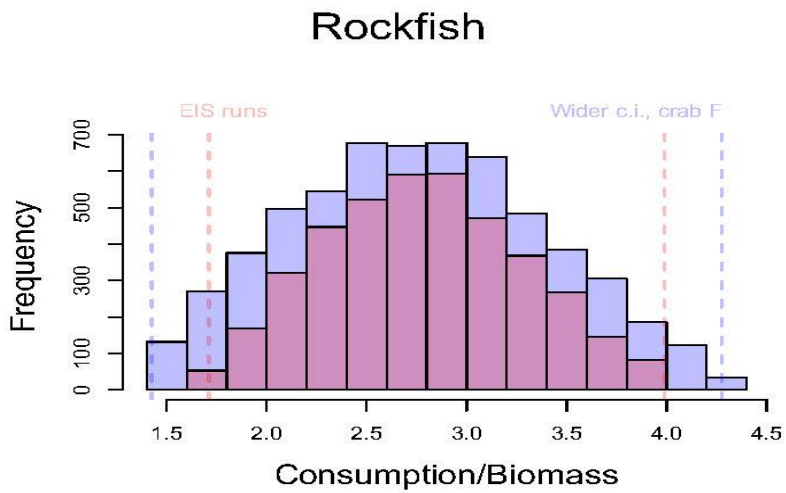

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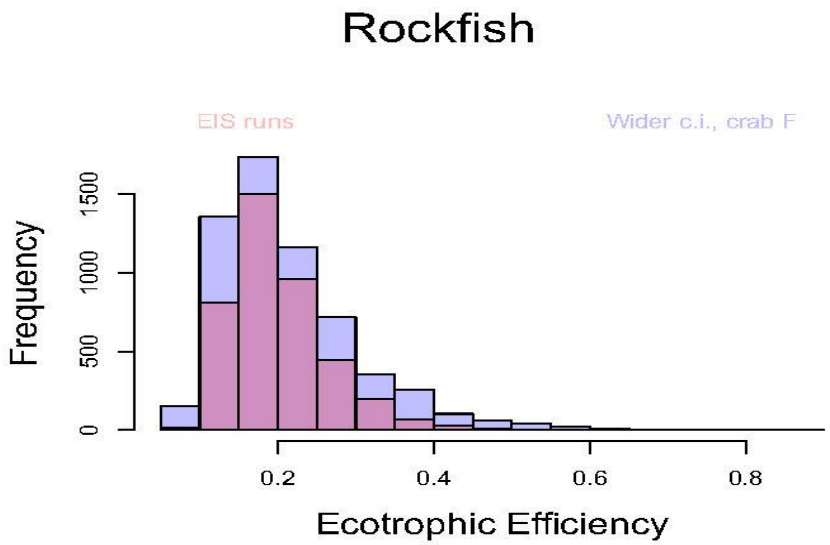

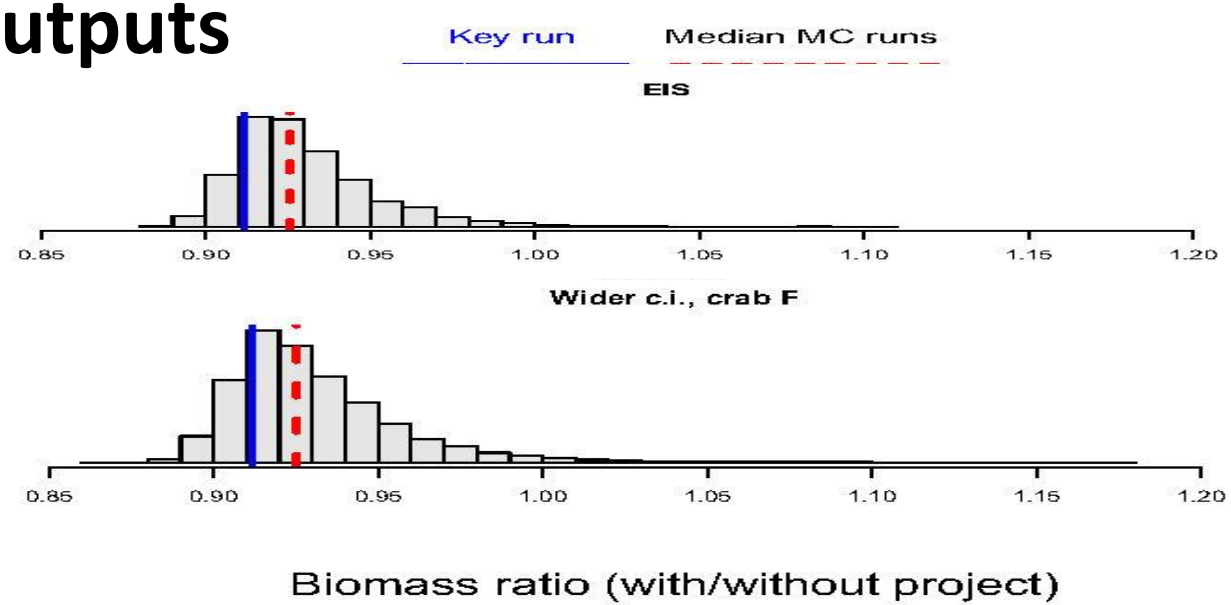

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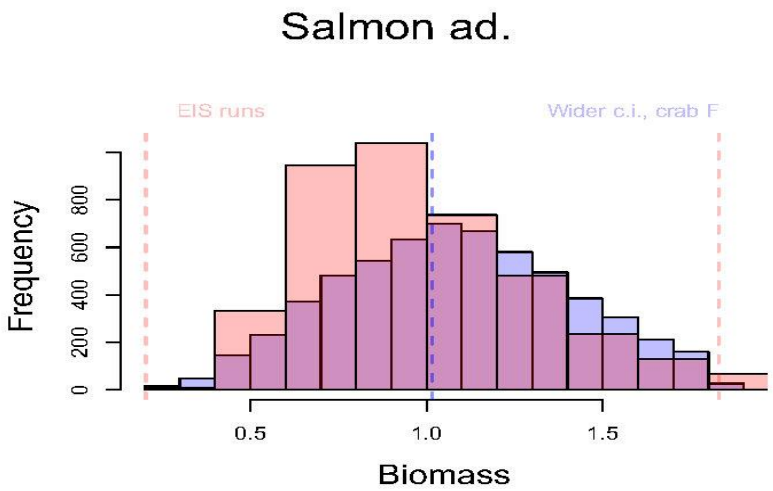

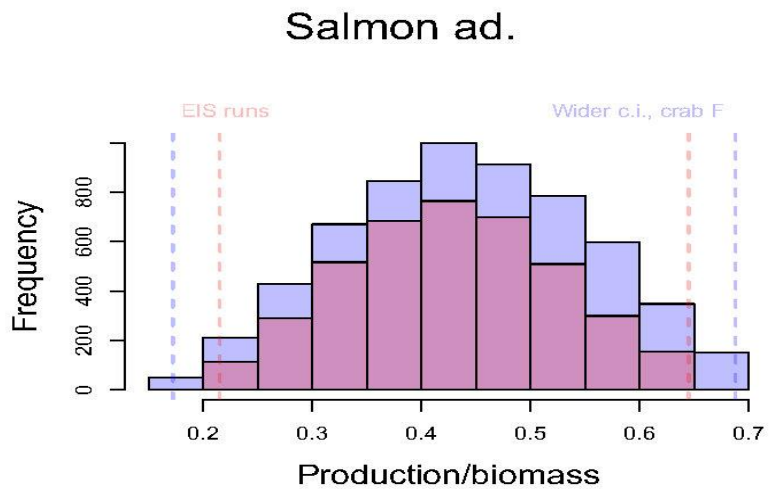

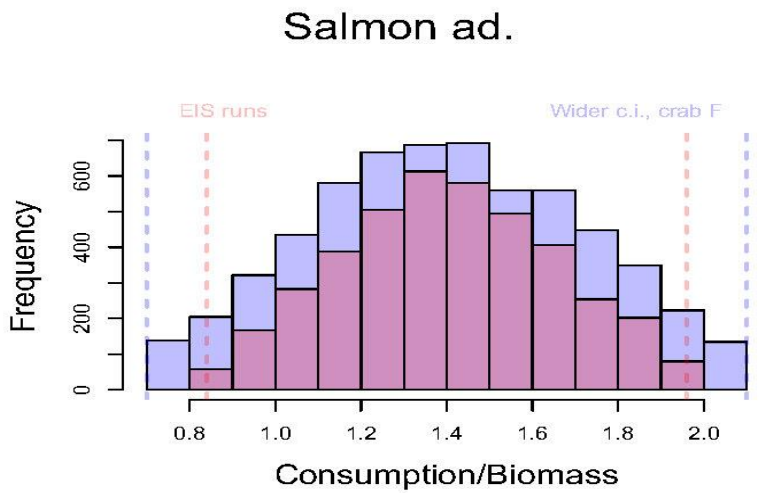

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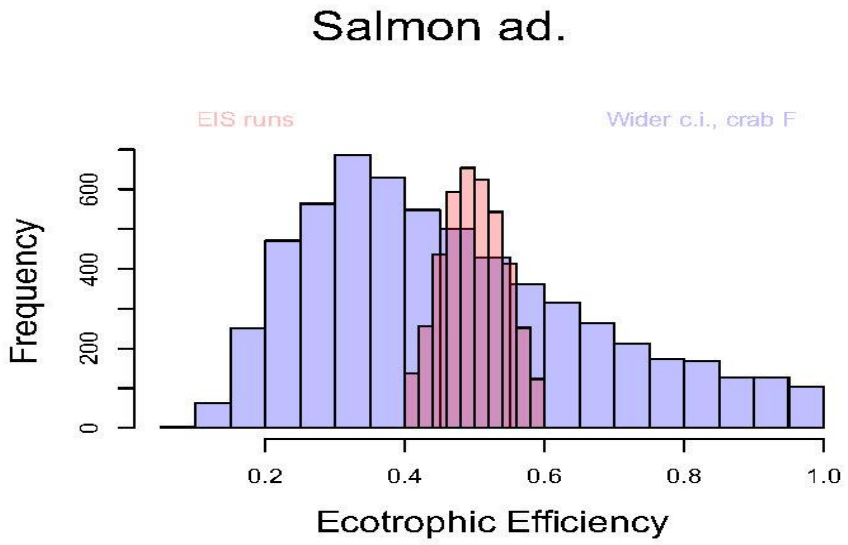

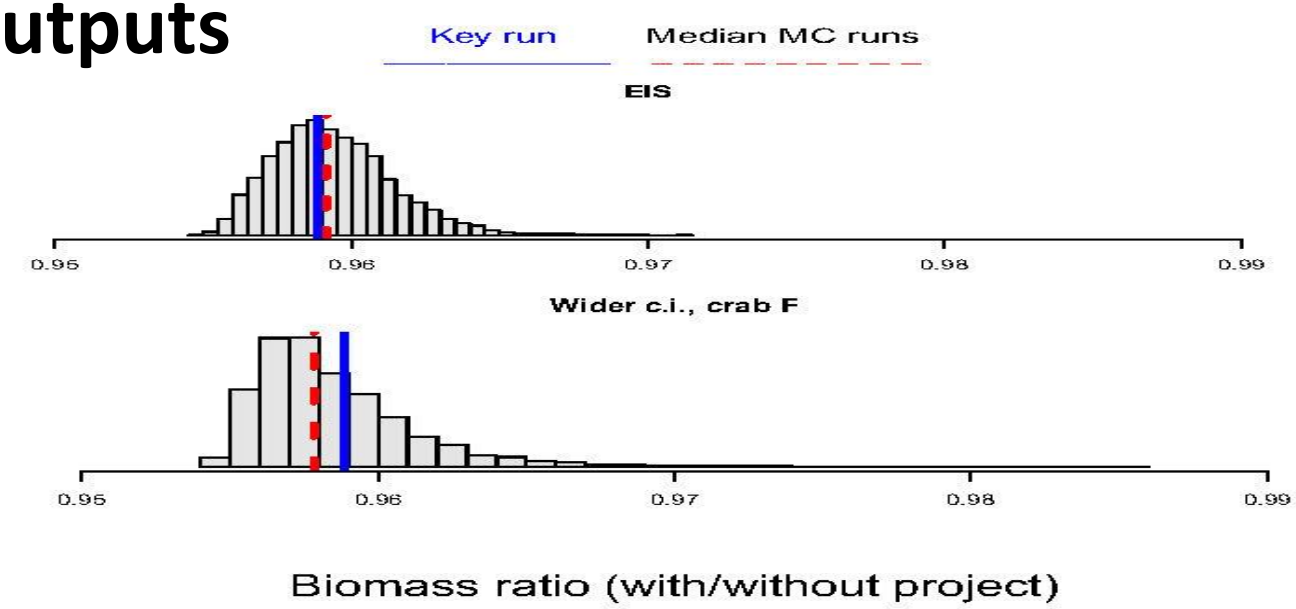

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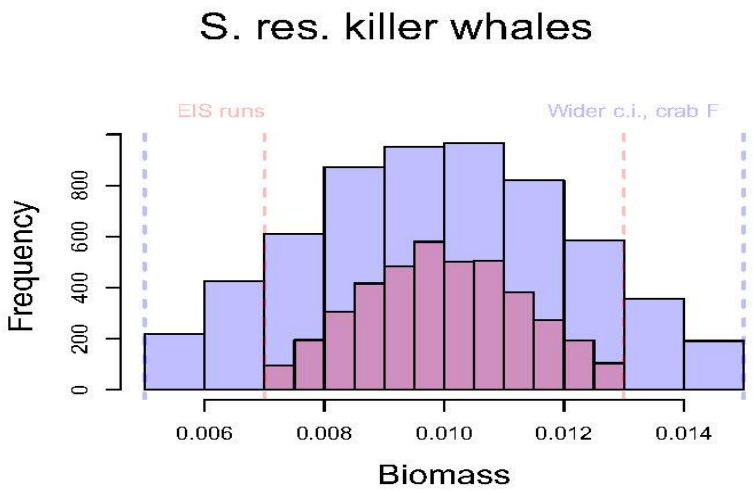

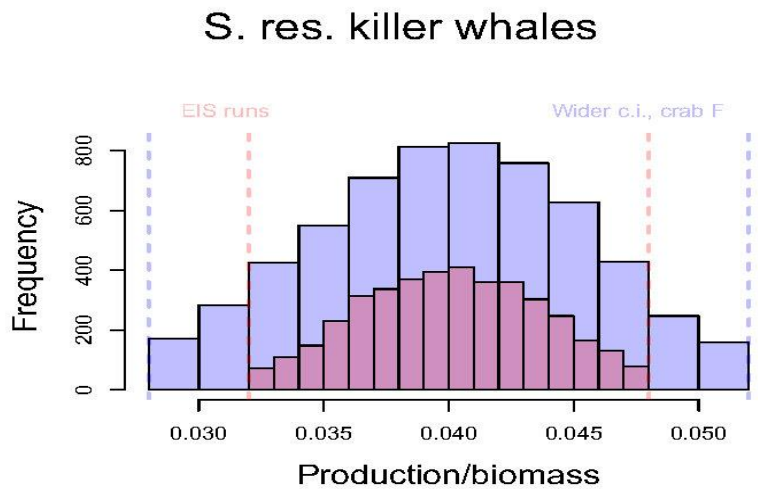

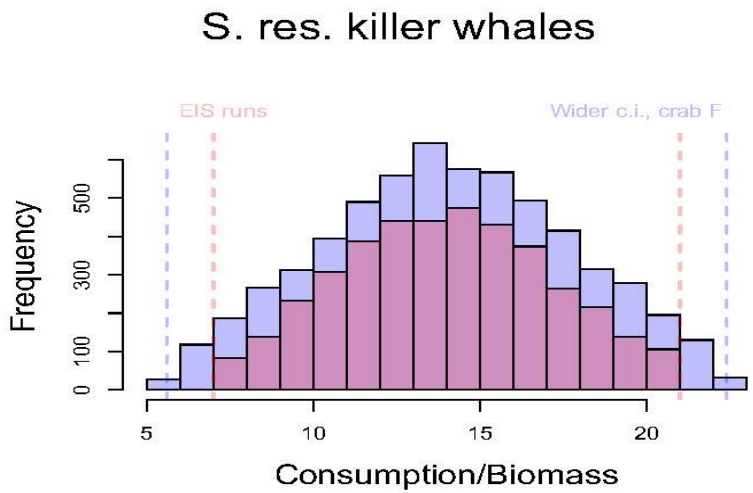

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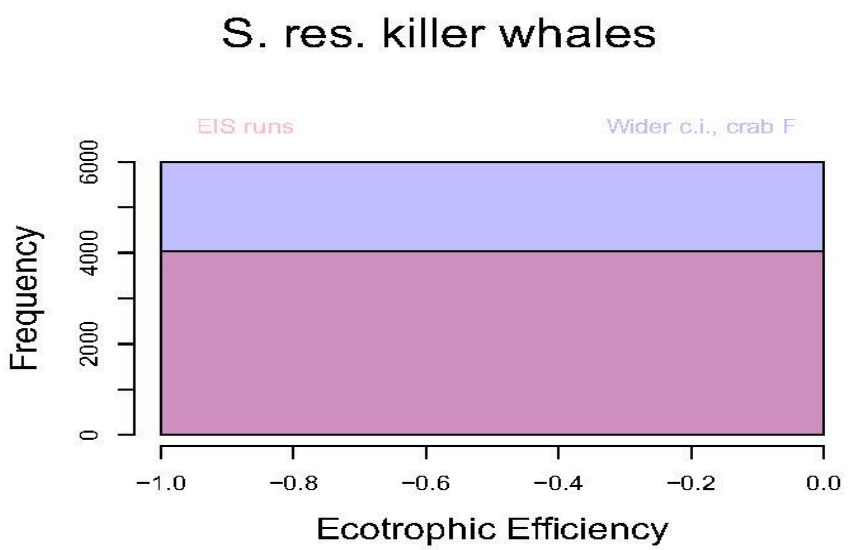

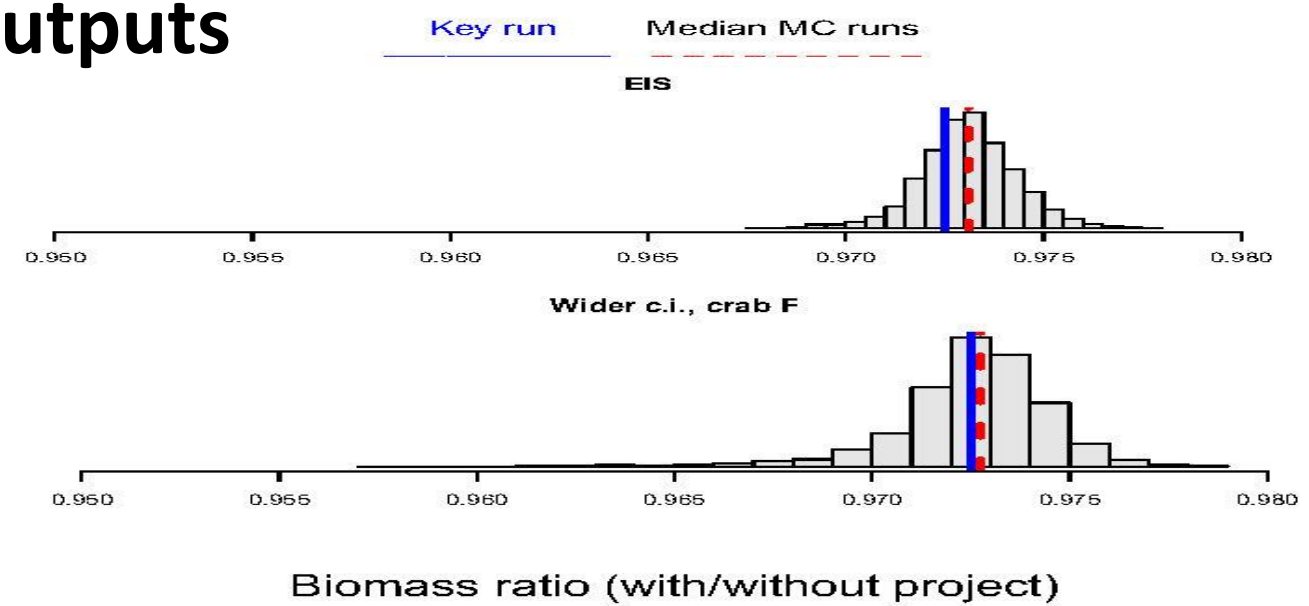

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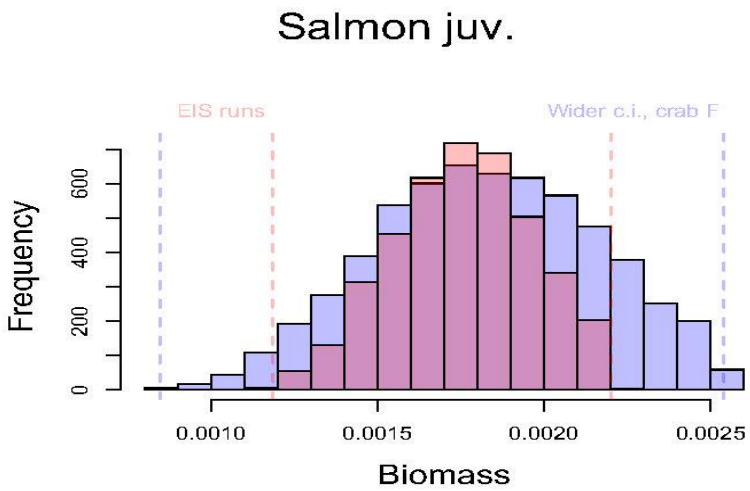

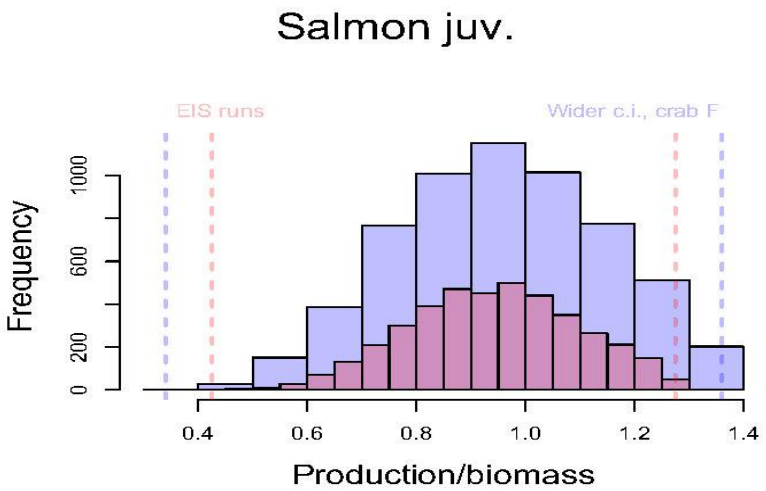

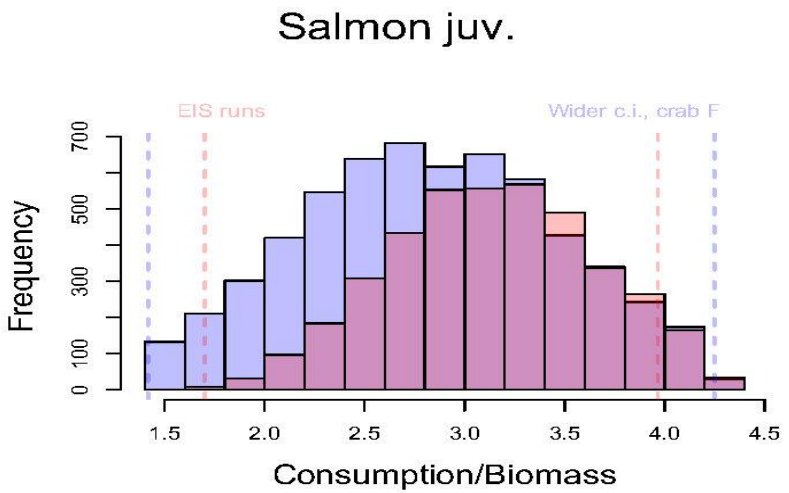

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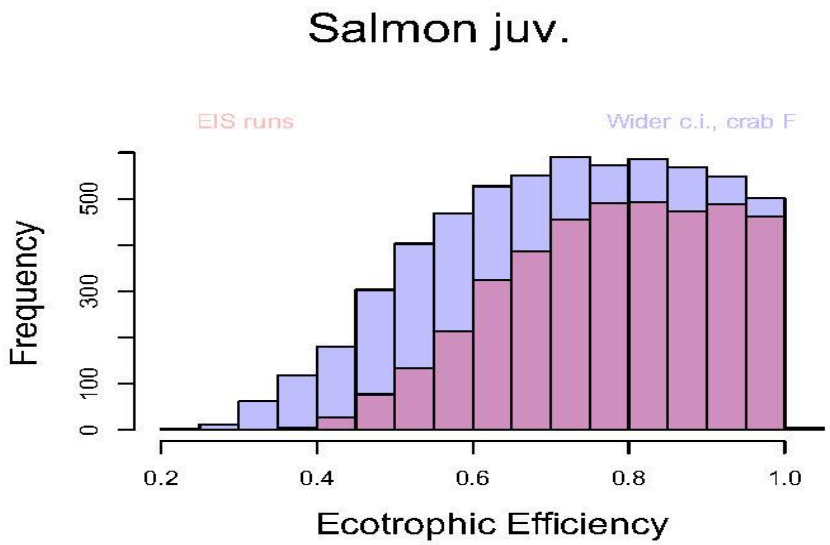

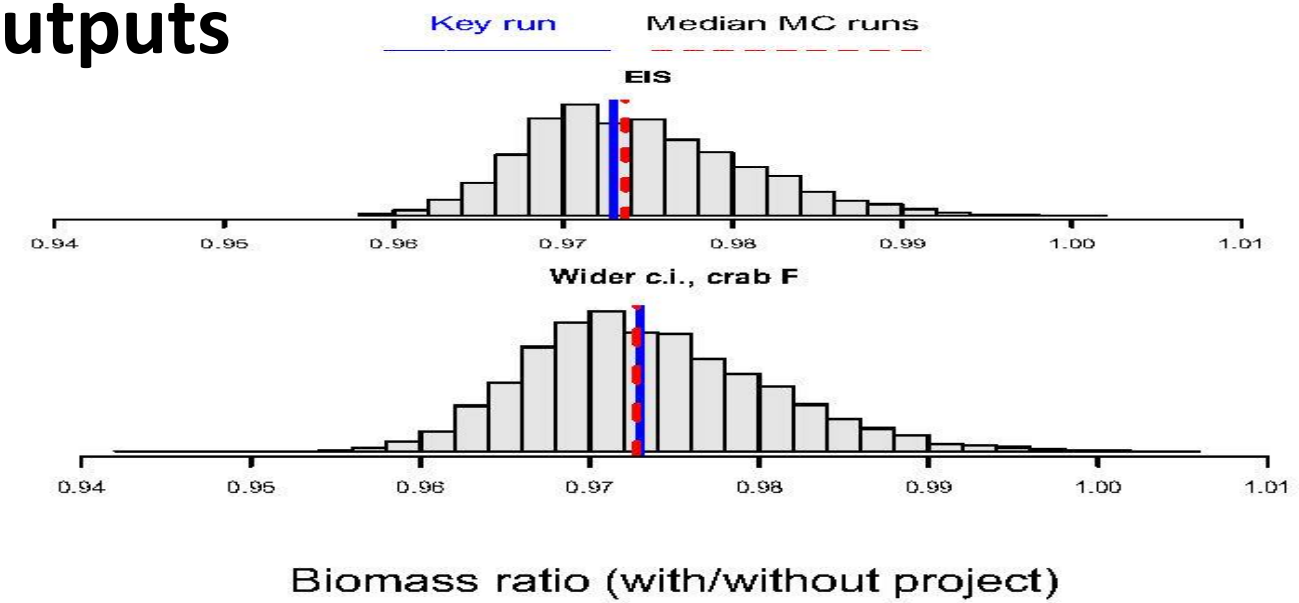

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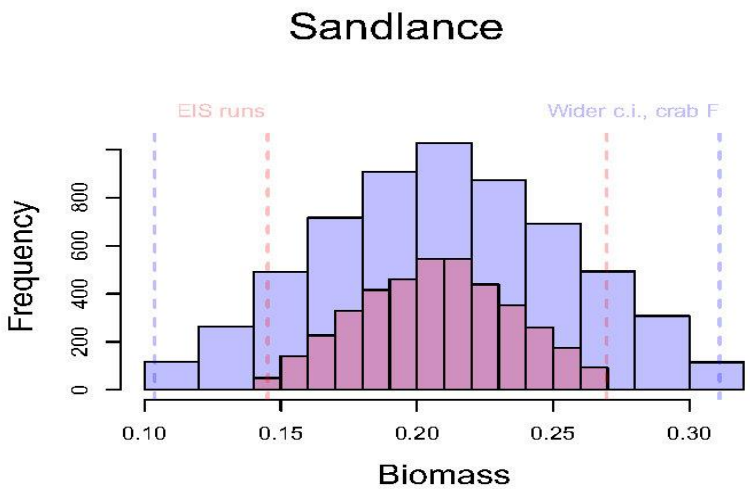

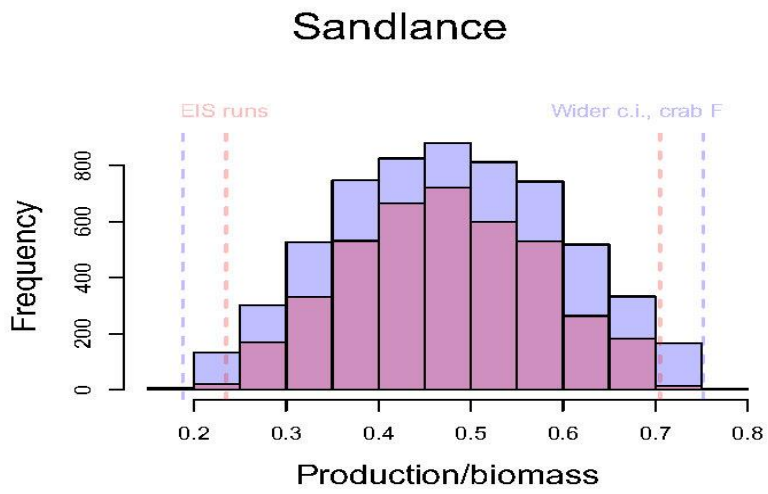

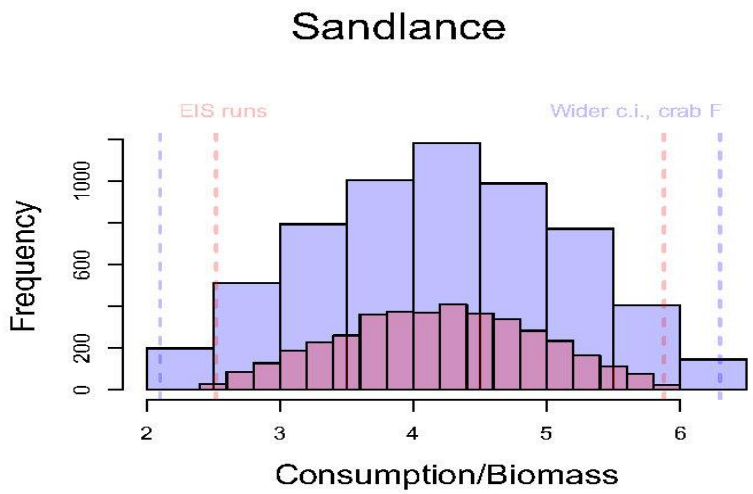

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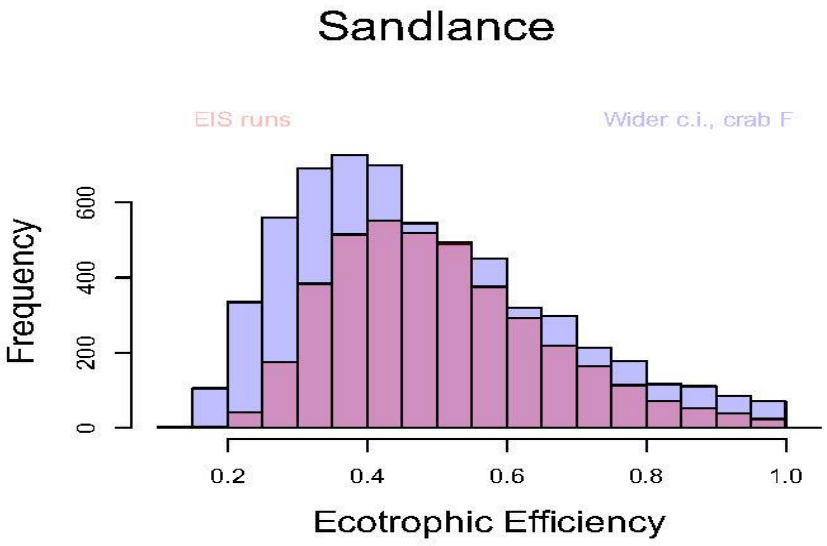

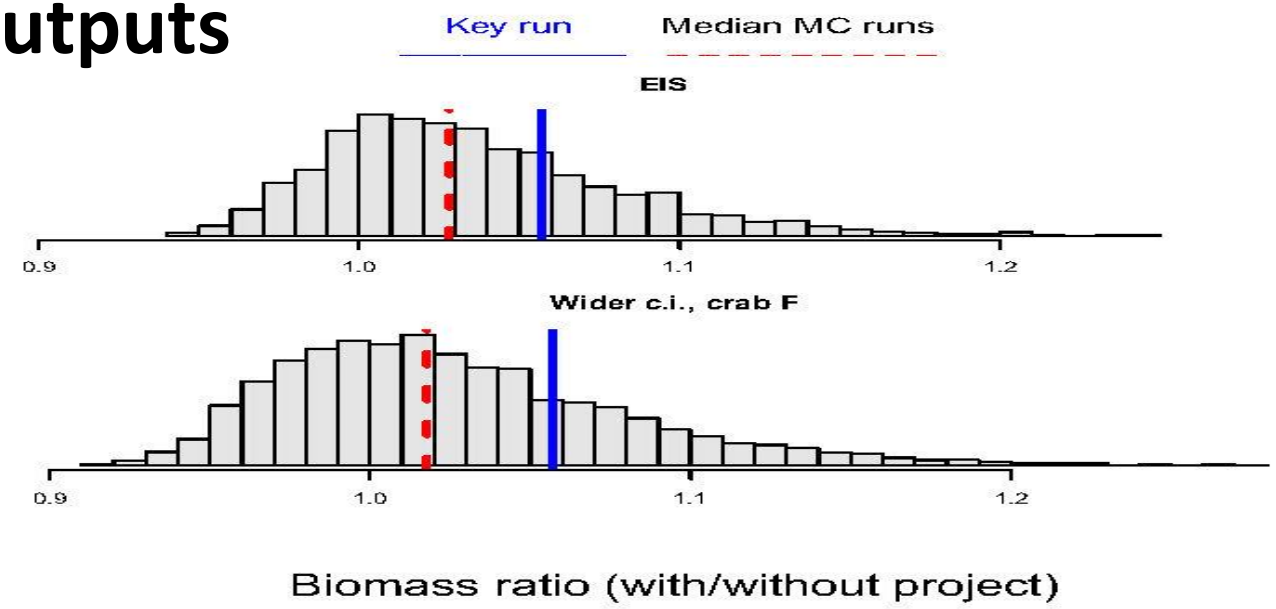

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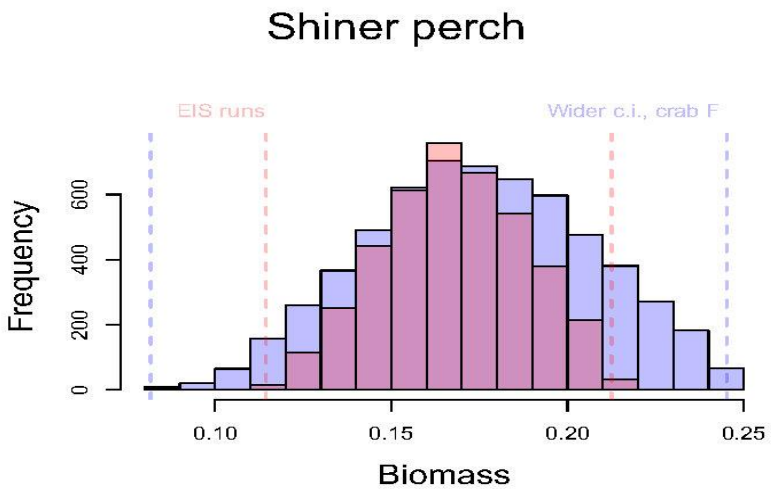

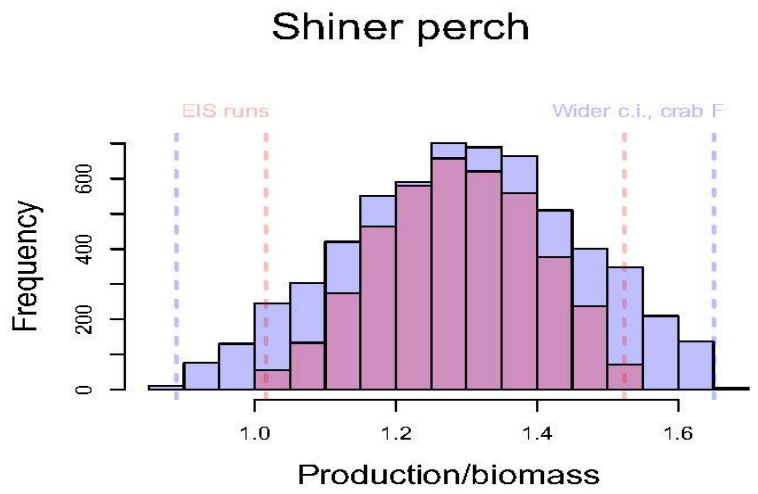

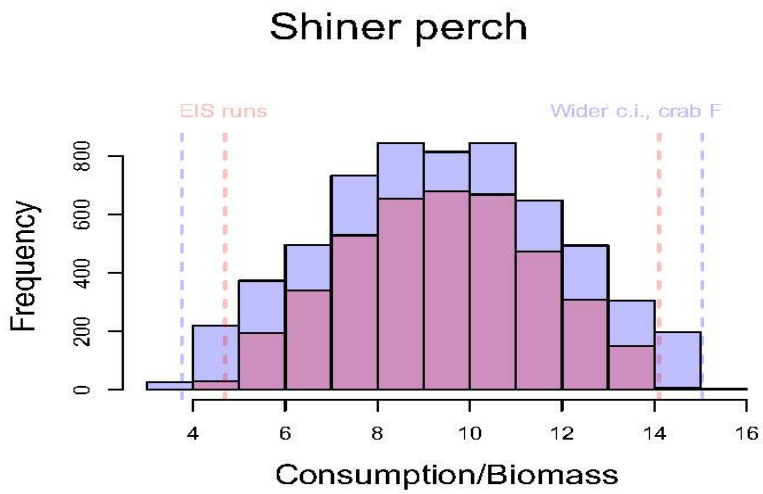

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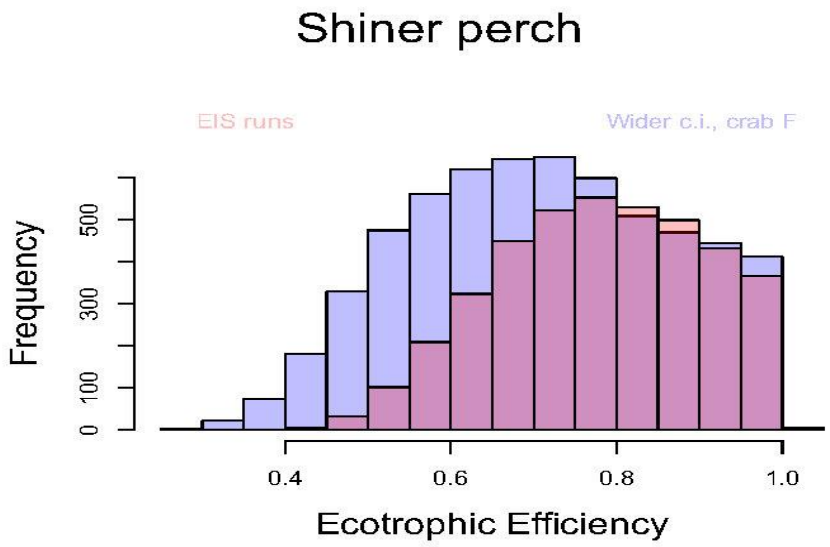

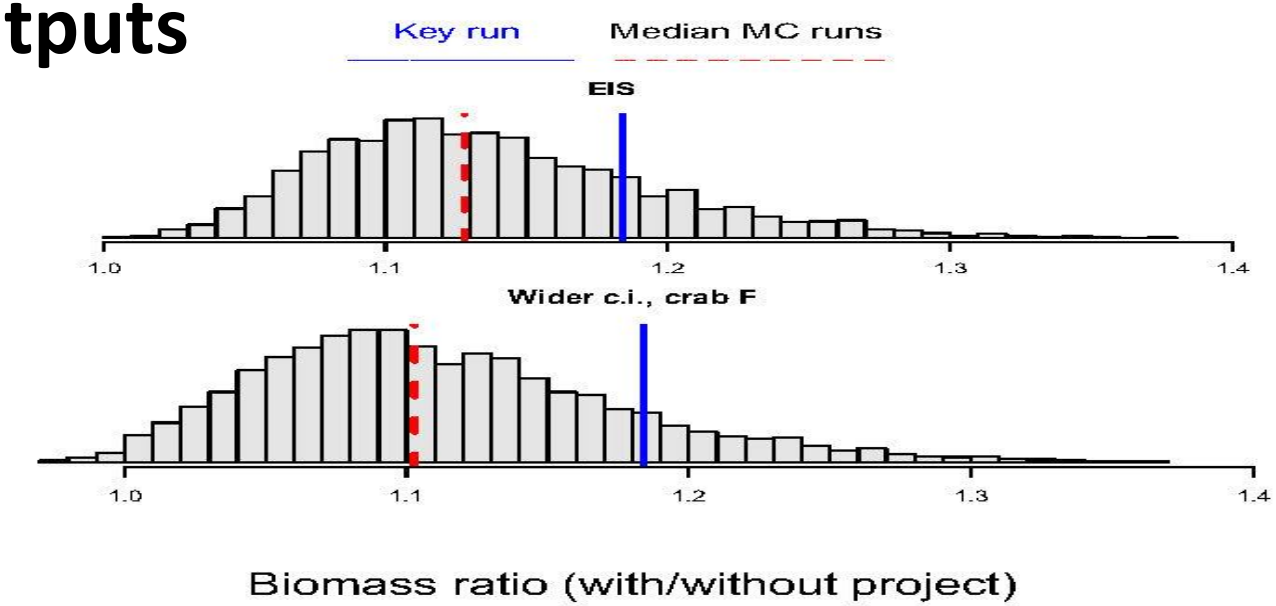

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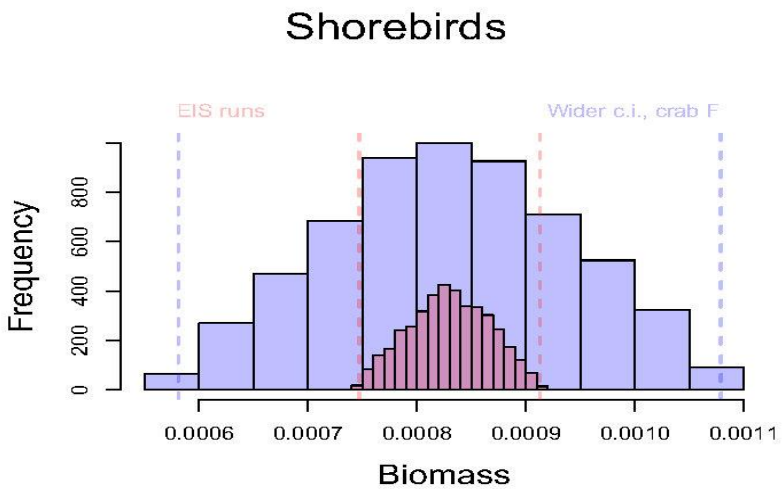

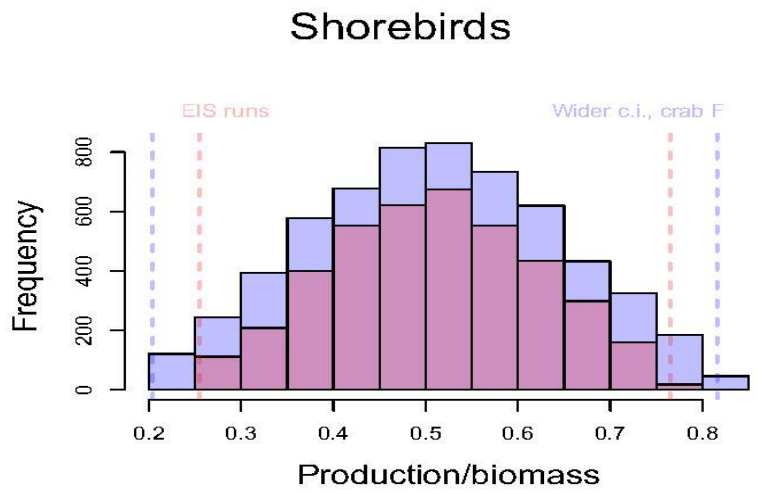

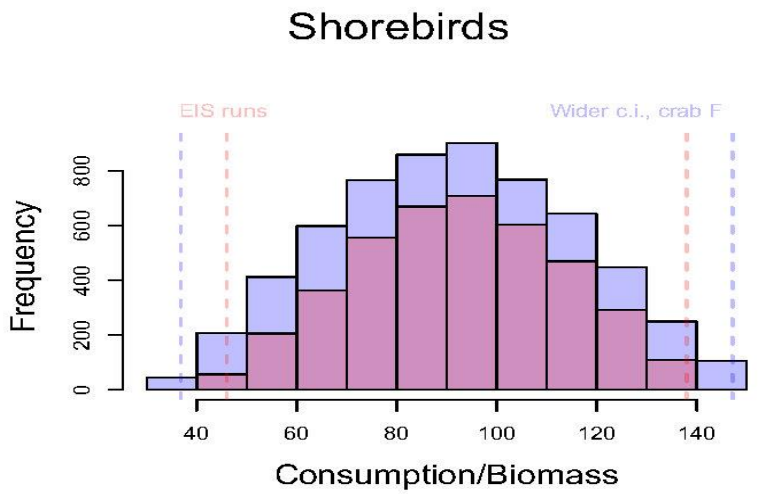

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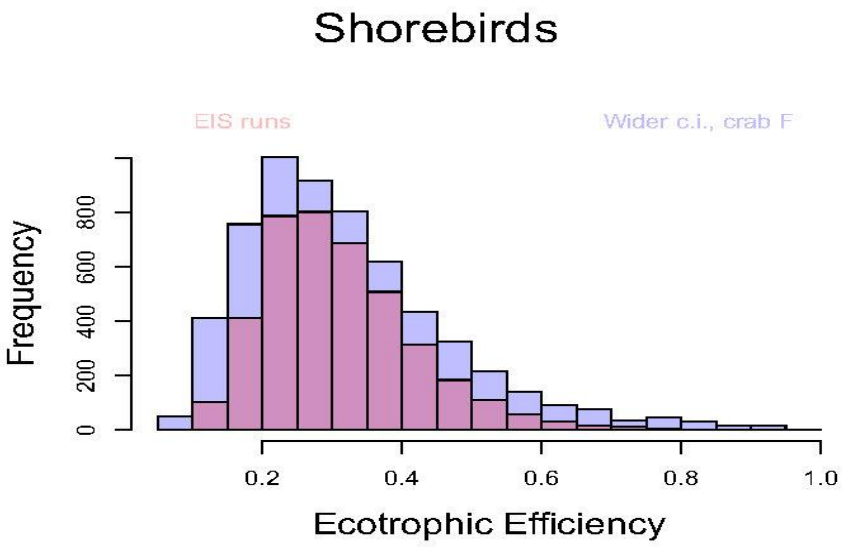

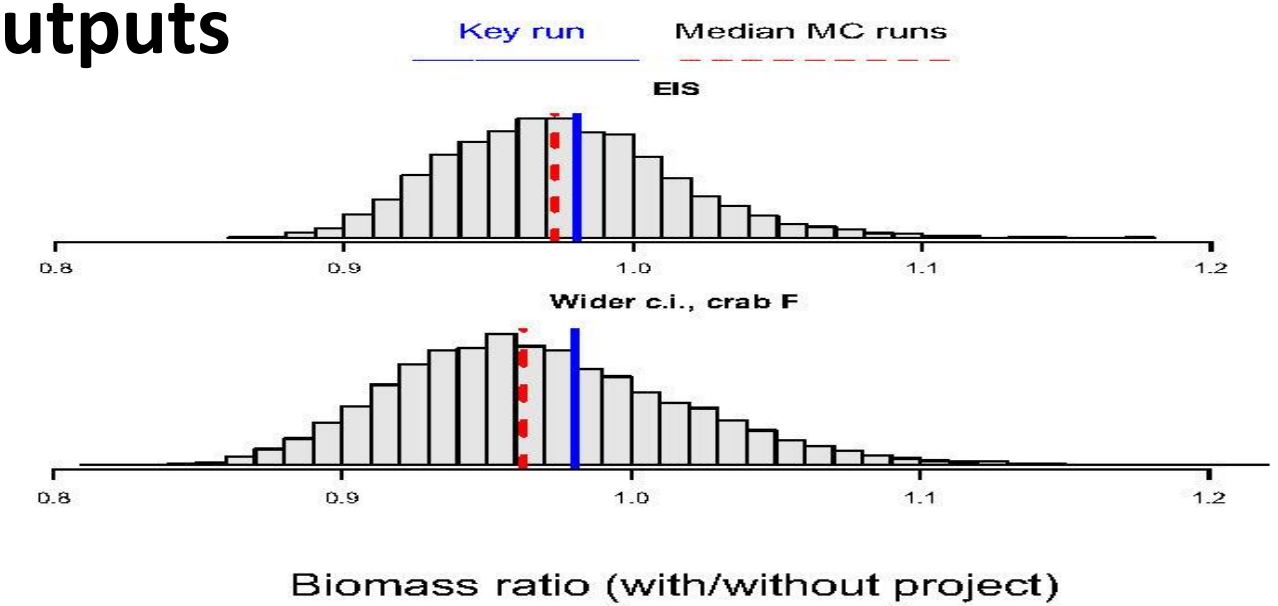

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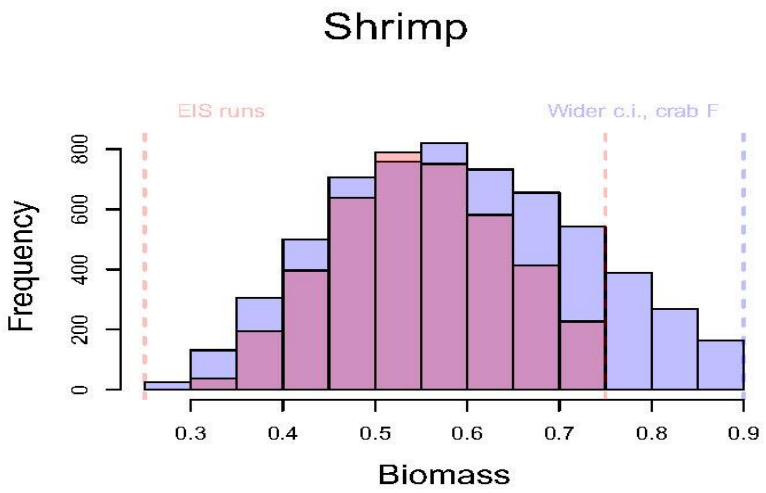

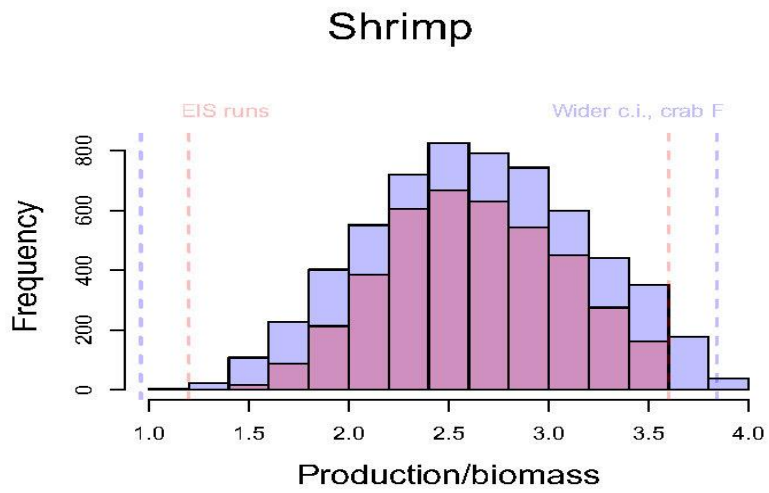

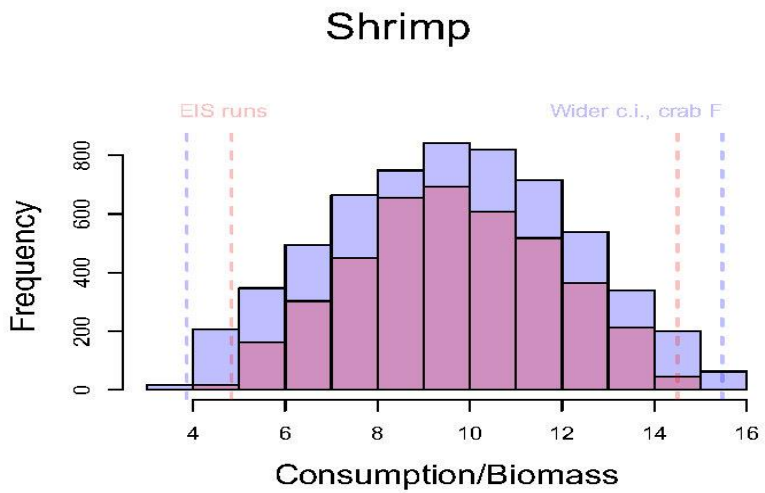

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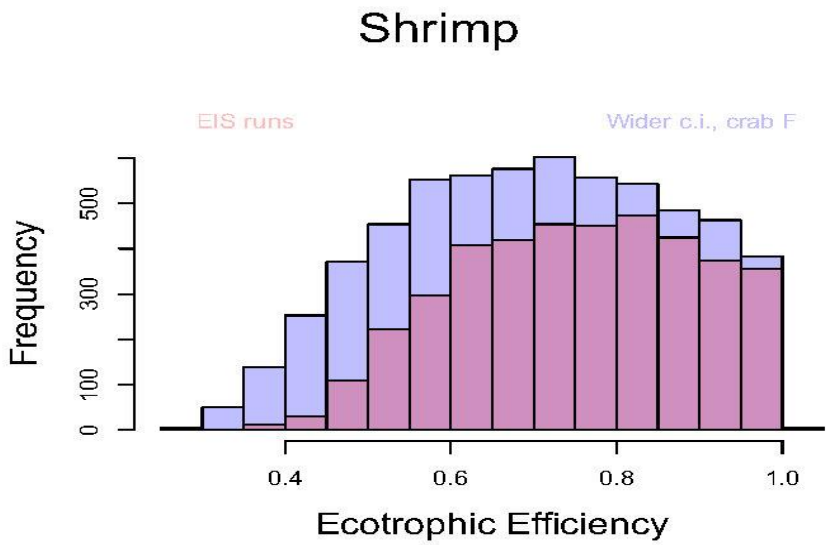

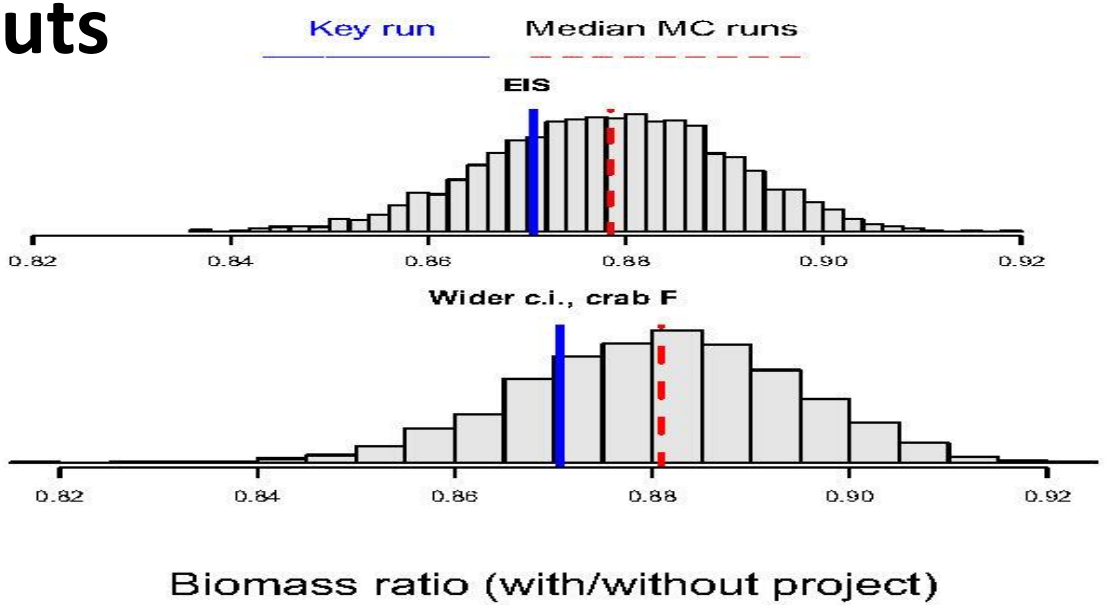

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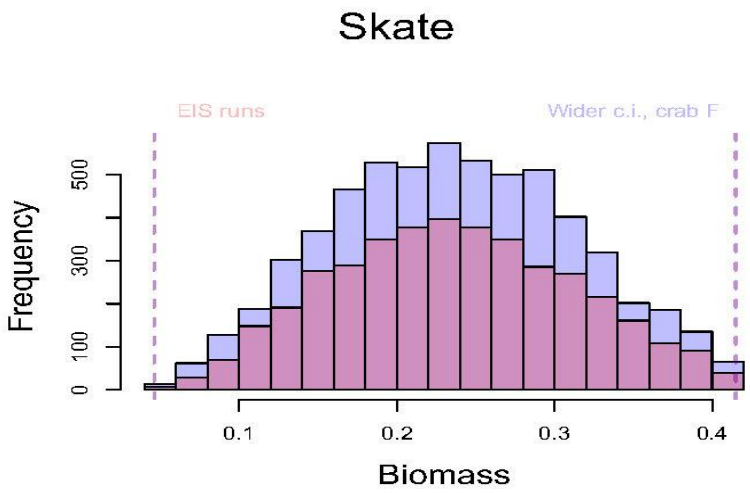

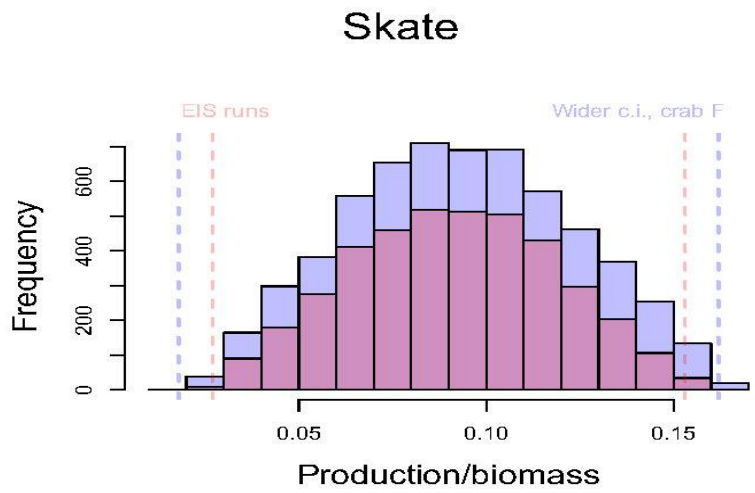

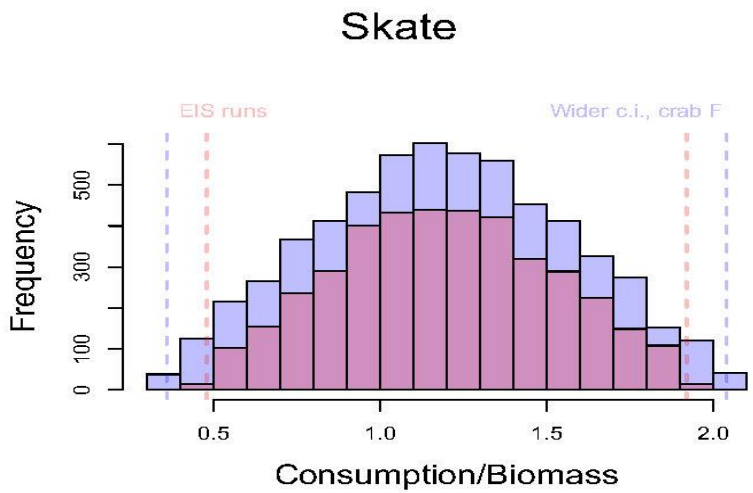

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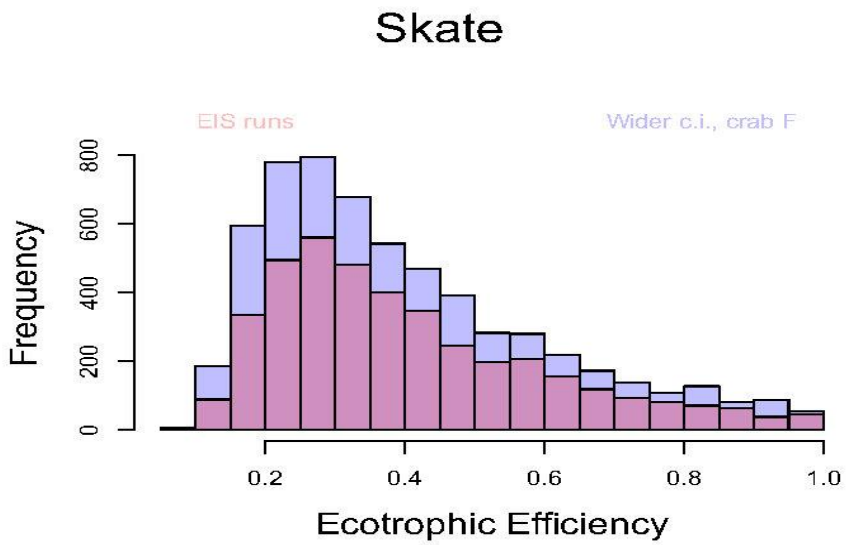

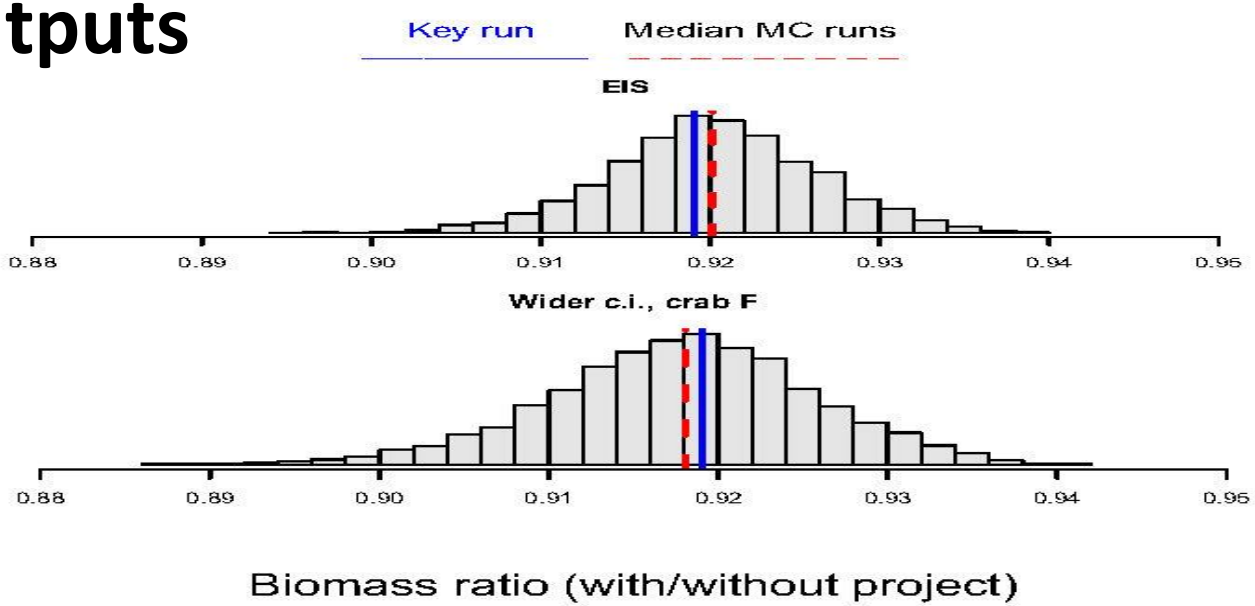

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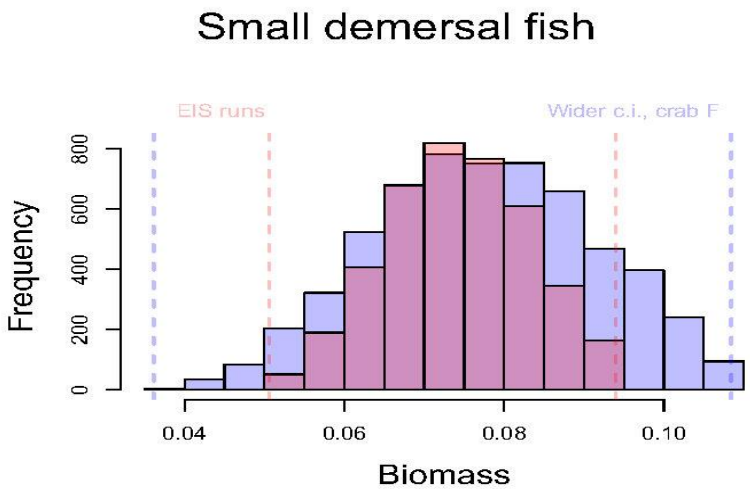

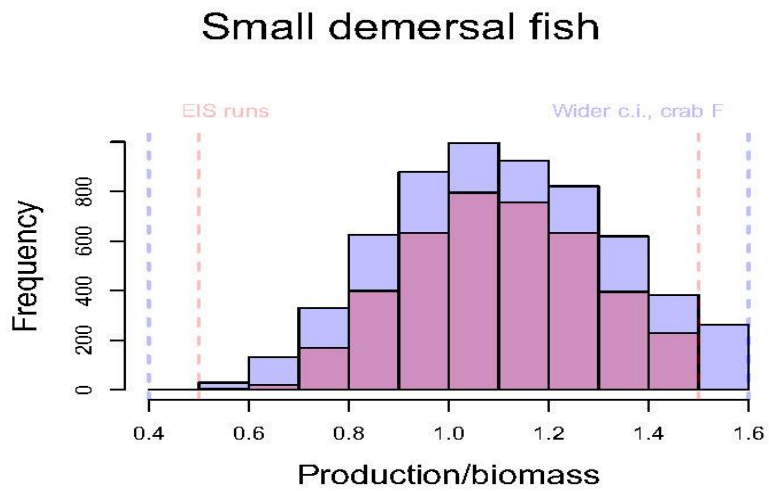

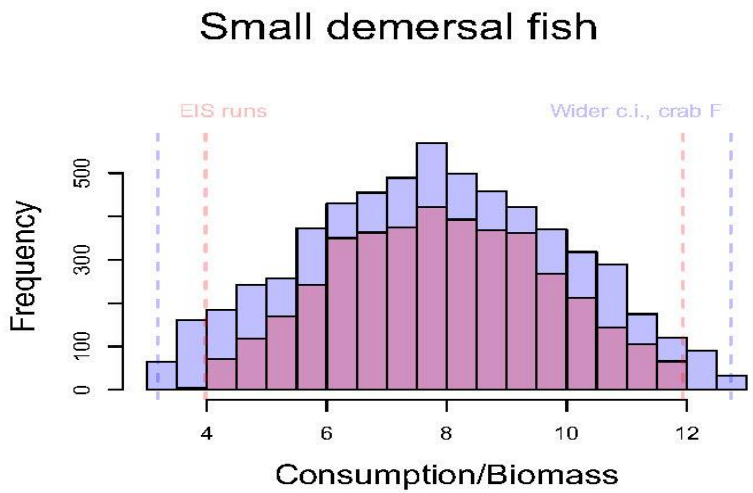

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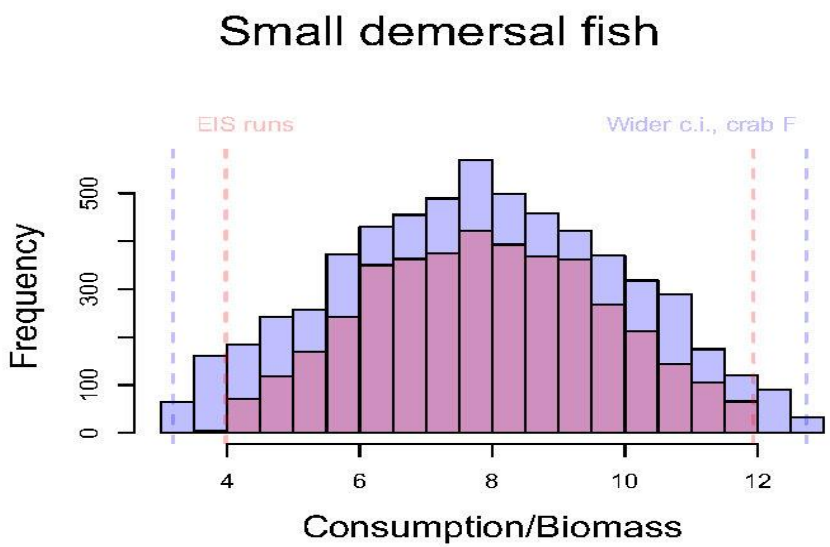

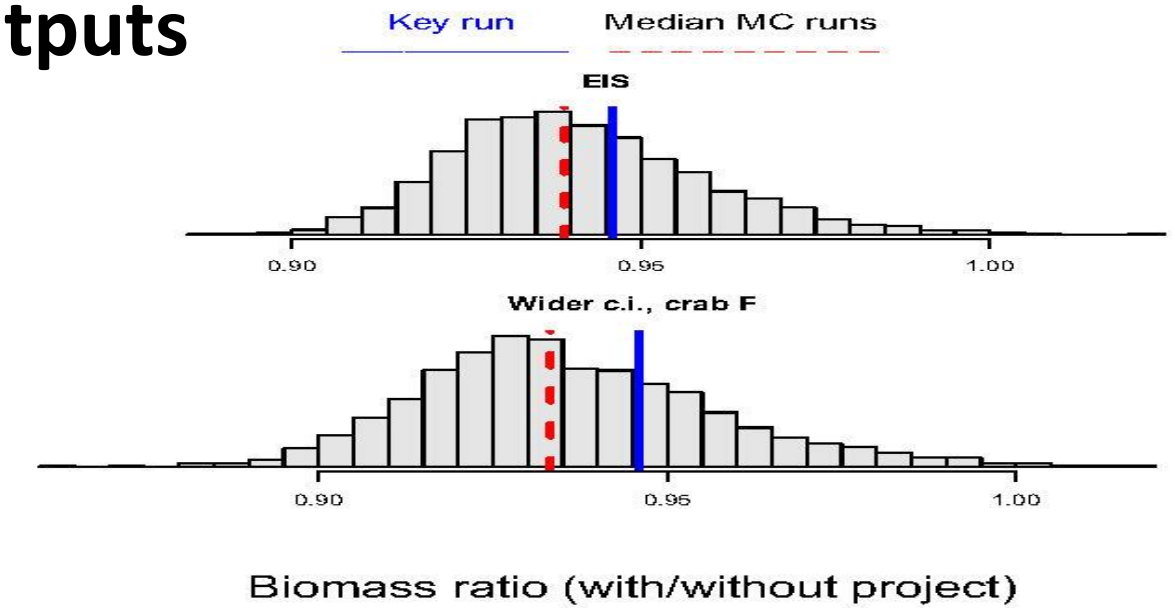

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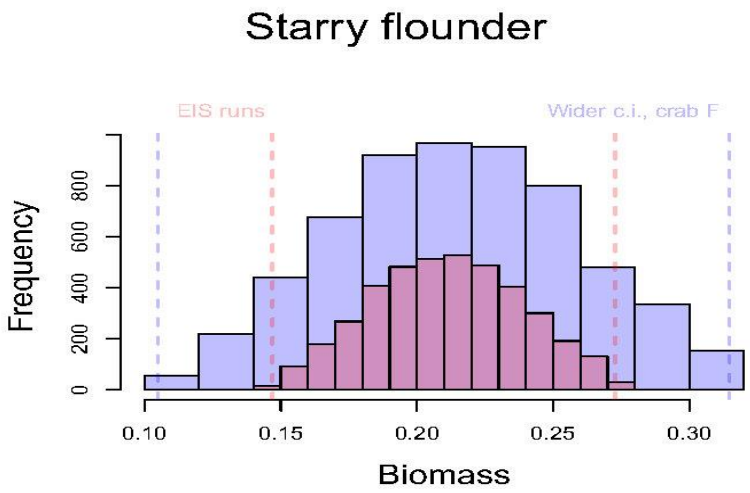

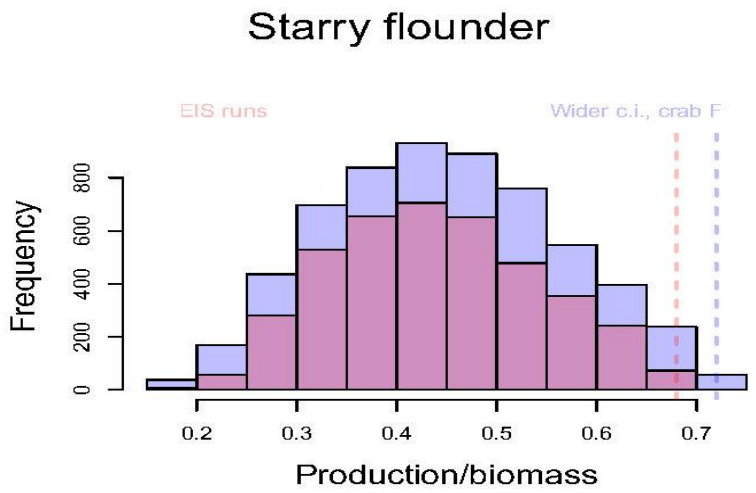

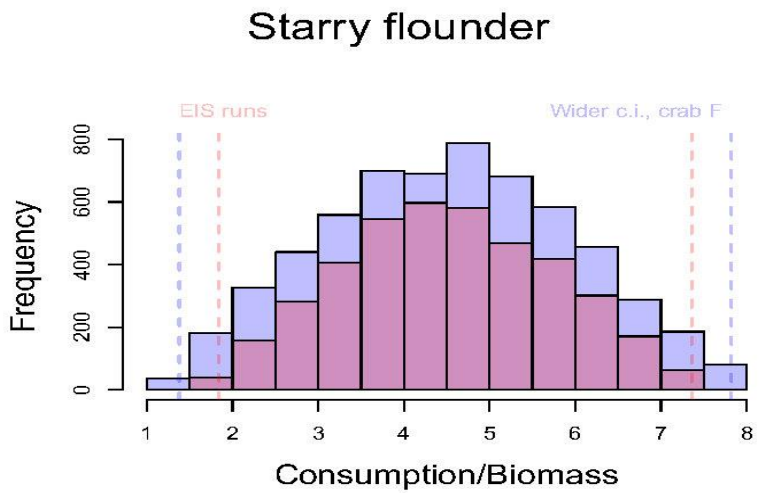

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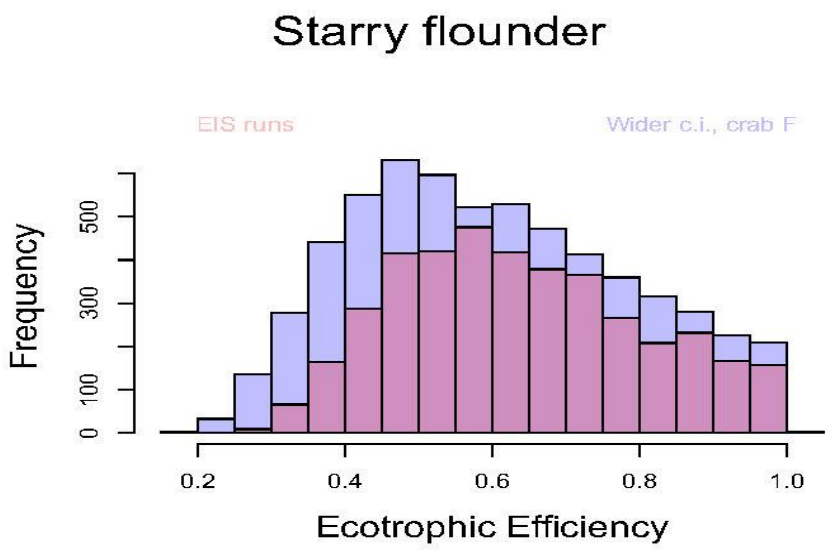

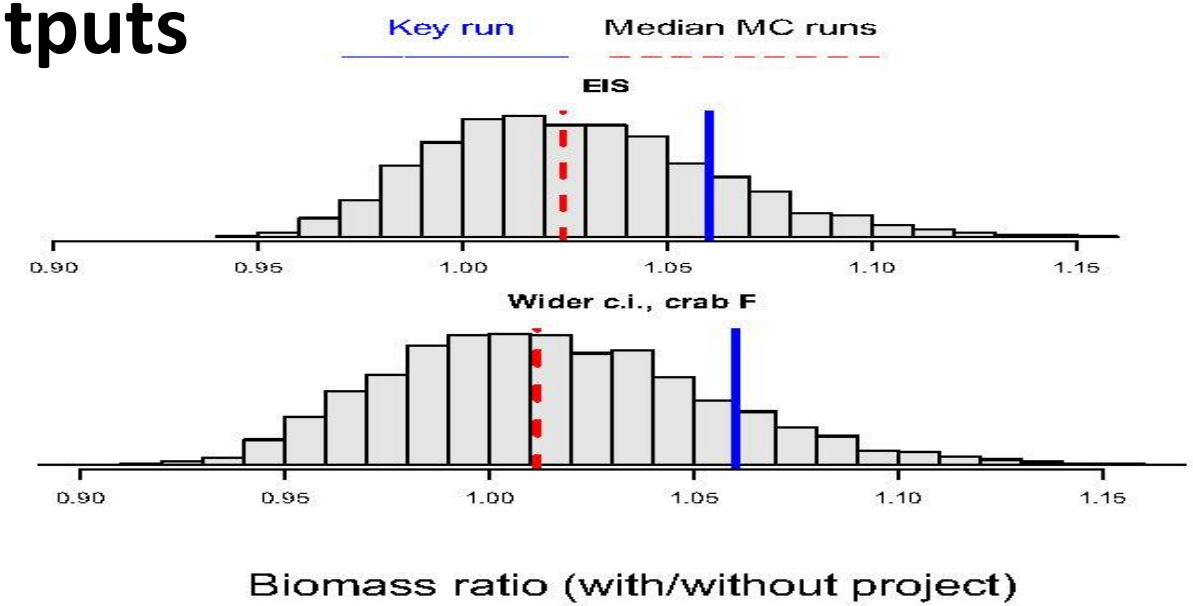

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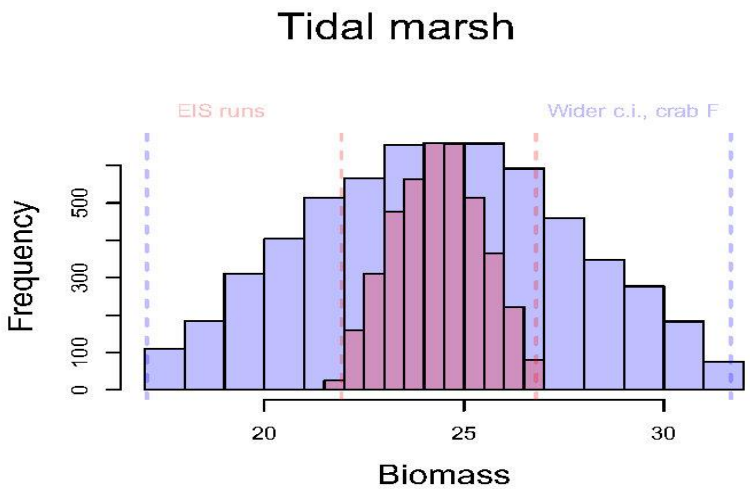

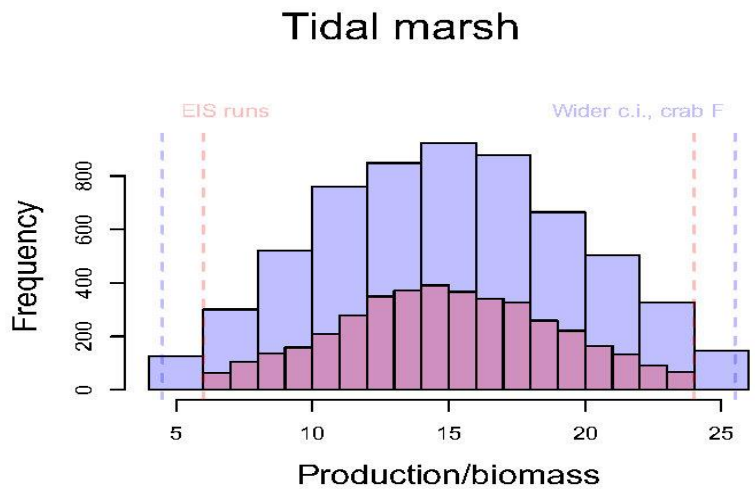

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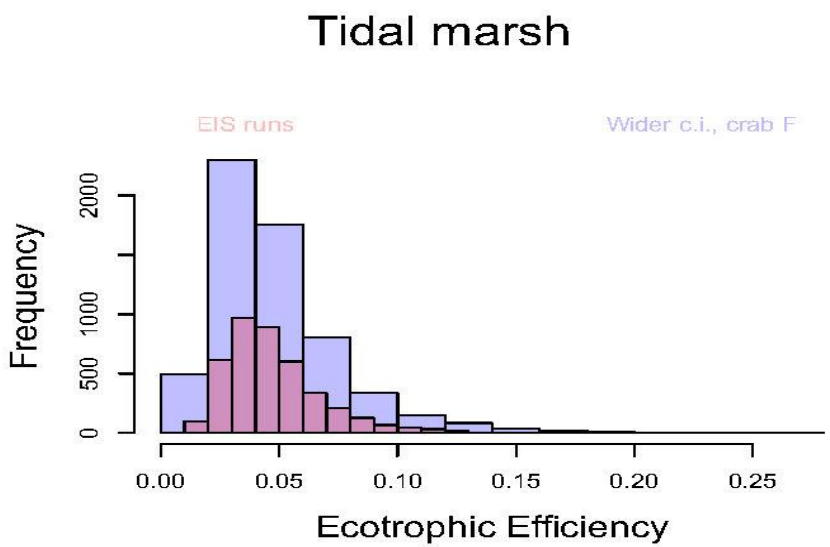

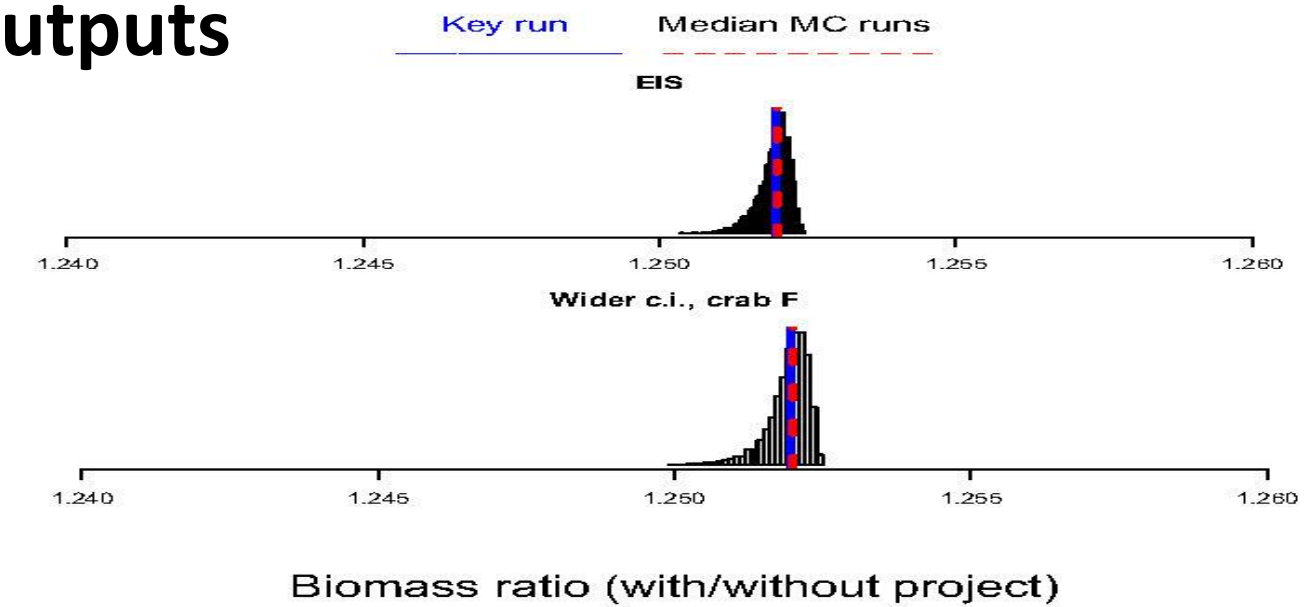

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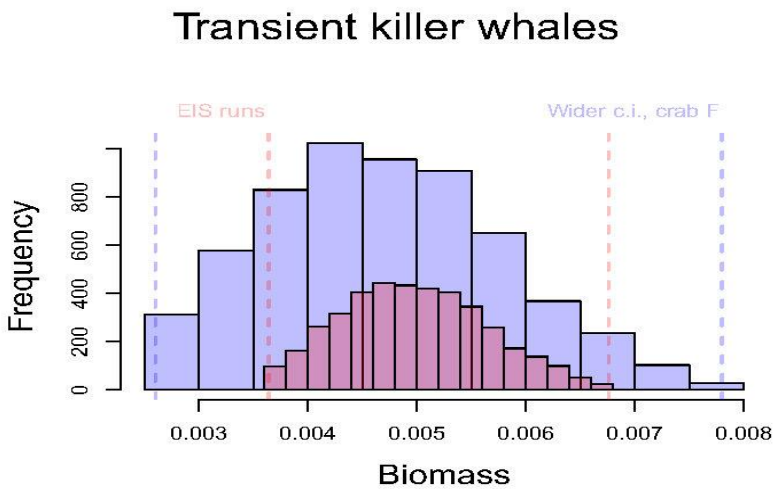

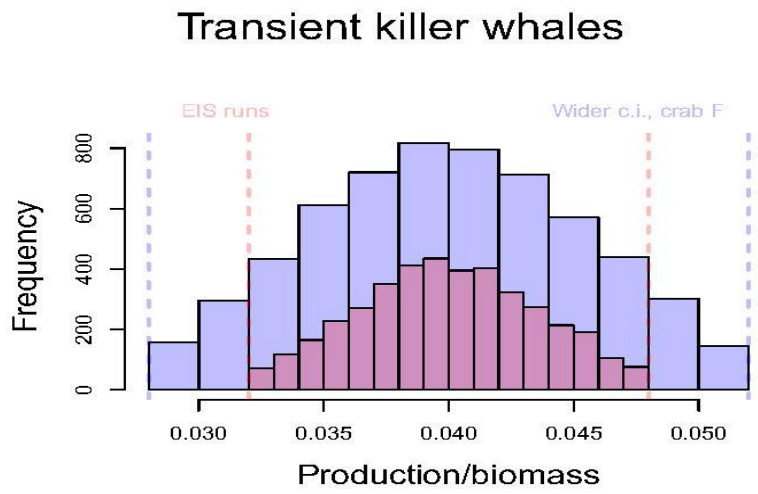

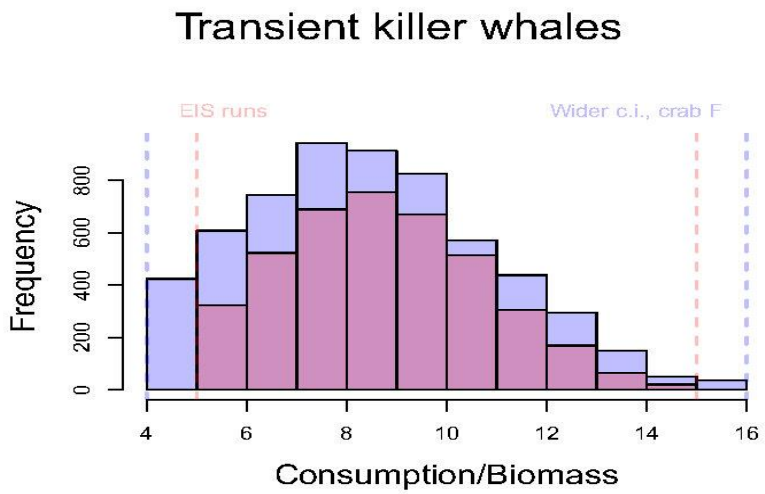

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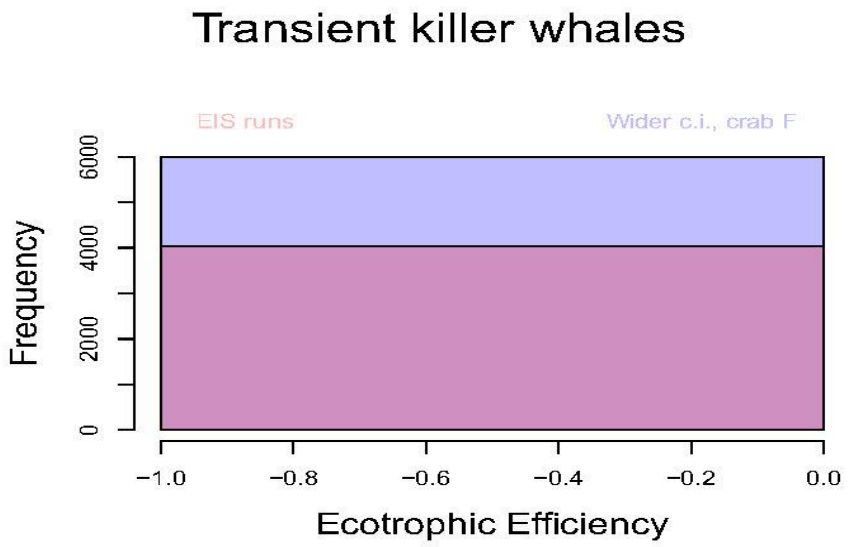

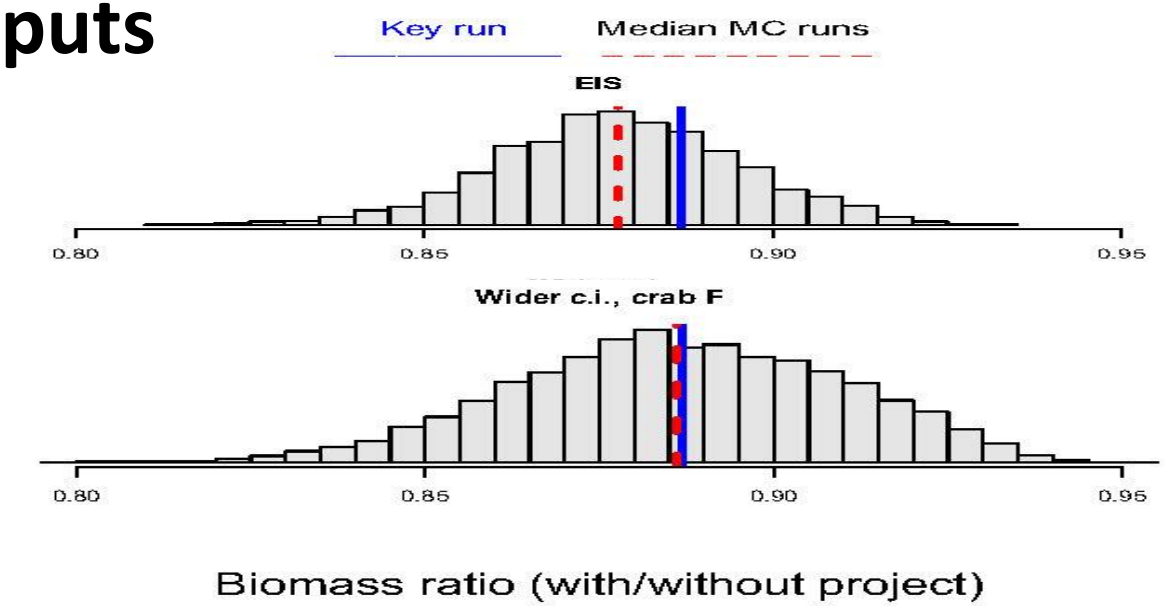

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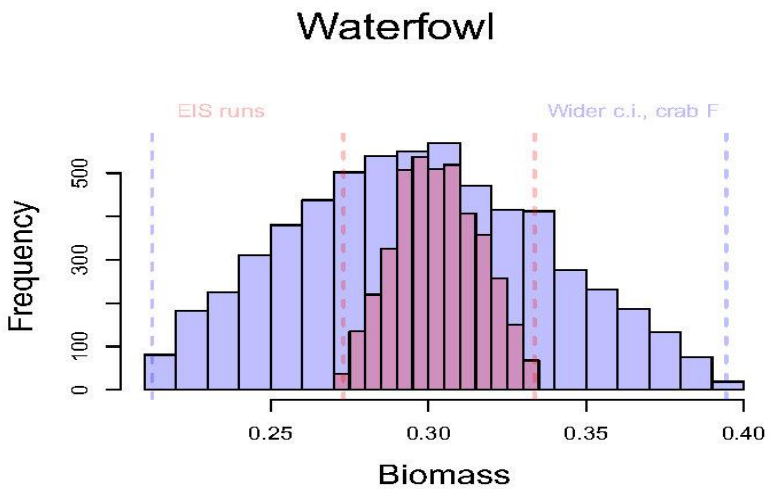

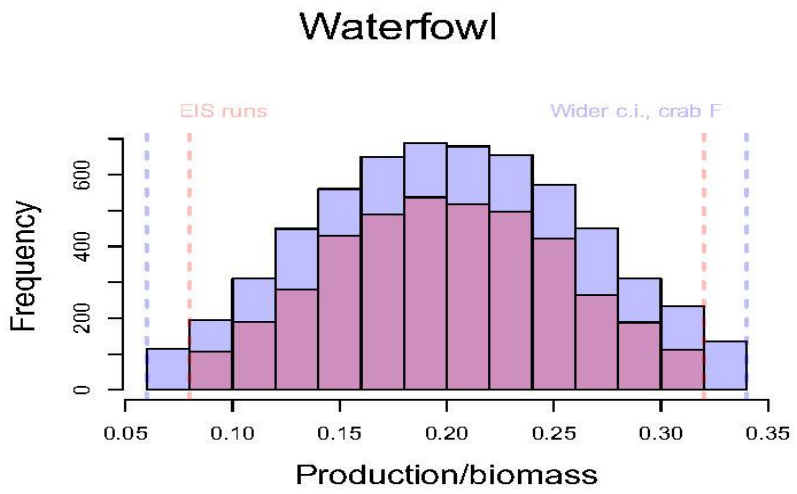

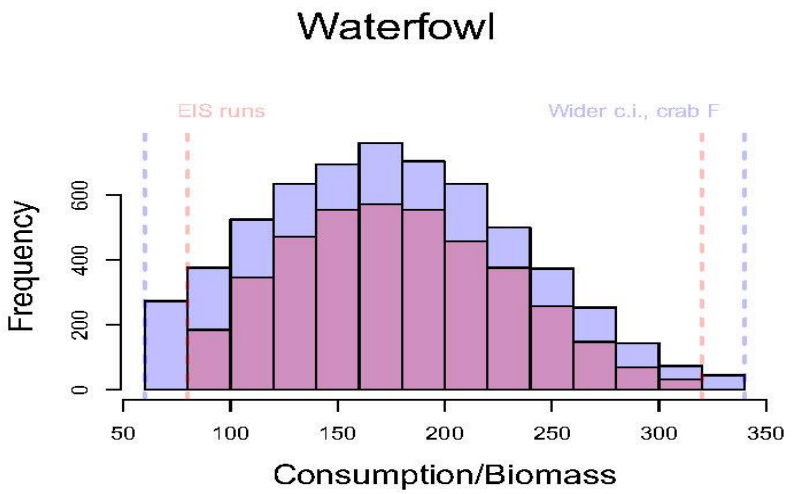

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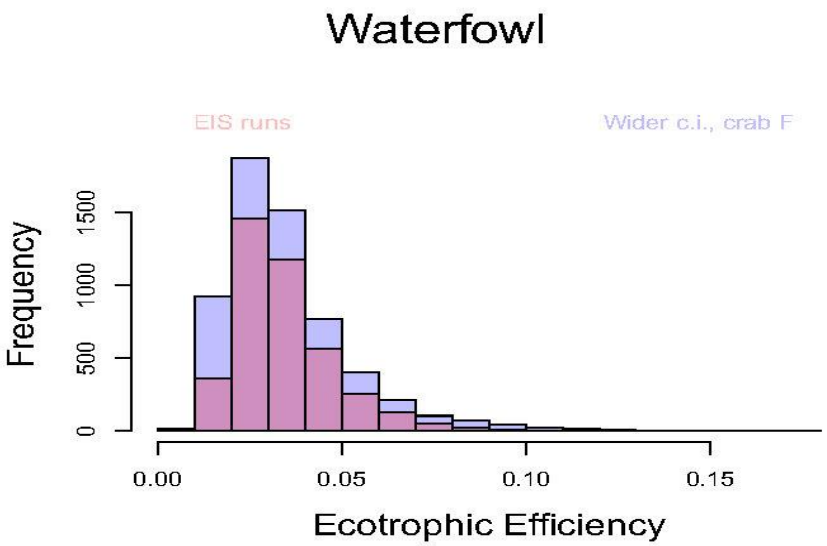

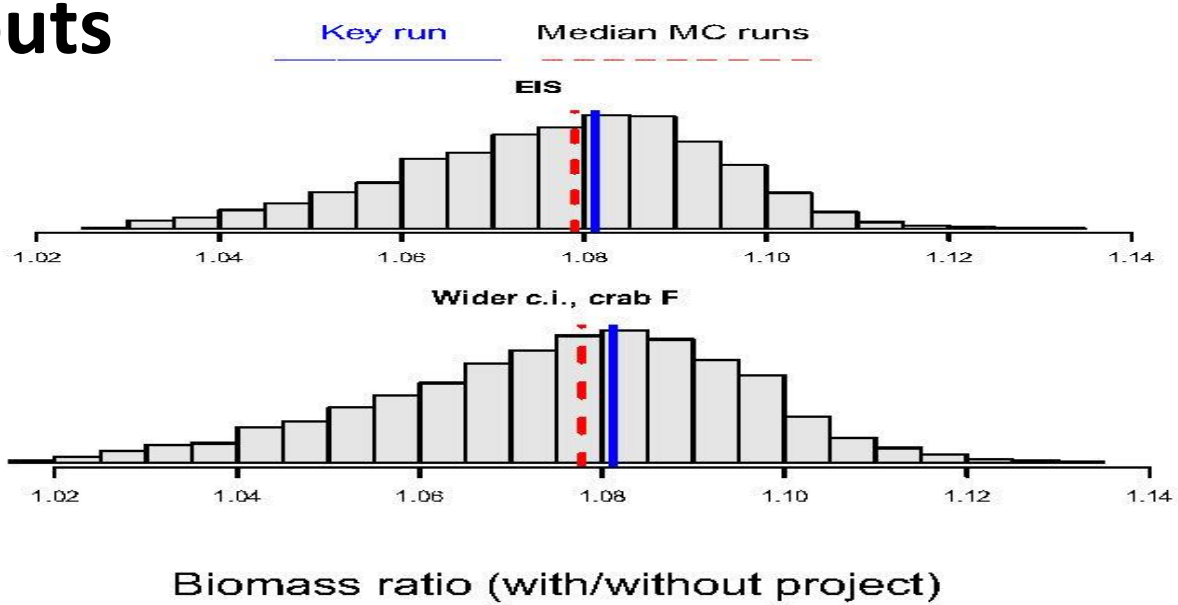

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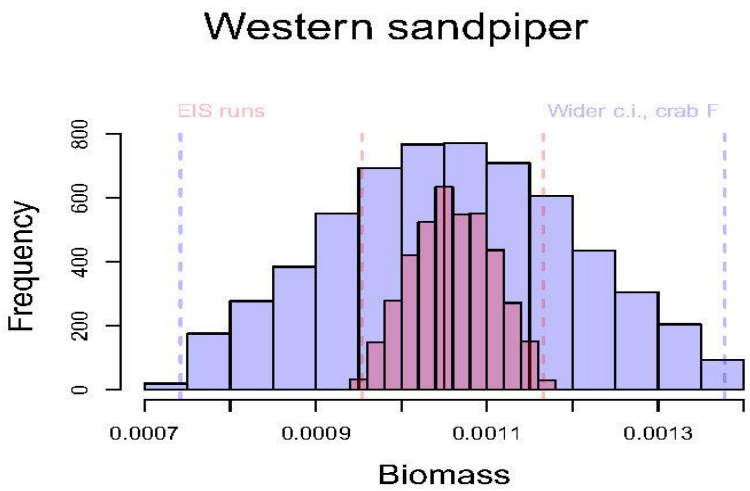

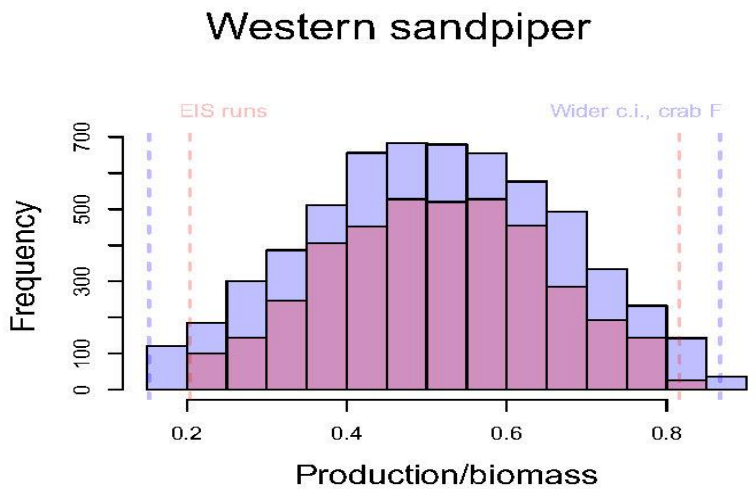

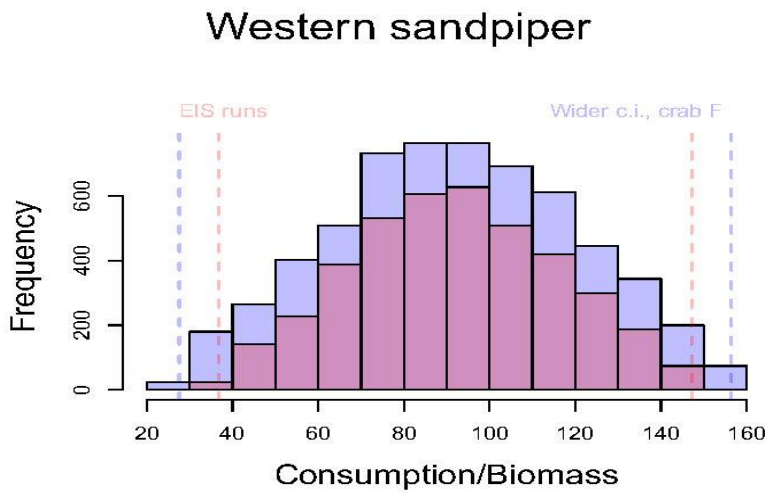

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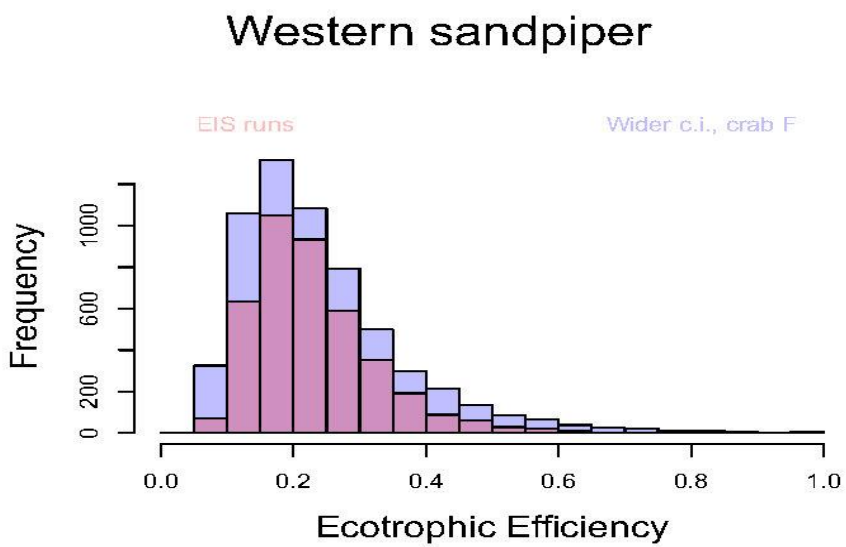

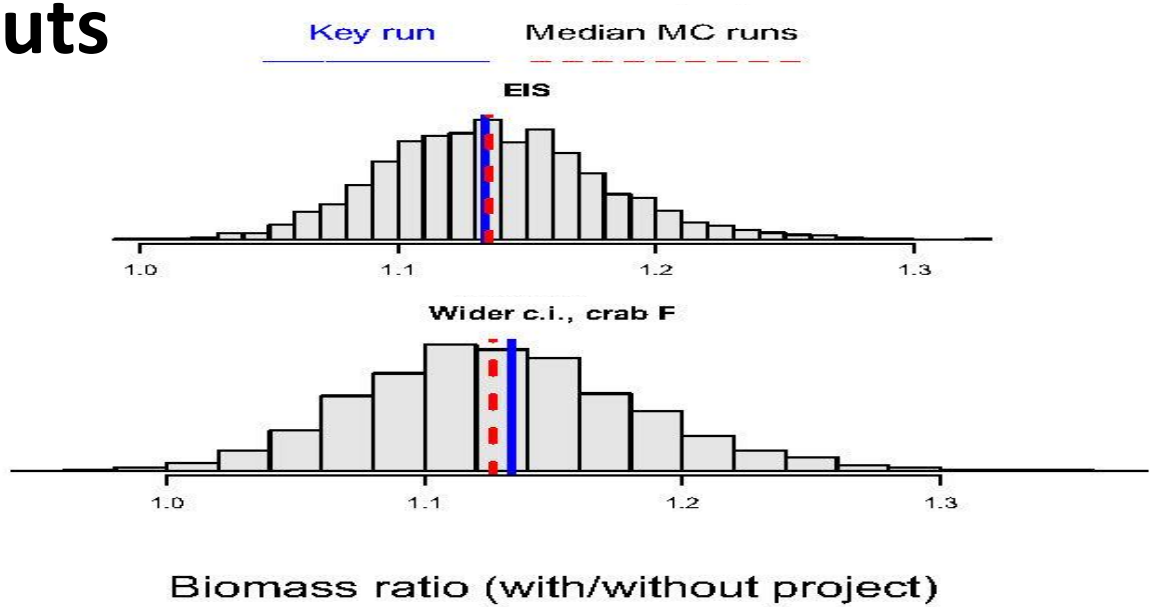

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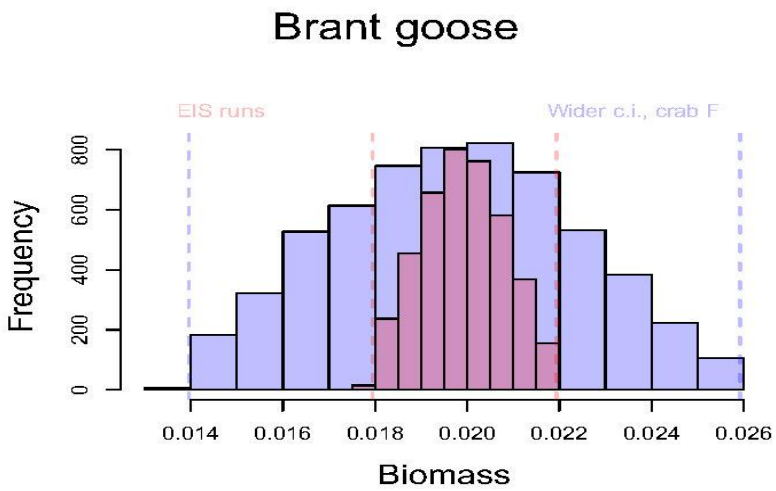

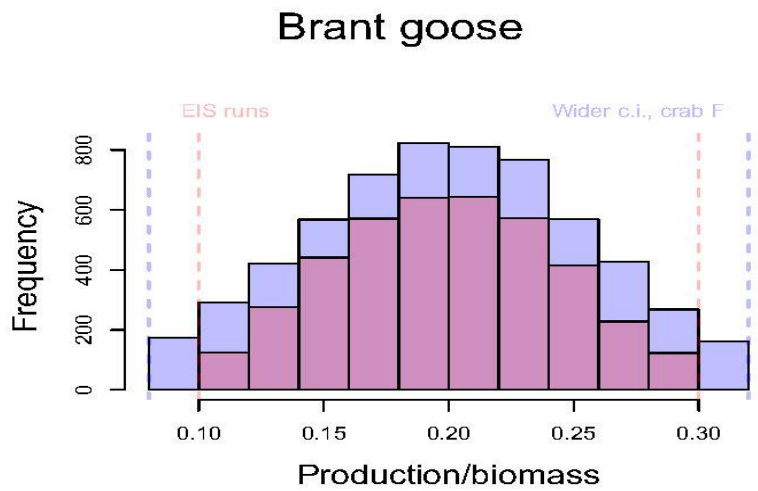

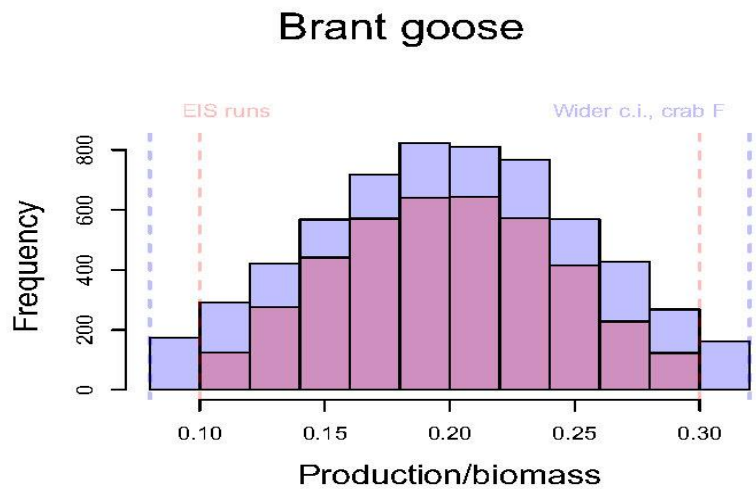

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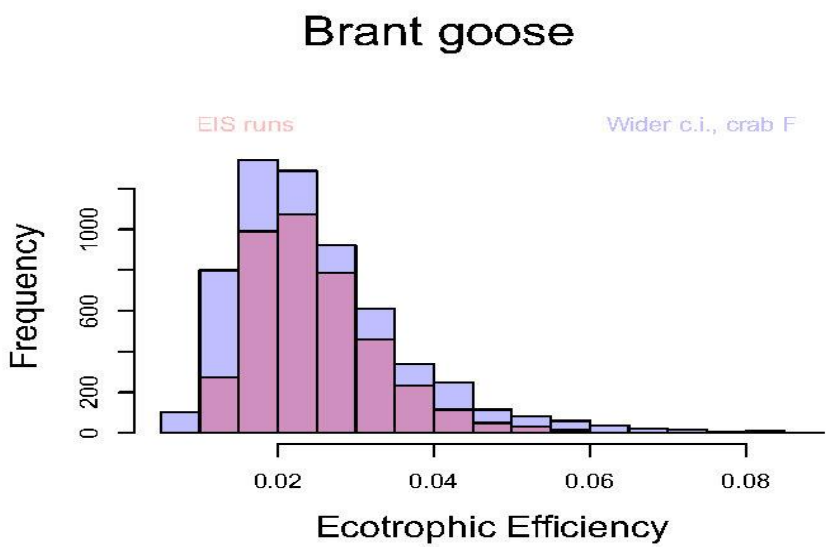
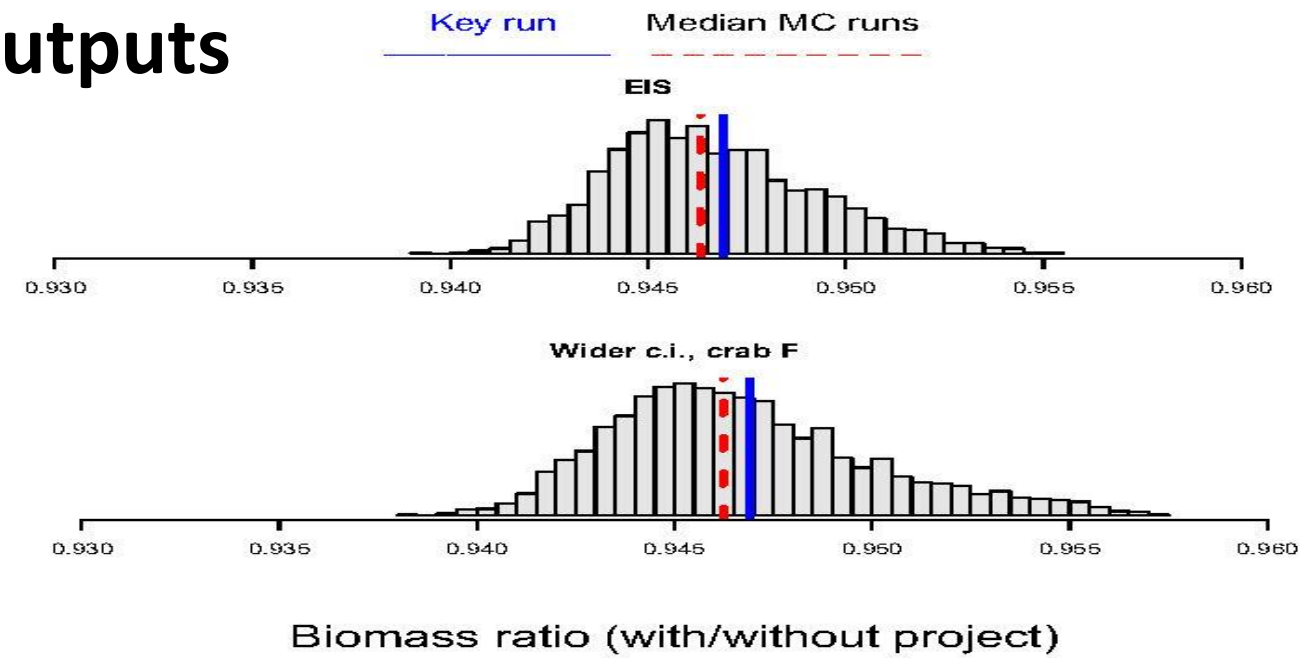




IR3-20 Roberts Bank Ecosystem Model – Validation: Biomass Discrepancies

Information Source(s)

EIS Volume 3: Section 10.3, Appendix 10-C

CEAR Doc #547

Context

The Proponent, in CEAR Doc #547 (2.12 Ecospace Documentation (1.2.6)) reported that during the 10 model-year spin up period, balancing was conducted to produce more realistic distributions and biomass values. The biomass of the functional groups from the Ecopath model after the spin-up period was adjusted to balance the 5468 separate cells of the Ecospace model. Changes in biomass values generated during the spin-up period were reported to be identical for both with and without Project scenarios and were interpreted by the Proponent to not be informative for predicting potential Project related effects on productivity.

According to Fisheries and Oceans Canada, several changes to the biomass result occurred as a result of the Ecospace balancing process (spin-up period). Analysis by Fisheries and Oceans Canada of the changes to biomass input, spin up and ratio results from the Ecospace balancing process revealed that the biomass of nine functional groups was larger or smaller than the widest confidence limits allowed for each group.

Information Request

Analyze the implications and impact on Ecopath and Ecospace model outputs when there are biomass discrepancies that exceed the widest confidence limits.

VFPA Response

Clarification and Key Terms

Model Balancing and Model Spin-up

It is important to distinguish between 'model balancing' and 'model spin-up'. The two terms refer to separate processes (see further discussion in CEAR Document #547, question 2.12).

Model balancing refers to a standard procedure in ecosystem modelling whereby input biomass, production estimates, and/or diet allocations are adjusted to create a realistic trophic model by ensuring predation pressure does not exceed prey availability. Changes in biomass values generated during the spin-up period are identical for both with and without Project scenarios (i.e., both scenarios begin from the same post spin-up equilibrium). For more details on model balancing, please refer to CEAR Document #547, question 2.9 and IR3-16 and IR3-17.

Model spin-up also refers to a standard procedure in ecosystem modelling; however, this process involves running the model until a state of statistical equilibrium is reached, allowing predators to redistribute to better align with their prey to produce more realistic distributions and biomass values. In the case of the Roberts Bank ecosystem model (RB model), functional groups reached equilibrium within a ten model-year spin-up period. It is important to note that all adjustments to the model during the spin-up period are a function solely of calculations performed by the model and are not made by the modelling team. The methodology used in the model spin-up period is documented in the EIS Appendix 10-C.

In CEAR Document #547, question 2.12, the term 'balancing' was used within the context of the spin-up, referring to reconciliation among adjacent and farther afield cells and not the process described above. To avoid such confusion going forward, the term 'adjustment' (and not 'balancing') will be used to refer to modifications in the spatial distribution of each functional group to account for predator-prey dynamics during spin-up.

Confidence Limits

The confidence limits reflect the level of certainty estimated for each input parameter—in this case, biomass; therefore, the confidence limits do not apply to spin-up biomass values. As outlined in CEAR Document#547, question 2.7, confidence limits are based on a pedigree approach that reflects differing confidence in different types or sources of data, depending on the nature of those data. As such, it is not technically valid to apply input parameter confidence limits to biomass equilibrium values reached after the spin-up period. It should also be re-emphasised here that changes in biomass values generated during the spin-up period are identical for both with and without Project scenarios.

The reason for changes between biomass input parameter values (i.e., 'biomass initial value') and post spin-up biomass at equilibrium values (i.e., 'biomass equilibrium value') is not uncertainty driven; rather, it is due to initial spatial mismatches between predators and prey, because the spatial distribution of each ecological group is initially assigned based solely on each group's specific environmental preferences. As outlined in CEAR Document #547, question 2.12, this initial process may have led to discrepancies in productivity, as the distribution of predators and consumers may not have aligned with prey species. For example, predators may have been placed in cells where there is no or little prey (and vice versa), which resulted in predator declines (or prey increases) in those cells and changes in overall biomass values after the spin-up period. This is the case for all spatial ecosystem models, and as such not a unique feature of the RB model.

During the spin-up period, the model undergoes an adjustment process to reconcile the spatial distribution of each functional group to account for both predator-prey dynamics and environmental preferences. This involves an inevitable change in biomass values from the initial input values for each of the 58 functional groups.

Spin-up Ratio

A comparison between the initial biomass estimates and the biomass estimates at statistical equilibrium is rarely assessed by modellers, as this 'spin-up ratio' is generally not considered

an ecologically relevant measure. This is because the pre-spin-up spatial distributions do not reflect an ecologically realistic starting point due to the above-mentioned spatial mismatches between predators and prey.

Further, spin-up values are not ecologically relevant because the spin-up period is not intended to function as a model run and, therefore, its outputs should not be considered as such; rather, after approaching equilibrium (i.e., post spin-up), the model was run an additional 10 years under two separate scenarios: with and without the proposed RBT2 development, and this is referred to as the 'key run' (see CEAR Document #547, question 2.12). The key run outputs, presented as relative differences in biomass after 10 years, are the values considered in the assessment. It should also be re-emphasised here that changes in biomass values generated during the spin-up period are identical for both with and without Project scenarios (i.e., both scenarios begin from the same post spin-up equilibrium), meaning that spin-up ratios do not provide information on the potential Project-related effects on productivity, which is the objective of the model.

Analyze the implications and impact on Ecopath and Ecospace model outputs when there are biomass discrepancies that exceed the widest confidence limits

It is not technically appropriate to compare spin-up outputs to input parameter confidence limits nor is it ecologically relevant to assess spin-up outputs because the spin-up period is a pre-model run process. Changes in biomass values generated during the spin-up period are identical for both with and without Project scenarios and therefore do not provide information on the potential Project-related effects on productivity, which is the objective of the model. The nine functional groups forecasted to have biomass estimates outside the widest confidence limits are presented in **Table IR3-20-1**.

Table IR3-20-1 Pre-model (i.e., spin-up ratio) and Model (i.e., key run ratio) Outputs of Functional Groups with Biomass Estimates that Exceed Confidence Limits

Functional Group	Pre-model Output (Spin-up Ratio)*	Model Output (Key Run Ratio)
Bald eagle	0.61	0.93
Dunlin	1.76	1.13
Gulls and terns	1.57	0.99
Shorebirds	2.03	0.98
Western sandpiper	2.29	1.13
Raptors	1.92	1.13
Large demersal fish	1.65	0.99
Small demersal fish	1.60	0.95
Meiofauna	2.46	1.11

Note: * spin-up ratio is based on initial biomass / post spin-up biomass

As shown in **Table IR3-20-1** above, spin-up ratios do not affect, nor influence, key run results; therefore, there are no implications or impact on Ecopath with Ecosim and Ecospace (EwE) model outputs to analyse. This is because the two modelled scenarios (i.e., with and without Project) used the same input parameters and began simulations from the same state (i.e., spin-up equilibrium). Therefore, the key run with/without scenarios are driven solely by the direct and indirect effects of the terminal and causeway, which is the core objective of the model.

In addition, the robustness of input parameters (i.e., initial state used for the spin-up period) and the effects of uncertainty were tested using Monte Carlo analyses. A total of 4,000 model iterations were created with each input parameter varied within the range of the confidence intervals. The Monte Carlo analyses demonstrated that the RB model was robust to large variations in the model inputs.

The reason for large differences in spin-up values for these nine functional groups is attributed to spatial mismatches. As outlined above, the spatial distribution of each ecological group in the model is initially allocated based solely on environmental preferences. As each group in the model has its own set of environmental preferences, it is reasonable to expect some level of spatial mismatch between groups that are trophically linked (i.e., predators and their prey). During the spin-up period, the model undergoes an adjustment process to reconcile the spatial distribution of groups, which allows predators to adjust to prey abundance and optimise the trade-offs between prey consumption needs and environmental preferences. Thus, prior to the model reaching equilibrium state, predators that require more time and effort to find food resources will have reduced productivity (thus reduced biomass) during the spin-up period. Conversely, prey groups which have low spatial overlap with their predators will have an increased period of time with lower predation and, consequently, have higher productivity (thus higher biomass) during the spin-up period. Spatial mismatch may result in loss or gain of biomass for each ecological group depending on its specific predator-prey dynamics; the purpose of the spin-up is to resolve these spatial mismatches to the extent possible before the model is run.

IR3-21 Roberts Bank Ecosystem Model – Validation: Other Methods

Information Source(s)

EIS Volume 3: Section 10.3, Appendix 10-C

CEAR Doc #547

Context

According to the Proponent, models that predict presence-absence distributions can be evaluated for sensitivity (true positive rate) and specificity (true negative rate). Sensitivity is a measure of the correctly classified presences - where a model predicts a species to occur in an area where it is known to occur in real life - whereas specificity is a measure of correctly classified absences - where a model predicts a species does not occur in an area where it is known not to occur in real life.

The Proponent, in CEAR Doc #547, identified that the RB EwE model used a goodness of fit measure to compare spatial distributions of model outputs with field observations. The chosen goodness of fit measure used was the percent correct classification (PCC) method. The results of the PCC, sensitivity and specificity goodness of fit was reported in Table 8 of CEAR Doc #547.

According to Fisheries and Oceans Canada, this goodness of fit comparison was done only for habitat-forming functional groups; no discussion of how well this analysis applies to mobile functional groups was provided. The PCC method did not take into account situations, such as that which occurs at Roberts Banks, where functional groups occurred at only a few locations. Habitat functional groups, like biofilm, brown algae, native eelgrass, green algae, Japanese eelgrass, tidal marsh, biomat and orange sea pens do not occur over most of the RB EwE model study area.

Information Request

Provide validation for the distribution fits for the Ecospace model using other methods than the PCC method. Do the evaluation for habitat-forming as well as for pelagic functional groups.

VFPA Response

The Roberts Bank ecosystem model (RB model) is one of the first Ecopath with Ecosim and Ecospace (EwE) models to have undertaken spatial statistical validation analyses. The VFPA has previously provided validation (i.e., percent correct classification (PCC), sensitivity evaluation, and specificity evaluation) for eight habitat-forming functional groups (see CEAR

Documents #314[1] and #547 for a description of these validation methods and results). The information request asks for validation of distribution fits for pelagic functional groups in addition to habitat-forming functional groups. Pelagic groups are highly mobile and spatially indistinct (e.g., they tend to cover the entire RB model study area) and goodness of fit validation requires precise understanding of where these groups will occur. Spatial data on pelagic group distribution are necessary for validation, and such data do not exist; therefore, statistical validation for pelagic groups is not technically feasible and has not been addressed further in this response.

However, in response to this information request for additional validation methods, an additional method for assessing model accuracy, Cohen's Kappa (Kappa), was undertaken for habitat-forming groups and is presented here (see **Table IR3-21-3** below for results). This method confirms the results already identified by the RB model and presented in the EIS. For convenience, a summary of the four validation methods is presented in **Table IR3-21-1**.

Kappa provides a simple, effective, standardised, and appropriate statistic for evaluating distribution models. Kappa is a robust metric because it discriminates between goodness of fit due to agreement between observed and forecasted distribution and goodness of fit due to chance distribution and accounts for low occurrence of functional groups (Franklin 2010). Kappa values generally agree with the previous metrics used to assess goodness of fit (i.e., PCC, sensitivity, and specificity) presented in the EIS; however, as expected, there is some variation in model performance among the habitat-forming functional groups, with the RB model showing fair to substantial agreement for all but one group (i.e., green algae).

Variation in model performance among habitat-forming groups is to be expected because the habitat maps used to compare forecasts are more variable for some groups. Habitat maps for persistent groups (e.g., native eelgrass) will represent potential distribution well. Conversely, habitat maps for ephemeral groups will not provide a good representation of potential distribution. For example, green algae are distributed by a combination of wind, tide, and current, creating near-random distributions within larger areas of potential distribution. The RB model forecasts potential distribution for these functional groups, and model fit will likely be lower for more ephemeral groups, while performing better for persistent groups.

The application of the Kappa method for validation of forecasts demonstrates that the RB model performed well in forecasting distribution of habitat-forming functional groups. These habitat-forming functional groups occupy the lower trophic level and largely drive the productivity of bottom-up systems, such as Roberts Bank. Therefore, validation of model performance of habitat-forming functional groups is evidence that RB model performance is based on a solid foundation, which can also be seen in the PCC, sensitivity, and specificity analyses conducted.

[1] CEAR Document #314 From Port Metro Vancouver to the Canadian Environmental Assessment Agency re: Completeness Review - Responses to Additional Information Requirements (See reference document #271) for the Environmental Impact Statement.

Kappa results and further detail on each habitat-forming functional group is provided in the sections below. Kappa was not calculated for pelagic groups because the data required is not available and the analysis is not technically feasible, as described above.

Table IR3-21-1 Validation Methods: Four Standard Measures of Fit for Spatial Distribution Models Calculated for Each Habitat-forming Functional Group

Fit Measure	Equation	Comment
Percent correct classification (PCC)	$\frac{TP + TN}{TP + FP + TN + FN}$	Percent of all observed presence and absence that is correctly classified.
Sensitivity	$\frac{TP}{TP + FN}$	Percent of observed presence that is correctly classified.
Specificity	$\frac{TN}{TN + FP}$	Percent of observed absence that is correctly classified.
Cohen's Kappa	$\frac{PCC\ - Expected\ PCC}{1 - Expected\ PCC}$	Cohen's Kappa is similar to PCC but accounts for agreement occurring by chance. It measures the difference between the model's PCC and the expected PCC from a random model. When two measurements agree by chance only, Kappa = 0. When the two measurements agree perfectly, Kappa = 1. For details on calculation, see Cohen (1960) or Franklin (2010).

Note: TP = True Positive
TN = True Negative
FP = False Positive
FN = False Negative

Kappa Overview

Kappa (Cohen 1960) is a well-regarded and commonly used statistical test for measuring agreement between presence-absence observations and forecasts (Manel et al. 2001). It is similar to PCC but provides an assessment of the extent to which models forecast occurrence at a rate higher than chance (i.e., how much better the model's forecasts are compared to a random distribution (Monserud and Leemans 1992)).

A Kappa value of 1 relates to perfect agreement between observation and forecasts, while a negative or 0 value means that the model's performance is no better than random (i.e., slight to poor agreement) See **Table IR3-21-2** for Kappa statistics and 'strength of agreement' categories.

Table IR3-21-2 Kappa Statistics and Qualitative Strength of Agreement Categories (Landis and Koch 1977)

Kappa Statistics	Strength of Agreement
<0.00	Poor
0.00-0.20	Slight
0.21-0.40	Fair
0.41-0.60	Moderate
0.61-0.80	Substantial
0.81-1.00	Almost perfect

A common limitation with all goodness of fit metrics is the sensitivity of each metric to the relative prevalence of the group being assessed, i.e., the number of occurrences in relation to the number of samples. Groups with few occurrences, i.e., rare groups, often have lower agreement values than more prevalent groups (Viera and Garrett 2005). Kappa has been shown to be less sensitive to effects of prevalence than other metrics (Manel et al. 2001); however, Kappa values are not comparable between functional groups with different prevalence in the study area (McPherson et al. 2004; Vaughan and Ormerod 2005; Allouche et al. 2006).

Kappa Methodology

To test the accuracy of fit of model forecasts using Kappa, all cells in the spatial RB model (5,468 sample points) were sampled for both presences and absences of eight habitat-forming groups from both observed (i.e., field data) and forecasted distributions (i.e., results of the RB model). The eight habitat-forming groups consist of biofilm (freshwater and marine), brown algae, native eelgrass, Japanese eelgrass, tidal marsh, biomat, orange sea pens, and green algae. Observed distributions were estimated using the habitat map created using hyperspectral survey data and field sampling of Roberts Bank for 2012 (see Appendix D of TDR MVB-1[2] for methodology). While the hyperspectral sampling intensity and field validation provided an accurate estimate of observed distributions, it represents a static representation against which to compare forecasts. Static representations are likely more representative of relatively spatially static groups such as native eelgrass, but may not be as accurate for more spatially dynamic groups such as green algae. Forecasted distributions were generated as mapped distribution of productivity for each functional group in the RB model, with any value greater than 0 classified as a presence.

[2] See Appendix AIR10-C of Additional Information Request #10 (AIR-12.04.15-10) in CEAR Document #388 From Port Metro Vancouver to the Canadian Environmental Assessment Agency re: Completeness Review - Responses to Additional Information Requirements Follow-Up (See Reference Document #345) including 22 Technical Data Reports.

Kappa Results and Interpretation

Overall, Kappa statistics indicate that the RB model results for habitat-forming groups are accurate and generally consistent with PCC conclusions (**Table IR3-21-3**). There is more variation in the Kappa strength of agreement statistic and all forecasted distributions show fair to substantial agreement with observed distributions, with the exception of green algae's 'slight' agreement rating. Interpretations of the accuracy assessment are provided for each of the eight habitat-forming functional groups and include considerations of the Kappa value, group prevalence, spatial variability of the group, and group interactions. Note that the PCC conclusions were previously demonstrated to be generally consistent with sensitivity and specificity validation methods (CEAR Document#547, Section 7.0 of Information Request #6 (IR-7.31.15-06 in CEAR Document #897[3])) and these metrics are presented for comparison to the Kappa statistic in **Table IR3-21-3** and discussed further below.

For each of the eight habitat-forming functional groups discussed below, a figure is presented to illustrate the accuracy of the RB model in forecasting spatial distribution of each group across Roberts Bank compared to the observed distribution (habitat map). The spatial overlap between forecasted (RB model) and observed distributions for each group is classified into four groups and labelled as coloured pixels to illustrate where there is agreement (true positive and true negatives) or disagreement (false positives and false negatives). For the goodness of fit assessments, the number of pixels for each of these four categories is used to calculate PCC, sensitivity, specificity, and Kappa.

Table IR-3-21-3 Percent Correct Classification and Kappa Accuracy of Fit Statistics, Strength of Agreements for Habitat-forming Species

Focal Species	Percent Correct Classification	Sensitivity	Specificity	Cohen's Kappa Statistic	Kappa Strength of Agreement
Biofilm (freshwater and marine)	84%	56%	88%	0.37	Fair
Brown Algae	95%	96%	95%	0.41	Moderate
Native Eelgrass	90%	86%	91%	0.68	Substantial
Japanese eelgrass	80%	88%	79%	0.42	Moderate
Tidal marsh	91%	63%	92%	0.30	Fair
Biomat	97%	100%	97%	0.45	Moderate
Orange Sea Pens	91%	98%	91%	0.37	Fair
Green Algae	59%	52%	63%	0.15	Slight

[3] CEAR Document #897 From the Vancouver Fraser Port Authority to the Review Panel re: Responses to Information Request Package 1 (See Reference Document #559).

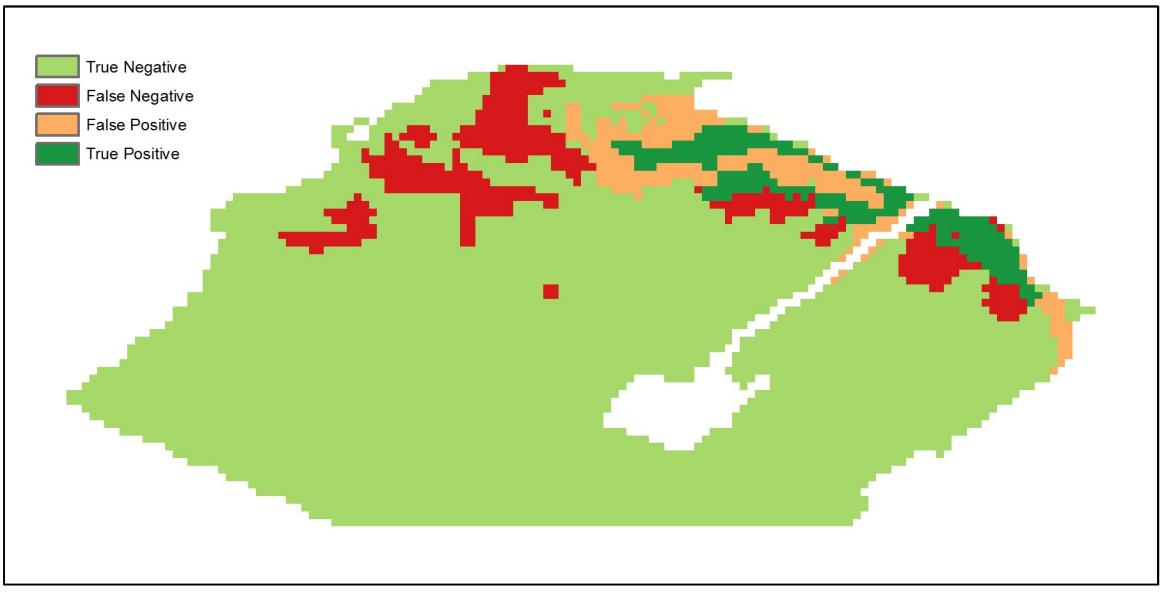
Biofilm (Freshwater and Marine)

The RB model is considered to have adequately forecasted biofilm distribution compared to visual observations based on both PCC and the Kappa value (**Table IR3-21-3**, **Figure IR3-21-1**). Overall accuracy was moderate for biofilm with a PCC of 84% and showed fair agreement based on the Kappa statistic (0.37). The model accuracy for forecasting biofilm presence (sensitivity = 56%) was lower than its accuracy for biofilm absence (specificity = 88%).

These results are anticipated given the large degree of spatial and temporal variability associated with biofilm dynamics at Roberts Bank (WorleyParsons 2015) and limitations of the habitat map used to measure accuracy of dynamic groups. For example, relative to the habitat map, the RB model forecasts less biofilm around Canoe Passage (false negative forecast), and more biofilm in the upper intertidal zone around Brunswick Point (false positive forecast). These two patterns are responsible for the lower Kappa accuracy of fit estimate and can be attributed to two main factors: 1) the habitat map is a static representation of a dynamic system, and 2) biotic interactions such as competition are not captured by the model.

The RB model adequately forecasts biofilm distribution because it forecasts biofilm occurrence in areas that are known to have biofilm and where it is fed upon by shorebirds. For example, the model forecasts the occurrence of biofilm at Brunswick point, where we know biofilm occurs ephemerally, and along the upper intertidal, a more persistent area of biofilm coverage, both of which are biofilm feeding areas for western sandpiper.

Figure IR3-21-1 Classification of Forecasted versus Observed Spatial Distribution for Biofilm

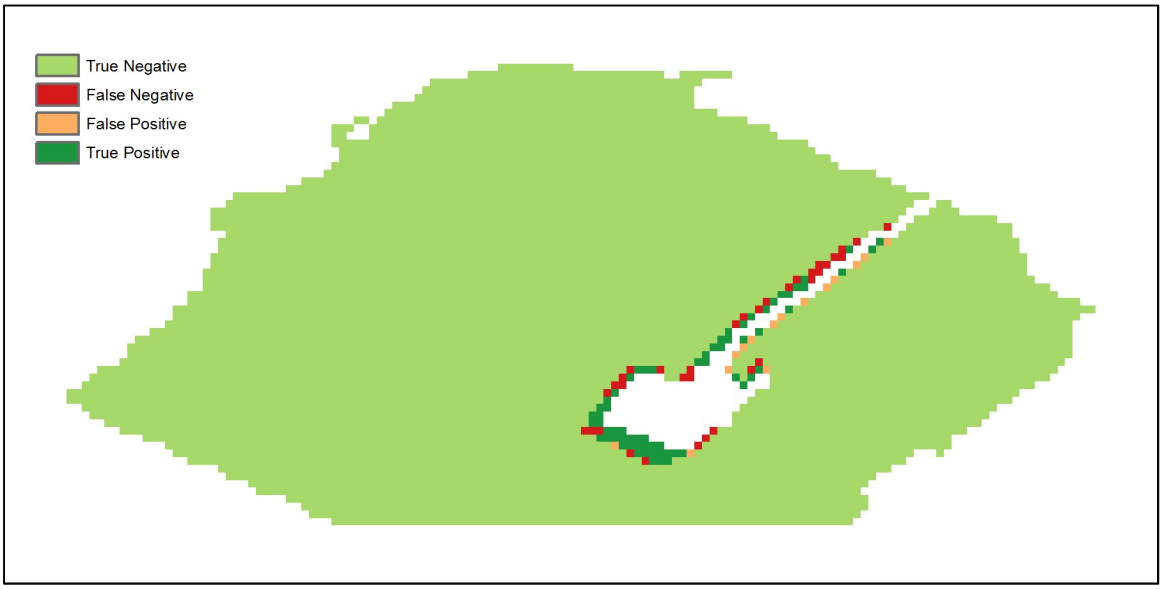


Brown Algae

The RB model forecasted the distribution of brown algae with a high level of accuracy compared to visual observations, based on both PCC and Kappa values (**Table IR3-21-3**, **Figure IR3-21-2**). Overall, accuracy was high for brown algae with a PCC of 95%, and showed moderate agreement based on the Kappa statistic (0.41). The model accuracy was high for forecasting both brown algae presence (sensitivity = 96%) and absence (specificity = 95%).

The RB model forecasts slightly less brown algae along the causeway than documented in the habitat map (a false negative forecast). The lower Kappa value is likely related to low prevalence of brown algae at Roberts Bank (i.e., it is not widely distributed). The RB model does a good job of forecasting both where brown algae occur and where they do not occur but the relatively low prevalence in the study site produces a lower Kappa value despite high accuracy of forecasts of presences and absences.

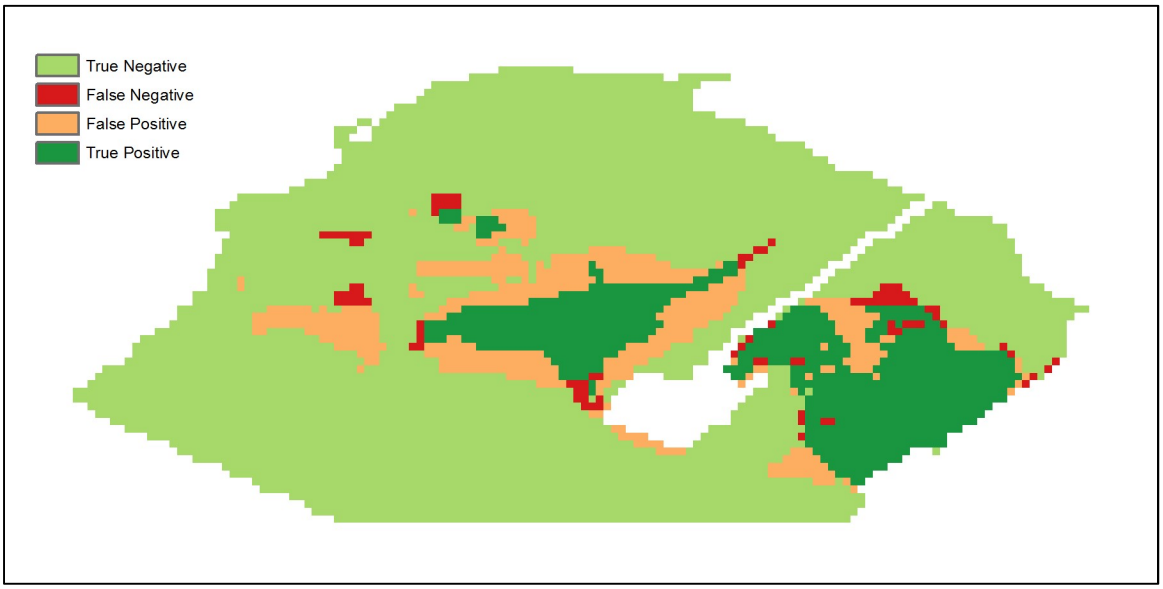
Figure IR3-21-2 Classification of Forecasted versus Observed Spatial Distribution for Brown Algae



Native Eelgrass

The RB model adequately forecasted the distribution of native eelgrass (*Zostera marina*) compared to visual observations, based on both PCC and Kappa values (**Table IR3-21-3**, **Figure IR3-21-3**). Overall, accuracy for native eelgrass was high with a PCC of 90%, and showed substantial agreement based on the Kappa statistic (0.68). The model performed well in forecasting both native eelgrass presence (sensitivity = 86%) and absences (specificity = 91%). The high degree of agreement between the model and the habitat map likely reflect the within-year stability of eelgrass distribution resulting in a close alignment of potential productivity and species distribution.

Figure IR3-21-3 Classification of Forecasted versus Observed Spatial Distribution for Native Eelgrass



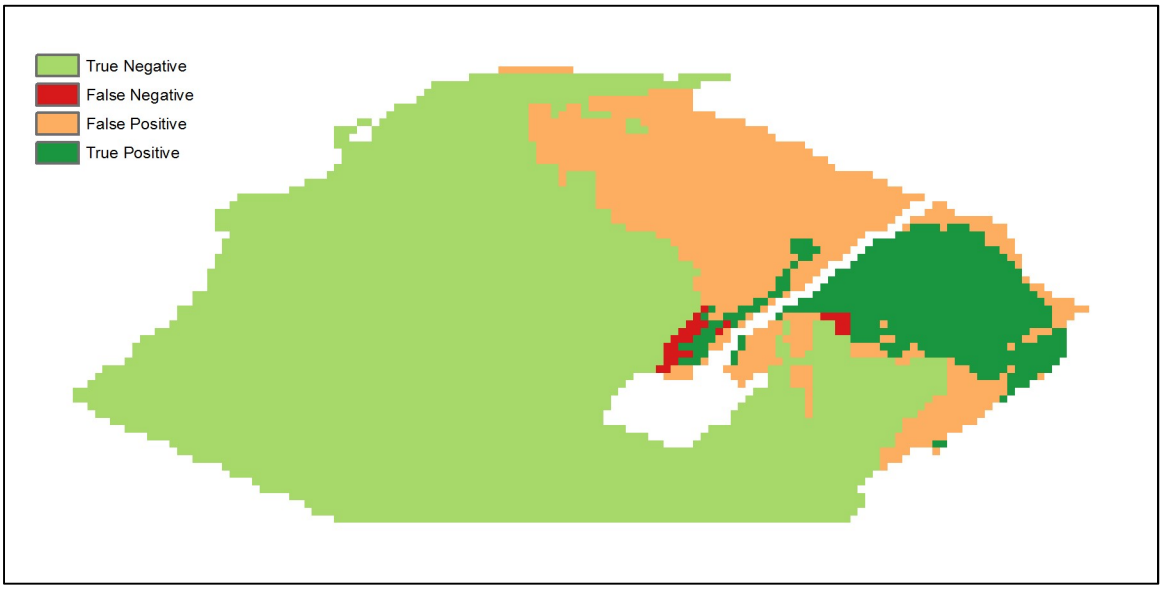
Japanese Eelgrass

The RB model forecasted the distribution of Japanese eelgrass (*Zostera japonica*) with a moderate level of accuracy compared to visual observations, based on both PCC and Kappa values (**Table IR3-21-3**, **Figure IR3-21-4**). Overall, PCC for Japanese eelgrass was 80% and the Kappa value indicated moderate agreement (0.42). The model performed slightly better at forecasting presence of Japanese eelgrass (sensitivity = 88%) than forecasting its absence (specificity = 79%).

Similar to native eelgrass, the distribution of Japanese eelgrass typically exhibits only minimal changes from year to year, making it a good indicator of model performance relating to habitat-forming and sessile groups. However, false positive forecasts (i.e., the model forecasting a presence of Japanese eelgrass where it is shown to be absent on the baseline habitat map) resulted in the lower accuracy values. The model forecasts Japanese eelgrass to occur over much of the nearshore area, north of the causeway. The habitat map shows little Japanese eelgrass in this area (which at Roberts Bank is dominated by biomat and biofilm).

The habitat map delineates dominant vegetation only and does not reflect all suitable habitats for a functional group. Additionally, the overlap in distribution forecasted by the model may not be realised due to competitive interactions with other species; for example, interspecies competition between *Z. japonica* and *Z. marina* has been widely documented in the literature (Mach et al. 2010; Bulthuis 1995; Ruesink et al. 2010; Hay 2011) and is likely prevalent at Roberts Bank.

Figure IR3-21-4 Classification of Forecasted versus Observed Spatial Distribution Japanese Eelgrass



Tidal Marsh

The RB model forecasted the distribution of tidal marsh with an adequate level of accuracy compared to visual observations, based on both PCC and Kappa values (**Table IR3-21-3**, **Figure IR3-21-5**). Overall accuracy was high for tidal marsh, with a PCC of 91%, and with fair Kappa agreement (0.30). The model performs moderately in forecasting presences (sensitivity = 63%), while it performs well at forecasting absences (specificity = 92%).

The lower Kappa value results from tidal marsh rarely occurring in the study site (low prevalence; see 'Kappa Overview' section earlier which explains the influence of rarity on Kappa) and the RB model not forecasting tidal marsh around Canoe Passage (false negative forecast). This is attributed to three factors: 1) the habitat map, while a reliable depiction of habitat distributions at Roberts Bank, is a static representation of a dynamic system and therefore susceptible to sources of error and natural variance; 2) the habitat map delineates dominant vegetation only, such that species can cover larger areas than represented but are generally sparse relative to other vegetation that is present; and 3) competition, or some other biotic interaction not captured by the model, is restricting tidal marsh's realised distribution.

Figure IR3-21-5 Classification of Forecasted versus Observed Spatial Distribution Tidal Marsh

Biomat

The RB model forecasted the distribution of biomat with a high level of accuracy compared to visual observations, based on both PCC and Kappa values (**Table IR3-21-3**, **Figure IR3-21-6**). Overall accuracy was high for biomat with a PCC of 97%, and showed moderate agreement based on the Kappa statistic (0.45). The model was highly accurate in forecasting both presences (sensitivity = 100%) and absences (specificity = 97%) of biomat.

The moderate Kappa value is likely driven by the low prevalence of biomat at Roberts Bank and due to the RB model forecasting slightly more biomat than documented in the habitat map (a false positive forecast) that surrounds its known distribution. Biomat formation is not well understood and there are competing theories on whether the biomat physical features are accreting or eroding (see TDR MVB-1).

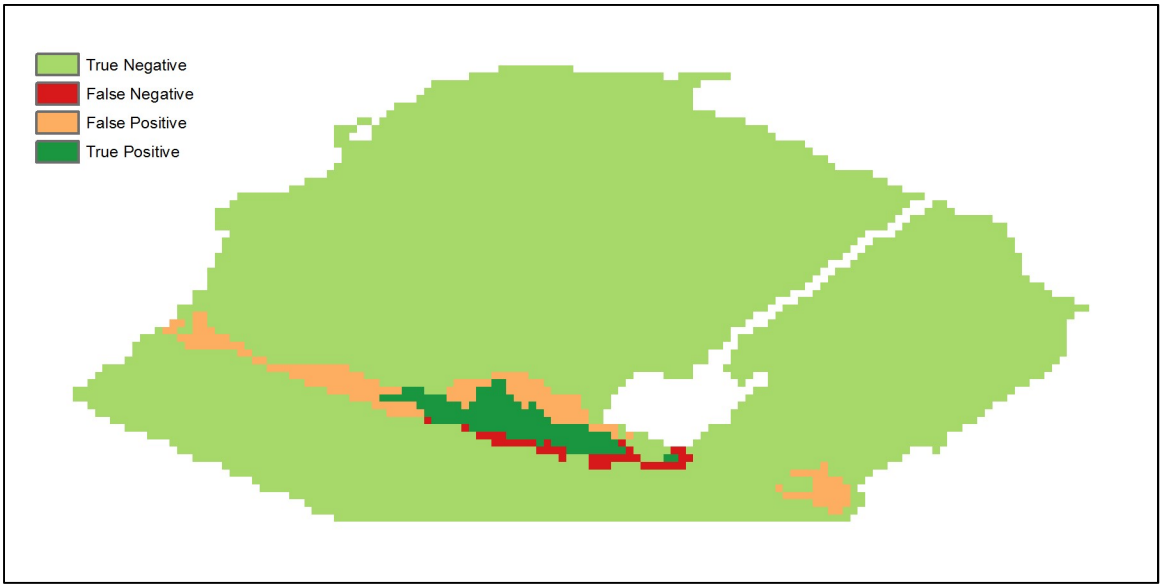
Figure IR3-21-6 Classification of Forecasted versus Observed Spatial Distribution for Biomat

Orange Sea Pens

The RB model accurately forecasted the distribution of orange sea pens compared to visual observations, based on both PCC and Kappa values (**Table IR3-21-3**, **Figure IR3-21-7**). Overall accuracy was high with a PCC of 91%, and the Kappa value showed fair agreement (0.37). The model performed well for both forecasting presence (sensitivity = 98%) and absence (specificity = 91%) of orange sea pens. The fair Kappa value is driven by the low prevalence of sea pens in the study area and an overestimation of distribution of orange sea pens at Roberts Bank.

The lateral distribution of orange sea pens forecasted by the model (i.e., to the northwest) is slightly larger than the habitat map, particularly for the sparse portion of the aggregation, while the forecasted distribution at depth is slightly smaller. The area to the northwest where orange sea pen presence is forecasted by the model but not observed in mapping surveys encompasses subtidal channels that have obvious geomorphic patterns consistent with sediment slumping and slope failure, which could not be captured by the model.

Figure IR3-21-7 Classification of Forecasted versus Observed Spatial Distribution for Orange Sea Pens



Green Algae

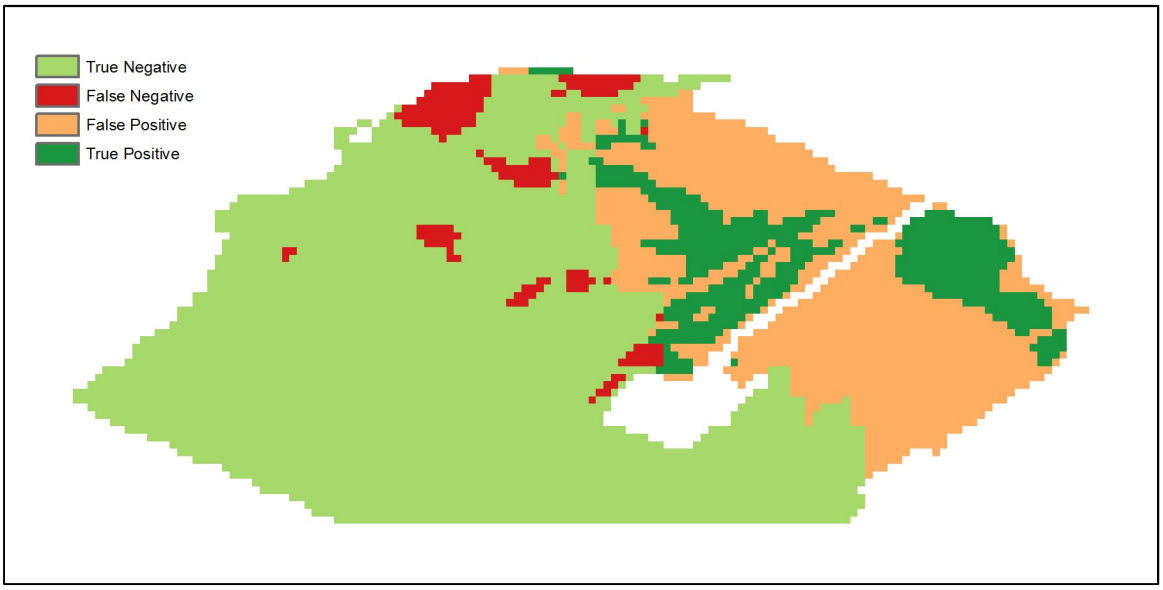
The RB model forecasted the distribution of green algae with average accuracy compared to visual observations, based on the PCC accuracy of fit statistic (**Table IR3-21-3**, **Figure IR3-21-8**). Overall, PCC for green algae was 59%, Kappa values indicated slight agreement (0.15). The model performance for presence and absence forecasts were similar (sensitivity = 52% and specificity = 63%). These results are reasonable given the ephemeral nature of green algae, environmental drivers of distribution, and the life history of green algae at Roberts Bank.

Green algae at Roberts Bank consists primarily of sea lettuce (*Ulva lactuca* and *Ulva intestinalis*), two highly ephemeral species known for their fluctuating distribution patterns. Both species have forms that do not have a holdfast for attachment and their distribution is primarily determined by the stochastic combination of wave height, currents, and tidal patterns. Surveys conducted at Roberts Bank in 2012 and 2013 were unable to pinpoint a consistent and defined distribution for green algae (TDR MVB-1 in Appendix AIR10-C in Additional Information Request #10[4]), indicating that modelling the precise distribution of sea lettuce would be challenging.

False positive forecasts drove the model's low accuracy for green algae (i.e., the model forecasted a presence of green algae where they are shown to be absent on the habitat map). This is attributed to three factors: 1) the habitat map, while a reliable depiction of habitat distributions at Roberts Bank, is a static representation of a dynamic system and therefore susceptible to natural variance, particularly in the case of green algae where distribution constantly shifts as oceanographic conditions vary; 2) the habitat map delineates dominant vegetation only, such that species can cover larger areas than represented but are generally sparse relative to other vegetation that is present; and 3) competition, or some other biotic interaction, not captured by the model, is restricting green algae's realised distribution.

[4] See Additional Information Request #10 (AIR-12.04.15-10) in CEAR Document #389 From Port Metro Vancouver to the Canadian Environmental Assessment Agency re: Marine Shipping Addendum Completeness Review - Additional Information Requirements.

Figure IR3-21-8 Classification of Forecasted versus Observed Spatial Distribution Green Algae



Conclusion

Kappa values generated for habitat-forming groups agreed with the previous metrics used to assess goodness of fit (PCC, sensitivity, specificity). As expected, there was some variation in model performance among the eight habitat-forming functional groups, with the RB model showing fair to substantial agreement for all but one group (i.e., green algae).

This additional work using the Kappa demonstrated that the RB model generally performed well in forecasting the distributions of the eight habitat-forming functional groups. These habitat-forming functional groups occupy the lower trophic level and largely drive the productivity of bottom-up systems, such as Roberts Bank. Therefore, validation of model performance of habitat-forming groups is evidence that RB model performance is based on a solid foundation, which is supported by the PCC, sensitivity, and specificity analyses presented in the EIS.

Validation of distribution fits for pelagic functional groups requires precise understanding of how these groups are distributed. Spatial data on pelagic group distribution are necessary for validation, and such data do not exist; therefore, statistical validation for pelagic groups is not technically feasible and could not be presented in this response.

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IR3-22 Roberts Bank Ecosystem Model - Sensitivity Analysis: Production Differences in Functional Groups

Information Source(s)

EIS Volume 3: Section 10.3, Appendix 10-D

CEAR Doc #547

Context

The Proponent used a pedigree approach as an indicator to identify how well-rooted the RB EwE model was to local data. More specifically, pedigree information was used for two different purposes:

- the approximate confidence interval (CI; in % of mean) associated with the indicators were used for subsequent Monte Carlo uncertainty evaluation; and
- the pedigree indicator scores (ranging from 0.0 to 1.0) were averaged over all parameters and functional groups of a model to provide an index of quality of that model.

The appropriateness of relying on the pedigree approach to derive confidence intervals for the RB EwE model was raised by Fisheries and Oceans Canada. As a result, the Proponent reran the model with much larger confidence intervals, ranging from 30 to 100% depending on the input parameter and functional group.

The results from this new analysis using the broader confidence intervals were reported to be similar to those using the original pedigree approach. The Proponent noted in CEAR Doc #547 that while the production within each run was very different, there was little difference in the biomass ratio with and without the Project and that these results further demonstrate that even with a greater range in input values, the influence of the Project on the Roberts Bank ecosystem is consistent among all model runs.

According to Fisheries and Oceans Canada, this result provides confidence that the model may be robust regarding uncertainty in its input parameters. The Proponent's results indicate that the production measured by the model runs was different, though biomass ratios with and without the Project were similar.

Since biomass is not the same as production which is the rate of generation of biomass as expressed in units of mass per unit surface (or volume) per unit time - ($g/m^2/year$), results reported as production are required to provide further understanding of the model's performance and to understand the potential effects with and without the Project.

Information Request

Provide the production differences (rate of generation of biomass as expressed in units of mass per unit surface (or volume) per unit time) in functional groups as opposed to biomass that resulted from the model runs.

VFPA Response

Production differences in functional groups from the model runs are provided in Table 3.3 in EIS Appendix 10-C in *mass per unit of time* (tonnes (t) per year (yr)). The information request has asked for production differences in *mass per unit surface (or volume) per unit of time*. **Table IR3-22-1** provides this new information by dividing the production differences of functional groups from Table 3.3 in EIS Appendix 10-C by 54.68 km^2 (the size of the study area), to provide the 'unit surface' measure.

Table IR3-22-1 Production Differences for the Roberts Bank Ecosystem Model Study Area

No.	Group	Production (without t/km^2/yr)	Production (with t/km^2/yr)	Difference (with - without t/km^2/yr)
1	Baleen whales	0.000146	0.000146	-0.0000183
2	Dolphins and porpoises	0.000805	0.000768	-0.0000183
3	Pinnipeds	0.055889	0.054389	-0.001518
4	Southern resident killer whales	0.000402	0.000384	-0.0000183
5	Transient killer whales	0.000201	0.000183	-0.0000183
6	American wigeon	0.017429	0.015966	-0.001463
7	Bald eagle	0.000549	0.000512	-0.0000366
8	Brant goose	0.003987	0.003767	-0.000219
9	Diving waterbirds	0.00662	0.0062	-0.000421
10	Dunlin	0.004389	0.004956	0.0005669
11	Great blue heron	0.006017	0.005999	-0.0000183
12	Gulls and terns	0.011101	0.010936	-0.000165
13	Raptors	0.0000549	0.0000732	0.00001829
14	Shorebirds	0.000421	0.000421	0
15	Waterfowl	0.060571	0.06549	0.0049195
16	Western sandpiper	0.000549	0.000604	0.00007315
17	Chinook adult	1.060735	1.00684	-0.053877
18	Chinook juvenile	0.009583	0.011101	0.0015179
19	Chum adult	0.877944	0.837637	-0.040307
20	Chum juvenile	0.008083	0.009236	0.0011522
21	Dogfish	0.078895	0.077121	-0.001774
22	Flatfish	0.138314	0.136229	-0.002085
23	Forage fish	9.956693	9.81602	-0.140673

No.	Group	Production (without t/km²/yr)	Production (with t/km²/yr)	Difference (with - without t/km²/yr)
24	Herring	3.551024	3.468819	-0.082187
25	Large demersal fish	0.078219	0.077268	-0.000951
26	Lingcod	0.181584	0.176061	-0.005523
27	Rockfish	0.074342	0.067776	-0.006565
28	Salmon adult	0.436083	0.41816	-0.017941
29	Salmon juvenile	0.001445	0.00139	-0.0000366
30	Sandlance	0.09733	0.102871	0.0055413
31	Shiner perch	0.207206	0.245337	0.0381309
32	Skate	0.020721	0.019038	-0.001683
33	Small demersal fish	0.072147	0.068252	-0.003914
34	Starry flounder	0.083778	0.088844	0.0050658
35	Carnivorous zooplankton	207.8676	185.5991	-22.26847
36	Dungeness crab	11.55669	11.15234	-0.404353
37	Epifaunal grazers	22.12985	20.38332	-1.746525
38	Epifaunal omnivore	6.739027	6.584126	-0.154901
39	Epifauna sessile	1.524323	1.819495	0.2951719
40	Infaunal bivalves	248.156	228.6172	-19.53877
41	Jellyfish	105.2955	96.66478	-8.630761
42	Macrofauna	200.6898	254.3297	53.639905
43	Meiofauna	232.4278	258.0598	25.632224
44	Omnivorous and herbivorous zooplankton	1303.921	1212.241	-91.68069
45	Polychaetes	100.5649	89.57553	-10.98939
46	Orange sea pen	0.1688	0.076079	-0.092904
47	Shrimp	1.197879	1.042794	-0.154901
48	Biofilm fresh	1081.61	2048.382	966.77158
49	Biofilm marine	1198.036	921.6256	-276.4106
50	Brown algae	73.74799	64.99872	-8.749268
51	Native eelgrass	100.2628	104.045	3.7821873
52	Green algae	1639.171	1500.577	-138.594
53	Japanese eelgrass	1.253658	1.244879	-0.008778
54	Red algae	5.547732	4.972933	-0.574799
55	Phytoplankton	5190.452	5354.118	163.66587
56	Tidal marsh	364.804	456.7184	91.914411
57	Biomat	1847.501	1306.946	-540.5556

Note: Production differences may not be exact due to rounding.

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IR3-23 Roberts Bank Ecosystem Model – Sensitivity Analysis: Varying Vulnerability Settings

Information Source(s)

EIS Volume 3: Section 10.3, Appendix 10-D

CEAR Doc #547

Context

The Proponent, in Appendix 10-C, identified that it is usual practice to tune Ecopath models, including the vulnerability parameters, to time series data, such as for biomass, using the temporal simulation model, Ecosim. However, these data were not available for the EwE study area, so this robust method of fitting the model and estimating vulnerability parameters was not adopted. Instead, a vulnerability setting of 2 was used as the default value for the key model runs, which is, according to the Proponent, common practice when time series data are not available and estimates of vulnerability in the model cannot be made. The model was run both with and without the proposed Project because changes in vulnerability were expected to result in changes in biomass for both scenarios. Two performance measures were then calculated for each functional group:

- the biomass ratio, expressed as functional group biomass with the Project divided by functional group biomass without the Project; and
- the absolute difference in biomass ratio between the high and low vulnerability scenarios. The biomass ratio provided an index of sensitivity to biotic factors, with a larger difference indicating higher sensitivity.

According to Fisheries and Oceans Canada, EwE models are sensitive to the vulnerability parameters, and a main pitfall of EwE models is that predation vulnerabilities are often underestimated, lessening the modelled impacts of predation.

This narrow range of 1.5-3 of vulnerability settings for the sensitivity analysis was criticized by Fisheries and Oceans Canada in initial discussions about the model with the Proponent. The Proponent subsequently reran the model with a larger range of vulnerabilities (1.1 to 10), and concluded the broader vulnerability range produced similar results for the productivity ratio with and without the Project to those in the original EIS, and that the EIS was more likely to overestimate than underestimate potential Project effects.

The data in Table 7 of CEAR Doc #547 did indicate changes in productivity ratios ranging from 0 to 50% of the defined key run (which used a vulnerability setting of 2). For example, the Proponent simultaneously changed all vulnerability settings to the same value - all were 2 or all were 10.

The vulnerability parameters resulting from Ecosim models that are fitted to data, varying by functional group, was not explored. Therefore, although the results suggest that the original

choice of 2 for the default key run may be reasonable, the potential effects of variability in vulnerability settings was not fully explored.

Information Request

Determine the effects on RB EwE model outputs from independently varying the vulnerability settings for different functional groups.

VFPA Response

For reference, in addition to the documents cited in the context (i.e. EIS Appendix 10-C and CEAR Document #547) the following RBT2 documents also evaluated variable vulnerability settings:

- Section 8.0 in Information Request #6 (IR-7.31.15-06 in CEAR Document #314[1]) – provides rationale for the selection of 2 as a default vulnerability setting and rationale for selection of 1.5 to 3.0 as part of sensitivity analyses.

The range of vulnerabilities examined for all sensitivity analyses to date has produced consistent output results, as described in EIS Appendix 10-C, 10-D, CEAR Document #314 and CEAR document #547. The consistent results, characterised by the relative insensitivity of functional groups to changes in vulnerability settings, demonstrates that the default vulnerability setting of 2 used in the EIS (i.e. combination of bottom-up and top-down controls in the RB model) is appropriate for the Roberts Bank ecosystem (for discussion, see IR-7.31.15-06 in CEAR Document #314 and CEAR Document #547, question 2.13).

As indicated in the context to this information request, functional group *specific* vulnerability settings were not previously assessed, and the Panel has requested such an assessment. The additional work undertaken for this information request, as described below, provides further evidence that model sensitivity to vulnerability has been thoroughly examined and the default vulnerability value of 2 creates a balance between model sensitivity to terminal and causeway footprint effects and creating an ecologically realistic model (i.e. combination of bottom up and top down controls).

The following response addresses the Panel's request by providing an evaluation of vulnerabilities that were scaled according to the trophic level (TL) of functional groups (Cheung et al. 2002, Ainsworth et al. 2008, Li et al. 2010). In effect, a vulnerability setting was calculated for each group using the group's TL (as described below) resulting in a group specific vulnerability value. This approach differs from sensitivity analyses undertaken previously (Section 3.1 of EIS Appendix 10-D, CEAR Document #547, question 2.13) during which vulnerability settings (set from 1.1 to 10) were the same across functional groups.

[1] CEAR Document #314 From Port Metro Vancouver to the Canadian Environmental Assessment Agency re: Completeness Review - Responses to Additional Information Requirements (See reference document #271) for the Environmental Impact Statement.

The vulnerability expresses how much a predator theoretically could increase predation mortality it causes on its prey if the predator were to increase to its carrying capacity (Christensen and Walters 2004, 2011).

In particular, under a high vulnerability scenario (e.g., vulnerability setting of 10), prey is more vulnerable to predation (e.g., in situations where prey has no access to a refuge, such as an eelgrass bed), and hence is available for consumption by a predator at all times. For example, a doubling of a predator's biomass would cause a two-fold increase in predation mortality inflicted upon the prey. Such top-down control, however, leads to rapid fluctuations of prey and predator biomasses, and a system that is further from carrying capacity (Ahrens et al. 2012, Christensen and Walters 2004, 2011).

In contrast, under a low vulnerability scenario (e.g., vulnerability setting close to 1), prey is less vulnerable to predation (e.g., in situations where prey has access to a refuge, such as an eelgrass bed) and is only partially available for consumption by a predator (e.g., when away from its hiding place). As such, low vulnerabilities are thought to represent bottom-up control, and a large change in a predator's biomass would have an unnoticeable effect on predation mortality inflicted upon the prey. Low vulnerabilities are therefore characteristic of a stable system that is close to carrying capacity (Ahrens et al. 2012, Christensen and Walters 2004, 2011).

The approach presented in this response is further discussed and explained below.

Vulnerability Factors Scaled to Functional Group Trophic Levels

Group specific vulnerabilities (V_i) were scaled linearly with TL values for each functional group based on Equation 1, below (consistent with Cheung et al. (2002), Ainsworth et al. (2008), and Li et al. (2010)). The TL values for each functional group were generated by the EwE model. Primary consumers that feed exclusively on primary producers and detritus (e.g., infaunal bivalves) had the lowest TL value for consumers (TL_i=2) and the lowest corresponding consumer group specific vulnerability (V_i=1.01), i.e., they were assumed to be close to their carrying capacity (where V_{min}=1). At the opposite end of the scale, transient killer whales as top predators were assigned the highest TL value for all functional groups (TL_{max}=5.38) corresponding to the maximum vulnerability (V_{max}=10).

Equation 1: $$V_i = (V_{max} - V_{min})(TL_i - TL_{min})/(TL_{max} - TL_{min})$$

For each functional group, the TLs and scaled group specific vulnerabilities (V_i) generated from Equation 1 are presented in **Table IR3-23-1**, along with productivity ratios estimated using scaled group specific vulnerabilities (V_i). **Table IR3-23-1** also shows productivity ratios estimated using a vulnerability setting of 2 (Table 3.2 in EIS Appendix 10-C), using a range of vulnerability settings (from 1.5 to 3) during sensitivity analyses (described in Sections 2.1 and 3.1 of EIS Appendix 10-D), and using a broader range of vulnerability settings (from 1.1 to 10) during additional sensitivity analyses (described in CEAR Document #547, question 2.13).

As shown in **Table IR3-23-1**, productivity ratios estimated using scaled group specific vulnerabilities generally fall within the range of productivity ratios identified during the RB model run presented in the EIS, as well as during sensitivity analyses conducted to

evaluate RB model robustness (see Section 3.1 of EIS Appendix 10-D and CEAR Document #547, question 2.13).

For 11 out of 58 groups, an increase in productivity ratio (between 1% and 5% above the highest productivity ratio identified during the EIS key run and corresponding sensitivity analyses; shown in bold in **Table IR3-23-1**) is noted when scaled group specific vulnerabilities are applied. For these groups, scaled group specific vulnerabilities were higher (e.g., equal to 2.78 for western sandpiper, equal to 5.61 for starry flounder, etc.; **Table IR3-23-1**) than the default vulnerability value of 2 (EIS key run). Hence, an increase in productivity ratio under a high vulnerability scenario implies that these groups are further from carrying capacity and may exert increased predatory pressure on their prey. As a result, under a high vulnerability scenario, the RB model overestimates productivity gains or underestimates productivity losses with the Project. This is particularly pronounced for dunlin, western sandpiper, and starry flounder (**Table IR3-23-1**). These results confirm that the approach taken in the EIS key run (i.e., using default vulnerability settings of 2) is conservative, as it provides a combination of bottom-up and top-down controls in the RB model and does not increase the influence of predation in the system (for discussion see IR-7.31.15-06 in CEAR Document #314, and CEAR Document #547, question 2.13).

For 2 out of 58 groups, bald eagle and Dungeness crab, a decrease in productivity ratio (2% below the lowest productivity ratio identified during the EIS key run and corresponding sensitivity analyses; shown in red bold font in **Table IR3-23-1**) is noted when scaled group specific vulnerabilities are applied. Higher vulnerability values (i.e., equal to 8.02 for bald eagle and 3.55 for Dungeness crab; **Table IR3-23-1**) imply increased predatory pressure exerted by these two groups; however, if prey productivity remains unchanged (or decreases) under the same high vulnerability scenario, increased predatory pressure cannot be sustained within the system, and predator productivity declines.

For the remaining 45 out of 58 groups, the productivity ratio fell within the range of productivity ratio outputs presented for previous vulnerability sensitivity analyses (**Table IR3-23-1**). Therefore, most functional groups show no difference in sensitivity to group specific vulnerability settings compared to the previous concurrent vulnerability setting (i.e., all vulnerability settings are adjusted concurrently) sensitivity analyses.

The difference in vulnerability settings for consumers has no impact on primary producers (productivity ratios for primary producers under high vulnerability scenario are the same as the values identified during the EIS key run and corresponding sensitivity analyses; Section 3.1 of EIS Appendix 10-D and CEAR Document #547; **Table IR3-23-1**) because primary producers are only indirectly impacted through the food web by the changed vulnerability settings.

Table IR3-23-1 Trophic Level, Scaled Group Specific Vulnerability, and Derived Estimates of Production With Project Relative to Without Project in the Run with Scaled Group Specific Vulnerabilities

No.	Functional Group	TL	Scaled Group Specific Vulnerability Input (V_i)	Productivity Ratio Outputs by Vulnerability Scenario						
				V_i	1.1	1.5	2	3	5	10
1	Baleen whales	3.66	5.42	0.94	0.91	0.91	0.92	0.93	0.95	0.97
2	Dolphins and porpoises	4.34	7.24	0.97	0.92	0.95	0.97	0.95	0.94	0.93
3	Pinnipeds	4.38	7.34	0.97	0.97	0.97	0.97	0.97	0.97	0.97
4	Southern resident killer whales	5.23	9.61	0.97	0.97	0.97	0.97	0.97	0.97	0.97
5	Transient killer whales	5.38	10.00	**0.94**	0.82	0.86	0.89	0.91	0.92	0.93
6	American wigeon	2.00	1.01	**0.94**	0.93	0.92	0.92	0.91	0.89	0.87
7	Bald eagle	4.63	8.02	**0.90**	0.97	0.94	0.93	0.94	0.94	0.92
8	Brant goose	2.00	1.01	0.96	0.96	0.95	0.95	0.94	0.92	0.90
9	Diving waterbirds	3.65	5.40	0.93	0.92	0.93	0.94	0.94	0.95	0.95
10	Dunlin	2.83	3.21	**1.17**	1.10	1.12	1.13	1.14	1.14	1.13
11	Great blue heron	4.28	7.08	1.00	0.98	0.99	1.00	1.01	1.03	1.04
12	Gulls and terns	3.96	6.24	0.96	0.97	0.98	0.99	0.99	0.99	0.96
13	Raptors	4.24	6.97	1.30	1.18	1.24	1.31	1.44	1.45	1.31
14	Shorebirds	3.33	4.55	**1.02**	0.97	0.98	0.98	0.98	0.97	0.94
15	Waterfowl	2.33	1.89	1.08	1.06	1.07	1.08	1.10	1.12	1.14
16	Western sandpiper	2.78	3.09	**1.24**	1.11	1.12	1.13	1.15	1.19	1.19
17	Chinook salmon (adult)	4.27	7.04	0.95	0.95	0.95	0.95	0.95	0.95	0.95
18	Chinook salmon (juvenile)	3.64	5.37	1.26	1.05	1.10	1.16	1.25	1.34	1.30
19	Chum salmon (adult)	3.89	6.05	0.95	0.95	0.95	0.95	0.95	0.95	0.95
20	Chum salmon (juvenile)	3.64	5.36	1.29	1.07	1.10	1.14	1.21	1.30	1.30
21	Dogfish	3.95	6.19	0.99	0.96	0.97	0.98	0.98	0.99	0.98
22	Flatfish	3.80	5.81	**1.01**	0.95	0.97	0.98	0.99	0.99	1.00
23	Forage fish	3.36	4.63	0.98	0.97	0.98	0.99	0.99	1.00	1.00
24	Herring	3.24	4.31	1.00	0.95	0.97	0.98	0.99	1.01	1.02

No.	Functional Group	TL	Scaled Group Specific Vulnerability Input (V_i)	Productivity Ratio Outputs by Vulnerability Scenario						
				V_i	1.1	1.5	2	3	5	10
25	Large demersal fish	3.77	5.73	1.04	0.93	0.96	0.99	1.02	1.06	1.08
26	Lingcod	4.27	7.04	0.92	1.44	1.14	0.97	0.93	0.92	0.90
27	Rockfish	4.20	6.87	0.90	1.32	0.99	0.91	0.90	0.90	0.90
28	Salmon (adult)	4.24	6.98	0.96	0.96	0.96	0.96	0.96	0.96	0.96
29	Salmon (juvenile)	3.66	5.42	0.98	0.97	0.97	0.97	0.97	0.98	0.98
30	Sandlance	3.08	3.89	1.14	1.00	1.03	1.06	1.11	1.21	1.44
31	Shiner perch	3.26	4.36	**1.36**	1.07	1.13	1.18	1.27	1.35	1.33
32	Skate	3.76	5.71	0.94	0.88	0.90	0.92	0.94	0.96	0.99
33	Small demersal fish	3.56	5.17	0.98	0.89	0.91	0.95	0.97	1.00	1.02
34	Starry flounder	3.73	5.61	**1.16**	0.98	1.02	1.06	1.10	1.13	1.12
35	Carnivorous zooplankton	2.82	3.19	0.87	0.90	0.90	0.89	0.88	0.87	0.82
36	Dungeness crab	2.96	3.55	**0.91**	0.93	0.94	0.97	0.98	0.97	0.93
37	Epifaunal grazers	2.19	1.51	0.91	0.89	0.91	0.92	0.93	0.94	0.92
38	Epifaunal omnivore	3.07	3.86	1.01	0.93	0.95	0.98	1.01	1.04	1.08
39	Epifauna sessile	2.39	2.05	1.20	1.11	1.16	1.19	1.28	1.08	0.71
40	Infaunal bivalves	2.00	1.01	0.90	0.90	0.92	0.92	0.92	0.92	0.92
41	Jellyfish	2.97	3.60	0.89	0.92	0.92	0.92	0.91	0.89	0.87
42	Macrofauna	2.48	2.30	1.32	1.16	1.22	1.27	1.33	1.38	1.32
43	Meiofauna	2.05	1.15	1.11	1.07	1.09	1.11	1.13	1.13	1.12
44	Omnivorous and herbivorous zooplankton	2.05	1.15	0.93	0.91	0.92	0.93	0.93	0.94	0.94
45	Polychaetes	2.61	2.63	**0.91**	0.88	0.89	0.89	0.89	0.87	0.82
46	Orange sea pen	2.57	2.52	**0.46**	0.45	0.45	0.45	0.44	0.42	0.41
47	Shrimp	2.85	3.27	**0.89**	0.87	0.86	0.87	0.88	0.87	0.87
48	Biofilm (freshwater)	1.00	-	1.89	1.89	1.89	1.89	1.89	1.89	1.89
49	Biofilm (marine)	1.00	-	0.77	0.77	0.77	0.77	0.77	0.77	0.77
50	Brown algae	1.00	-	0.88	0.88	0.88	0.88	0.88	0.88	0.88
51	Eelgrass (native)	1.00	-	1.04	1.04	1.04	1.04	1.04	1.04	1.05

No.	Functional Group	TL	Scaled Group Specific Vulnerability Input (V_i)	Productivity Ratio Outputs by Vulnerability Scenario						
				V_i	1.1	1.5	2	3	5	10
52	Green algae	1.00	-	0.92	0.91	0.91	0.92	0.92	0.92	0.91
53	Japanese eelgrass (non-native)	1.00	-	0.98	0.98	0.99	0.99	1.00	0.99	0.99
54	Red algae	1.00	-	0.89	0.89	0.90	0.90	0.90	0.89	0.89
55	Phytoplankton	1.00	-	1.04	1.04	1.04	1.03	1.01	0.99	0.98
56	Tidal marsh	1.00	-	1.25	1.25	1.25	1.25	1.25	1.25	1.25
57	Biomat	1.00	-	0.71	0.71	0.71	0.71	0.71	0.71	0.71
58	Detritus	1.00	-	1.01	1.01	1.01	1.01	1.01	1.01	1.01

Note: TL = Trophic level of functional groups.

V_i = Group specific vulnerabilities scaled linearly with TL values for each functional group based on Equation 1 (see text above).

- = V_i do not apply to primary producers and detritus.

Productivity ratio estimates in bold font fall outside the range of productivity ratios identified during the EIS key run (vulnerability setting of 2), sensitivity analyses with vulnerability settings of 1.5 and 3 (described in Section 3.1 of EIS Appendix 10-D), and sensitivity analyses with vulnerability settings of 1.1, 5 and 10 (described in CEAR Document #547, question 2.13).

In summary, implementation of scaled group specific vulnerabilities produced similar results to those described in Section 3.1 of EIS Appendix 10-D, and CEAR Document #547, question 2.13. In general, most functional groups were shown to be relatively insensitive to changes in vulnerability values, with no notable changes in RB model outputs. As described in CEAR Document #314 (Information Request #6 (IR-7.31.15-06, Section 8.0)), high vulnerability settings such as those evaluated in this response (and in sensitivity analyses described in Section 3.1 of EIS Appendix 10-D and CEAR Document #547, question 2.13) are not reflective of estimated conditions at Roberts Bank (based on the RB model structure, expert knowledge of the area, and similar local ecosystem models from the Strait of Georgia). Instead, a vulnerability setting of 2 is consistent with an ecosystem neither fully driven by production and prey availability, nor dominated by high predation (which is how the Roberts Bank ecosystem is understood to function), and is justified for the RB model.

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IR3-24 Roberts Bank Ecosystem Model - Purpose of the EwE Model

Information Source(s)

EIS Volume 3: Section 10.3, Appendix 10-B, Appendix 10-C, Appendix 10-D, Section 11.6.1.4, Section 12.6.1.5, Section 13.6.1.4

CEAR Doc #547

Context

The Proponent, in CEAR Doc #547, identified that the objective of the RB EwE model was not to provide an assessment of Project impacts for each functional group at a fine temporal scale, but to estimate changes in productive potential, with and without the Project, at the ecosystem level.

In Sections 11.6.1.4, 12.6.1.5, and 13.6.1.4 of the EIS, the Proponent identified that the Project would induce changes in biotic interactions, including changes to the abundance of predators relative to their prey, which has the potential to influence the productivity of valued components such as marine vegetation and marine invertebrates, and the various levels of trophic dependencies. The RB EwE model made explicit the relationships and interdependencies within the Roberts Bank food web, which allows qualitative predictions as to whether changes in food supply or predation rates contributed to predicted changes in the productivity of valued components.

According to Fisheries and Oceans Canada, the RB EwE model results presented were for the selected functional groups; however, no assessment of the overall potential effects of the Project on the entire Roberts Bank ecosystem was presented.

Information Request

Undertake an analysis that utilizes the results of the EwE model to understand the effects of the proposed Project on the structure and function of the entire Roberts Bank ecosystem.

VFPA Response

RBT2 will not change the structure and function of the Roberts Bank ecosystem as explained below.

In response to this information request, which contains new information (not presented in the EIS or in responses to previous information requests), ecosystem structure and function are defined as follows (based on concepts used to describe ecosystem development by Odum (1969)):

- Ecosystem structure relates to the structural components depicted in an ecosystem model as functional groups, which are positioned vertically within a food web based on

their trophic level (TL). Each functional group's TL is calculated by Ecopath using information on the group's diet composition and the following equation (Pauly et al. 1995, 1998; Christensen et al. 2005):

$$TL_j = 1 + \sum_i DC_{ij} * TL_i ,$$

where the TL of a predator *j* is equal to the sum of the TLs of its prey *i* multiplied by the relative contribution (DC_{ij}) of prey *i* in the diet of predator *j*, plus 1. For example:

- Primary producers and detritus have a TL of 1.
- A functional group that feeds on primary producers has a TL of 2.
- A functional group that feeds 50% on a group with TL=2 and 50% on primary producers (TL=1) has a TL of [(2*0.5)+(1*0.5)]+1=2.5.

- Ecosystem function relates to the flow of energy and cycling of materials (i.e., by means of consumption, respiration, export, flow to detritus) through the ecosystem's structural components (i.e., functional groups). In Ecopath, flow of energy is graphically depicted in a flow diagram using lines that connect the functional groups; these lines are derived using information on the diet preference of functional groups and hence represent predator-prey linkages (Christensen et al. 2005).

Ecosystem Structure and Function Changes with RBT2

The Roberts Bank ecosystem without RBT2 is depicted in Figure IR3-24-A1 in **Appendix IR3-24-A** (also presented as Figure 2-6 in EIS Appendix 10-C). The Roberts Bank ecosystem model (RB model) incorporated 58 functional groups, including 25 focal species (additional information on the selection of functional groups, including focal species, for RB model construction is provided in the Preamble at the beginning of this response package, EIS Section 10.0, and EIS Appendix 10-B).

As shown in Figure IR3-24-A1 (**Appendix IR3-24-A**), the largest proportion of biomass (96% of total system biomass[1]) within the food web of the Roberts Bank ecosystem is allocated among functional groups with TLs lower than 3, including primary producers and primary consumers (such as benthic invertebrates and zooplankton). This is characteristic of a highly productive system where nutrients become available to benthic marine plants and nearshore phytoplankton and make their way up the food web to consumers through bottom-up processes.

[1] This value, calculated as the sum of the biomass of functional groups with TLs lower than 3 over the total Roberts Bank system biomass, is presented in the response to this information request for the first time.

The food web of the Roberts Bank ecosystem with the Project was also modelled using Ecopath and is depicted in Figure IR3-24-A2 in **Appendix IR3-24-A**. The food web structure of the Roberts Bank ecosystem remains unchanged and comprises the same 58 functional groups as without RBT2 (in other words, no functional groups are lost as a result of RBT2 within the ecosystem).

As shown in Figure IR3-24-A2 (**Appendix IR3-24-A**), with RBT2, and similar to the without Project scenario, the largest proportion of biomass (also equal to 96% of total system biomass) within the food web of the Roberts Bank ecosystem is allocated among functional groups with TLs<3, including primary producers and primary consumers.

Biomass changes (with/without RBT2, reported in decimals) for each functional group within the Roberts Bank food web are shown in Figure IR3-24-A3 in **Appendix IR3-24-A**. Percent increases are shown in a green shading gradient transitioning from light green (representing minor (6% to 30%) increases) to dark green (representing moderate (>30%) increases). Percent decreases are shown in a blue shading gradient transitioning from light blue (representing minor (-6% to -30%) decreases) to dark blue (representing moderate (<-30%) decreases). Negligible (-5% to 5%) to no changes in biomass are shown in white. Information on significance criteria, including definition for negligible, minor, and moderate change, is provided in Information Request #7 (IR-7.31.15-07 in CEAR Document #314[2]). The size of the circles is proportional to the amount of biomass change (with/without RBT2).

As shown in Figure IR3-24-A3 (in **Appendix IR3-24-A**), for 24 functional groups, percent biomass change is below 5%, which is considered negligible as it is within the margin of error of the RB model and therefore not considered detectable or measurable. Minor biomass changes (6% to 30%; considered to be within the range of natural ecosystem variability) are noted for 30 functional groups. A moderate (i.e., considered to be beyond the range of natural ecosystem variability) decrease is noted for orange sea pens, while a moderate increase is noted for raptors and freshwater biofilm[3]. Biomass changes are also discussed in EIS Appendix 10-C. Overall, the RB model shows that biomass decreases in higher TLs (e.g., skate, diving waterbirds) are counterbalanced by biomass increases in primary producers and primary consumers (e.g., macrofauna, zooplankton), also indirectly resulting in some increases in upper TL predators (e.g., raptors) through mixed trophic interactions (see Section 3.2 of EIS Appendix 10-C).

The mean TL of the Roberts Bank ecosystem community (mTLco) was also compared with and without the Project to investigate potential changes in the structure of the Roberts Bank

[2] CEAR Document #314 From Port Metro Vancouver to the Canadian Environmental Assessment Agency re: Completeness Review - Responses to Additional Information Requirements (See reference document #271) for the Environmental Impact Statement.
[3] Biofilm is a microphytobenthos assemblage comprising primarily diatoms, with a small proportion of cyanobacteria. At Roberts Bank, two distinct biofilm communities exist, one with composition influenced by freshwater conditions, and one with composition influenced by brackish-marine conditions (see EIS Section 11.0 and Section 6.3 of EIS Appendix 10-B).

ecosystem with RBT2. This information is presented here for the first time. The mTLco is an ecological indicator calculated using the following equation (Heymans et al. 2014):

$$mTLco = \frac{\sum_i TL_i * B_i}{\sum_i B_i},$$

where the average TL of a functional group *i* with TL≥2 (i.e., excluding primary producers) is weighted by the group's biomass (B_i) (Heymans et al. 2014). Primary producers (i.e., groups with TL=1) are excluded from the analysis to reduce variability in biomass and production characterising low TL groups (Heymans et al. 2014). The mTLco of the Roberts Bank ecosystem community is equal to the following:

- 2.348 without RBT2; and
- 2.309 with RBT2.

A slight reduction in mTLco with the Project is the result of some biomass decreases in higher TLs counterbalanced by biomass increases in primary producers and primary consumers, as described above and shown in Figure IR3-24-A3 (**Appendix IR3-24-A**). With the Project, the Roberts Bank ecosystem remains a highly productive system with prevailing bottom-up processes, and characterised by biomass accumulations within lower TL (TL<3) groups. It is therefore concluded that the Project will not change the structure and function of the Roberts Bank ecosystem.

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Appendices

Appendix IR3-24-A Supporting Figures

APPENDIX IR3-24-A
SUPPORTING FIGURES

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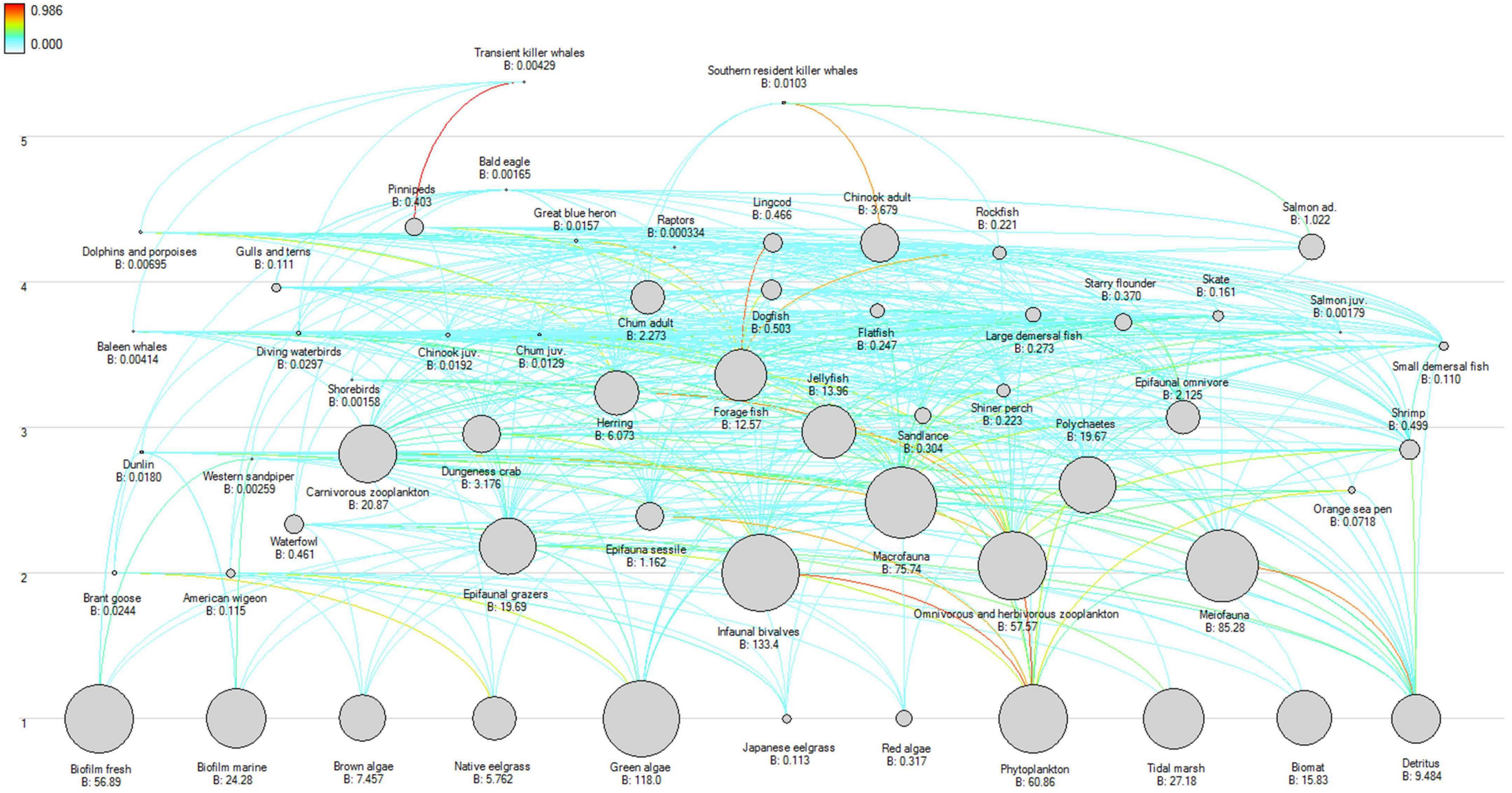
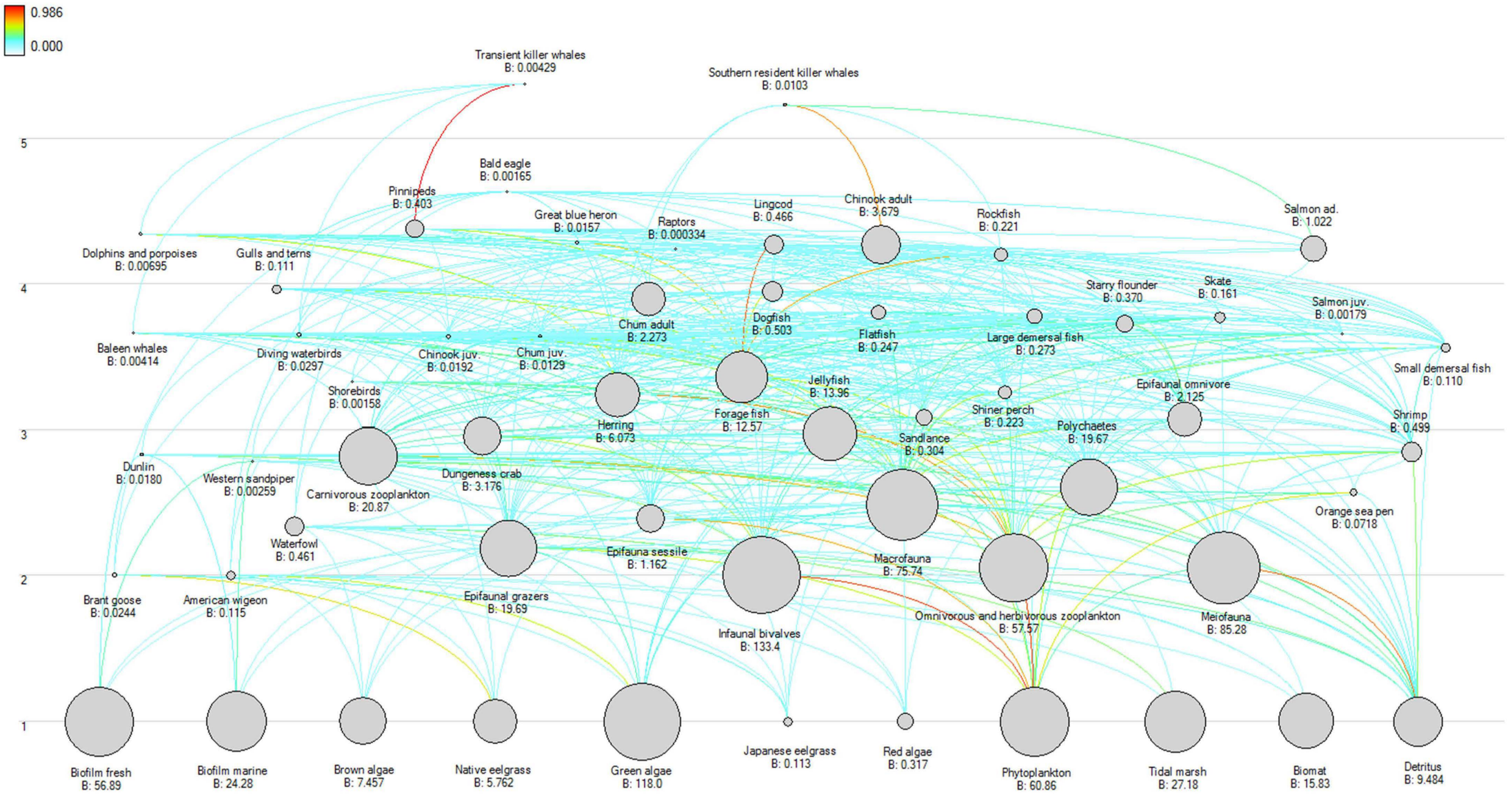
Figure IR3-24-A1 Representation of the Food Web in the Roberts Bank Ecosystem Model Without the Project



Note: B = Biomass (in tonnes per square kilometre (t/km^2)).

Functional groups are arranged by trophic level (y axis), with primary producers and detritus at trophic level 1, and consumers at increasing trophic levels depending on their diets. The size of the circles is proportional to the biomass of each functional group. The colour of the lines indicates interaction strength between groups based on their diets, with strength ranging from 0 (white, indicating no predator-prey interaction) to 1 (red, indicating prey group contributes to the diet of a predator group by 100%). Line strength reflects diet preference of predator groups described in Appendix A of EIS Appendix 10-B, and has no units. This figure is equivalent to Figure 2-6 of EIS Appendix 10-C.

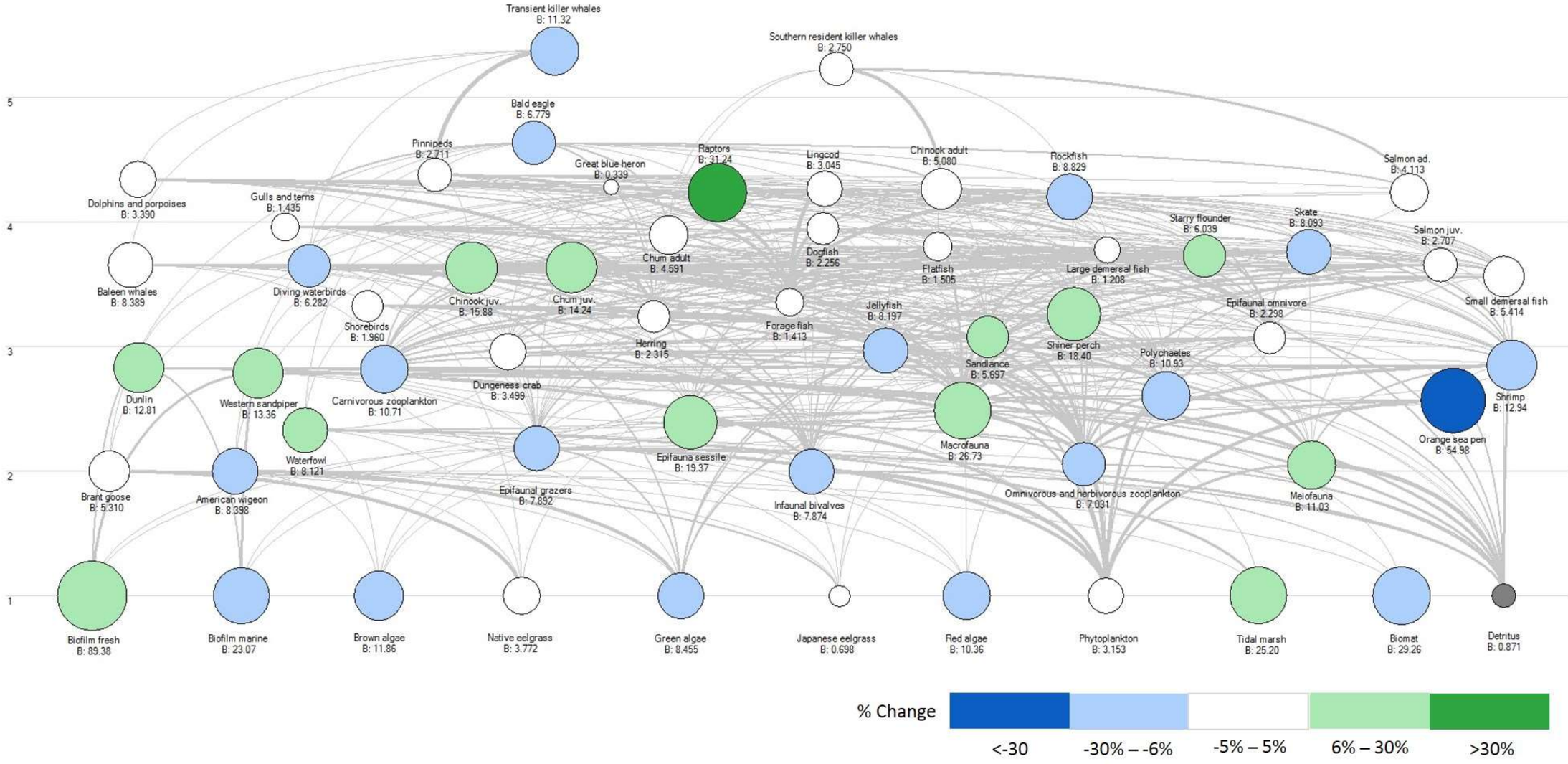
Figure IR3-24-A2 Representation of the Food Web in the Roberts Bank Ecosystem Model With the Project



Note: B = Biomass (in t/km^2).

Functional groups are arranged by trophic level (y axis), with primary producers and detritus at trophic level 1, and consumers at increasing trophic levels depending on their diets. The size of the circles is proportional to the biomass of each functional group. The colour of the lines indicates interaction strength between groups based on their diets, with strength ranging from 0 (white, indicating no predator-prey interaction) to 1 (red, indicating prey group contributes to the diet of a predator group by 100%). Line strength reflects diet preference of predator groups described in Appendix A of EIS Appendix 10-B, and has no units. This figure is new, not previously presented in the EIS or other information request responses.

Figure IR3-24-A3 Biomass Changes (%) With/Without the Project within the Food Web of the Roberts Bank Ecosystem



Note: B = % Biomass change with/without the Project.

Functional groups are arranged by trophic level (y axis), with primary producers and detritus at trophic level 1, and consumers at increasing trophic levels depending on their diets. The size of the circles is proportional to biomass change with/without the Project for each functional group. Biomass increases are shown with a shading gradient transitioning from light green (representing minor (6% to 30%) increases) to dark green (representing moderate (>30%) increases). Biomass decreases are shown with a shading gradient transitioning from light blue (representing minor (-6% to -30%) decreases) to dark blue (representing moderate (<-30%) decreases). Negligible (-5% to 5%) to no biomass changes are shown in white. Detritus is not considered in the biomass calculations as it is a non-living group that incorporates the ecosystem's unassimilated food.

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PART 2

GENERAL INFORMATION REQUESTS (IR3-25 TO IR3-46)

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Information Request Package 3 Preamble in Support of Responses to IR3-25 to IR3-40 – General and Disposal at Sea-related Project Construction Update

Introduction

The Vancouver Fraser Port Authority (VFPA) has continued to engage with Aboriginal groups, local stakeholders, and regulatory agencies following submission of the environmental impact statement (EIS) to discuss issues or concerns related to Project construction activities and potential Project-related effects, amongst others. To provide context and clarity in support of the VFPA's responses to information requests IR3-25 through IR3-40, updates to proposed Project construction activities are provided below.

Tsawwassen First Nation (TFN), along with other Aboriginal groups, have expressed concern over the Project's proposed intermediate transfer pit (ITP) and disposal at sea (DAS) activities. Further, Environment and Climate Change Canada (ECCC) outlined specific observations on proposed Project activities that may be subject to DAS permitting (see CEAR Document #564[1]), including key details that would be required to determine applicable regulatory requirements under the *Canadian Environmental Protection Act, 1999*.

The following Project construction activities, which were assessed for intermediate and valued components in the EIS, were identified as being subject to DAS permitting either in EIS Section 4.0 or subsequently by ECCC (see CEAR Document #564):

- Use of the ITP;
- Management of silty 'fallout' material from the vibro-replacement process in the dredge basin;
- Disposal of dredged material from the tug basin expansion; and
- Disposal of supernatant (containing unsettled fines from fill material) from the terminal containment dykes.

In response to feedback from Aboriginal groups, local stakeholders, and regulatory agencies, as well as information requests from the Panel, the VFPA has been working to optimise the design of the Project and update construction activities relevant to dredgeate handling and potential DAS regulatory requirements. As a result, a DAS permit is no longer anticipated to be required for Project construction. The key changes relevant to this conclusion are described below for each of the four Project construction activities identified above.

[1] CEAR Document #564 From Environment and Climate Change Canada to the Review Panel re: Comments on the information relating to the environmental assessment of the Roberts Bank Terminal 2 Project.

Intermediate Transfer Pit

During RBT2 Aboriginal consultation undertaken prior to and following the submission of the EIS, concerns that were raised by Aboriginal groups in relation to Project construction activities, and later specific to the ITP, included the potential for the Project to affect crab populations and crab health, the exercise of Aboriginal/treaty harvesting rights (i.e., crabbing), and access within the Project area.

Tsawwassen First Nation (TFN) noted the Project area is a productive area for TFN fishers and is actively harvested. TFN also stated that they were of the view that there would be a detectable effect to TFN's crab harvesting for traditional purposes in or near the Project area as a result of potential Project-related changes in access during the construction phase of the Project. TFN noted effects would be felt by TFN in ways distinct from others. The VFPA considered these concerns, and have deemed the ITP to no longer be required as a temporary storage location to support construction of the Project for the reasons explained below.

As background, the purpose of the ITP was to provide storage for Fraser River sand during the first year of construction while the perimeter dykes of the terminal were being built and as a site for receiving sand from the bottom dump hopper dredge throughout land development activities. During the development of the EIS, it was assumed that only locally available Canadian-registered dredging equipment would be available for the Project (EIS Sections 4.3.1 and 4.4.1.8). This assumption was based on restrictions outlined in the *Coasting Trade Act,* which limit the use of foreign ships in Canadian waters. At the time of construction schedule planning, a dredging vessel with a hopper and pump-ashore capability was not available locally (as explained in IR1-11 in CEAR Document #897[2]). As a result, the ITP was incorporated as a temporary Project component for receiving and storing Fraser River sand obtained from the annual Fraser River maintenance dredging program (with subsequent reclamation of material for use as fill material)..

Alternatives to underwater storage at the ITP have been investigated, including the storage of Fraser River sand on land (as described in IR1-10 in CEAR Document #897), importing more sand from existing quarries[3], and revising the Project construction schedule. Of these three options, importing sand from existing quarries and revising the Project construction schedule were deemed as viable alternatives to sand storage in the ITP.

Further, since completion of the preliminary construction schedule (presented in EIS Section 4.0), the local contractor Fraser River Pile & Dredge Inc. (FRPD) acquired a trailing arm suction hopper dredge with pump-ashore capability (*FRPD309*) in 2013, as outlined in EIS Section 4.4.1.8 and IR1-11 in CEAR Document #897. The *FRPD309* has been performing the annual maintenance dredging and pumping ashore as required, and with its proven capability, the VFPA has revised the Project construction sequence to incorporate the

[2] CEAR Document #897 From the Vancouver Fraser Port Authority to the Review Panel re: Responses to Information Request Package 1 (See Reference Document #559).
[3] Sand from other additional sources would not require temporary storage as material would be delivered directly to the Project site when needed.

discharge of Fraser River sand directly into fill areas, eliminating the need for storage in the ITP.

In addition, the constraints associated with the *Coasting Trade Act* regarding use of foreign dredging equipment in Canadian waters for marine activities of a commercial nature have been relaxed with the approval of the Canadian European Trade Agreement (CETA) in early 2017. The CETA enables European dredging equipment to work on the Project, thereby providing an alternative to the *FRPD309*, if needed (refer to IR1-09 in CEAR Document #897 for more information).

Through recent changes in dredging equipment options and further engineering analyses, and in consideration of the concerns of the TFN with respect to the ITP, Project construction no longer requires the ITP as a temporary sand storage location to support construction activities. This change addresses concerns with respect to the effects of the ITP on crab habitat and harvesting in particular.

Silty Fallout from Vibro-replacement at the Dredge Basin

The creation of the silty fallout material from the vibro-replacement process, and subsequent collection and disposal activities of fallout material, are no longer associated with or required for Project construction, for the reasons provided below.

As background, the conceptual wharf structure design described in EIS Section 4.2.1.2 was informed by geotechnical analyses of inferred ground conditions within the Project footprint and an overly conservative assessment of seismic requirements. Based on these, at the time of preliminary design, both vibro-densification and vibro-replacement processes[4] were incorporated as soil improvement techniques within the construction sequence (see EIS Section 4.4.1.9 for more information). The VFPA proposed to collect fallout material resulting from the vibro-replacement process within the dredge basin with a cutter-suction dredge, pump it into the terminal containment basins, and subsequently discharge supernatant containing unsettled fines to DAS locations situated at the -45 m chart datum (CD) level seaward from the terminal (subject to ECCC's DAS permit requirements).

Further geotechnical analysis has been completed using data obtained in 2016 from the in situ and laboratory testing of ground conditions within the terminal footprint. Native soil beneath the terminal footprint has been determined to have a more favourable seismic response than was initially inferred. In addition, seismic performance requirements from the American Society of Civil Engineers (Standards ASCE/COPRI 61-14, Seismic Design of Piers and Wharves) were adopted in 2016 for all non-public marine structures within the Port of Vancouver. This ASCE/COPRI 61-14 standard had previously been adopted for wharves not

[4] The vibro-replacement process is a technique for subsoil improvement that utilises special depth vibrators and coarse material to replace finer material (e.g., clay and sand) with the coarser material. In contrast, vibro-densification also uses a depth vibrator, but it densifies in situ material and is not considered a material replacement technique. As a point of clarification, silty fallout is associated with the vibro-replacement technique, not the vibro-densification technique.

accessible to the general public by many U.S. west coast ports (e.g., US Navy, Port of Los Angeles, and Port of Long Beach).

With the improved understanding of the seismic response of the material within the terminal footprint, along with the adoption of the ASCE/COPRI 61-14 standard, vibro-replacement activities are no longer required to improve the seismic response of the soil below the base of the dredge basin. Therefore, the creation of the silty fallout and its associated disposal requirement are no longer part of Project construction.

Tug Basin Dredgeate

Disposal of tug basin dredgeate to the Project-specific DAS site via a dumping barge is no longer being considered, as outlined below.

The original construction program for the management of material dredged from the tug basin (outlined in EIS Section 4.4.1.18) included an option to dispose of dredgeate material via direct barge dumping to the DAS site. Although the preference is to re-use the material for general fill for terminal development or causeway widening, this option was proposed should the quality of the material be unsuitable for construction purposes or the timing be unacceptable for use of the material as fill.

Based on further evaluation of the physical and chemical characteristics of sediment within the tug basin footprint in 2016, the tug basin dredgeate material is considered suitable for use as general fill for terminal development or causeway widening. Disposal of tug basin dredgeate to a DAS site, therefore, is no longer being considered as a construction activity alternative.

Supernatant Discharge Area

Based on information provided by ECCC (CEAR Document #564), discharge of supernatant containing unsettled fines from the containment dykes during filling is not expected to be subject to DAS permitting, for the reason explained below.

Fill materials sourced from the Fraser River and dredging of the dredge and tug basins will be deposited as a slurry to containment basins to settle, and supernatant containing unsettled fines will be discharged to Roberts Bank via a pipeline, with the outfall of the pipeline anticipated to be located at -45 m CD level.

The discharge of supernatant associated with use of material for construction purposes is not expected to require DAS permitting, as outlined by ECCC in CEAR document #564, provided that the VFPA confirms that 1) the dredged material has the physical and chemical characteristics required for construction purposes; and 2) the use of the dredged material for construction purposes including any resulting release of a supernatant must not be contrary to the purposes of Division 3 Part 7 of the *Canadian Environmental Protection Act, 1999* and the aims of the London Convention and Protocol. The VFPA confirms that all fill materials can be used for construction purposes and that the proposed work can be carried out in a manner that does not create marine pollution. Therefore, the VFPA no longer anticipates that

discharge of supernatant will require a DAS permit, and the location of supernatant discharge (formerly referred to as the candidate DAS area), will now be referred to as the discharge area in responses provided in this information request package and subsequent correspondence.

Details pertaining to the management of sediment and water will be addressed during the development of the Dredging and Sediment Discharge Plan prior to the start of construction activities (should the Project be approved), as outlined in EIS Section 33.3.10. The VFPA committed to the development of this plan to mitigate potential Project-related effects on water and sediment quality. The plan will describe the management and timing of dredging activities and the discharge of sediment-laden water.

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IR3-25 Surficial Geology and Marine Sediment – Contaminant Levels in Sediment: Profiles

Information Source(s)

EIS Volume 1: Section 4.2

EIS Volume 2: Section 9.6, Appendix. 9.6-B

Context

As stated by the Proponent in the EIS, changes in sediment contaminant concentrations are not expected, as sediments that will be re-suspended and deposited as a result of construction phase activities will not be contaminated. The assessment of sediment contamination was based on the following sediment sampling depths:

- for the dredge basin and tug basin areas: surface to depths of 2m; and
- for the Intermediate Transfer Pit (ITP), Fraser River, and candidate Disposal at Sea (DAS) areas: surface only.

For some contaminants, such as copper and polychlorinated biphenyls (PCBs), concentrations varied with the depth of sediments. However, there is no information on contaminant concentrations provided at the depths where sediment would be mobilized for various construction phase activities. For example, according to Section 4.2, the dredge basin is to be dredged to a depth of -30 m CD (20 m below existing seabed), but samples were only collected at the surface to a depth of 2 m. In consideration of the Proponent's proposal to carry out dredging in the berth pocket and the tug basin, loading and unloading of the ITP, and the reuse of certain materials for Project construction, the vertical profile of the contaminants in the sediment from areas which will be mobilized is required.

Information Request

Determine the values for all parameters outlined in Table 9.6-4 of Section 9.6 of the EIS for the dredge basin, tug basin and ITP as a function of depth, down to the depth that the sediments will be mobilized (i.e. through dredging or other means) and compare these to applicable standards. Present the results in tables that clearly identify the depth of sample, sample size, and the mean, minimum, maximum, and standard deviation for contaminant concentrations for each of the locations requested.

For samples where metals, polycyclic aromatic hydrocarbons (PAHs), and PCBs are detected, provide figures similar to that of Figure 5-9 of Appendix 9.6-B that display the vertical distribution of the parameters sampled in part 1 of this information request and describe any trends in the vertical distribution.

Provide a map that indicates sampling locations.

VFPA Response

This response provides the requested information for the dredge basin and tug basin areas. Information for the intermediate transfer pit (ITP) is not provided, as the ITP is no longer proposed for use as a temporary Fraser River sand storage site, as outlined in the Preamble at the beginning of this response package.

As background, the characterisation of surficial geology and marine sediment contamination provided in EIS Section 9.6 focused on sediments that could potentially be influenced by historic anthropogenic contaminant inputs. Based on radioisotopic (210Pb) age dating of sediments collected in vibracores from the dredge basin and estimates of annual sedimentation rates in the Fraser River estuary from other studies, sediment deposits deeper than 1 m to 2 m generally predate the era of polychlorinated biphenyl (PCB) production, which began in the 1930s (EIS Appendix 9.6-B), and it is assumed that sediments below 2 m depth from seabed are not influenced by anthropogenic contaminants. Therefore, sediments in the upper 2 m of the dredge basin and tug basin areas were the focus of the descriptions provided in EIS Section 9.6, as they were most likely to contain contaminants.

Subsequent to the analyses of sub-surface sediments collected in 2011 for the dredge basin, and surface and sub-surface sediments collected in 2013 for the dredge basin and tug basin areas, deeper sediments were collected and analysed from both areas in fall 2016 to characterise sediments within and beyond the extent of the areas to be dredged (i.e., dredge prisms)[1]. Figures IR3-25-A1 and IR3-25-A2 in **Appendix IR3-25-A** illustrate sampling locations within the dredge basin and tug basin areas for the three campaigns.

For the dredge basin dredge prism (dredging from the surface of the seabed to a maximum depth of -26.7 m chart datum (CD)), particle size density (i.e., percent sand, silt, and clay), percent total organic carbon (TOC), and concentrations in micrograms per gram dry weight (µg/g) of metals (i.e., arsenic, cadmium, copper, chromium, lead, mercury, and zinc concentrations), total polyaromatic hydrocarbons (PAHs), and total PCBs from sediment samples collected in 2011, 2013, and 2016, as well as applicable analytical detections limits, are provided Table IR3-25-B1 in **Appendix IR3-25-B**.

For the tug basin area, including the dredge prisms of the existing tug basin and tug basin expansion areas (dredging from the surface of the seabed to a maximum depth of -6.5 m CD), Tables IR3-25-B2 and IR3-25-B3 in **Appendix IR3-25-B** provide the requested parameters for sediment samples collected in 2013 for the tug basin expansion area and 2016 for both areas.

[1] Sediment sampling information and results for the 2011, 2013, and 2016 campaigns are detailed in Hemmera 2011, EIS Appendix 9.6-B, and Hemmera 2017, respectively. The specific objectives and scope of each campaign varied; however, all sample collection and analytical methodologies were conducted in accordance with best practices. The earlier sampling campaigns focussed on establishing existing conditions in surface and sub-surface sediments to characterise physical parameters, metal concentrations, and contaminant levels (e.g., PCBs), and the most recent sampling campaign in 2016 focused on characterising at-depth sediments within and beyond the extent of the dredging at the dredge basin (dredging depth to -26.7 m CD) and tug basin (dredging depth to -6.5 m CD) areas.

Table IR3-25-1 provides summary statistics for the sampling campaigns conducted in the dredge basin and tug basin areas, including the number of samples collected[2], mean, minimum, and maximum concentrations, plus standard deviation. Comparisons of parameter concentrations are provided, as applicable, to the Environment and Climate Change Canada (ECCC) Disposal at Sea Regulations Lower Level (DAS LL) concentrations and the Canadian Council of Ministers of the Environment (CCME) Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, including the Interim Marine Sediment Quality Guidelines (ISQGs) and the Probable Effects Levels (PELs). Exceedances are shown in bold text.

Table IR3-25-1 Dredge Basin and Tug Basin Sediment Characterisation – Summary Statistics for 2011, 2013, and 2016 Sampling Campaigns

Parameter	Screening Criteria[a]			Dredge Basin Area	Tug Basin Expansion Area	Existing Tug Basin
	DAS LL	CCME ISQG	CCME PEL			
Sand (percent)						
No. of samples				107	51	6
Minimum				0.3	14.3	92.4
Mean				62.8	63.3	94.6
Maximum				95.5	94.4	96.5
Standard Deviation				24.0	27.2	1.5
Silt (percent)						
No. of samples				107	51	6
Minimum				2.8	4.6	2.2
Mean				29.4	29.6	3.3
Maximum				73.4	68.9	4.8
Standard Deviation				18.5	21.9	0.9
Clay (percent)						
No. of samples				107	51	6
Minimum				1.2	1.1	1.1
Mean				7.8	7.2*	1.3
Maximum				28.8	22.5	1.5
Standard Deviation				5.9	5.6	0.1
TOC (percent)						
No. of samples				102	53	6
Minimum				0.1	0.1	0.1
Mean				0.8	0.5	0.2

[2] The distribution of sample depths at each location are shown in the vertical profiles provided in **Appendix IR3-25-A**: Figures IR3-25-A3 to IR3-25-A18.

Parameter	Screening Criteria[a]			Dredge Basin Area	Tug Basin Expansion Area	Existing Tug Basin
	DAS LL	CCME ISQG	CCME PEL			
Maximum				4.8	2.3	0.2
Standard Deviation				0.7	0.44	0.05
Arsenic (µg/g)		7.24	41.6			
No. of samples				79	40	6
Minimum				2.77	2.18	3.37
Mean				5.10	5.27	3.72
Maximum				**7.99**	**10.9**	4.21
Standard Deviation				1.24	2.29	0.29
Cadmium (µg/g)	0.6	0.7	4.2			
No. of samples				79	40	6
Minimum				0.05	0.05	0.05
Mean				0.18*	0.14*	0.06*
Maximum				**0.67**	0.48	0.07
Standard Deviation				0.12*	0.11*	0.01*
Copper (µg/g)		18.7	108			
No. of samples				79	40	6
Minimum				11.4	11.9	10.4
Mean				**21.9**	18.3	11.8
Maximum				**45.8**	**31.9**	14.6
Standard Deviation				7.6	5.73	1.76
Chromium (µg/g)		52.3	160			
No. of samples				79	40	6
Minimum				21.3	27.2	22.4
Mean				34.5	33.6	25.7
Maximum				**54.0**	43.0	28.9
Standard Deviation				5.7	3.94	2.77
Lead (µg/g)		30.2	112			
No. of samples				79	40	6
Minimum				2.5	2.2	2.1
Mean				4.4	4.1	2.3
Maximum				11.6	6.7	2.7
Standard Deviation				1.5	1.59	0.21
Mercury (µg/g)	0.75	0.13	0.70			
No. of samples				79	40	6

Parameter	Screening Criteria[a]			Dredge Basin Area	Tug Basin Expansion Area	Existing Tug Basin
	DAS LL	CCME ISQG	CCME PEL			
Minimum				0.015	0.014	0.016
Mean				0.037*	0.031	0.018
Maximum				**0.149**	0.095	0.022
Standard Deviation				0.02*	0.016	0.002
Zinc (µg/g)		124	271			
No. of samples				79	40	6
Minimum				36.1	33.9	35.1
Mean				52.8	47.4	36.1
Maximum				89.5	68.6	38.2
Standard Deviation				11.7	9.53	1.2
Total PAHs (µg/g)	2.5					
No. of samples				79	40	6
Minimum				<DL	<DL	<DL
Mean				<DL*	<DL*	<DL*
Maximum				**6.87**	<DL	<DL
Standard Deviation				N/A*	N/A*	N/A*
Total PCBs (µg/g)	0.1	0.0215	0.189			
No. of samples				102	53	6
Minimum				0	0	<DL
Mean				0.000020*	0.000125*	<DL*
Maximum				0.000045	0.000655	<DL
Standard Deviation				0.000014*	0.000206*	N/A*

Notes: a. Disposal at Sea Regulations Lower Level (DAS LL) concentrations as per Section 4 of the *Disposal at Sea Regulations*. Interim Marine Sediment Quality Guidelines (CCME ISQG) and Probable Effects Levels (CCME PEL) as per Canadian Council of the Ministers of the Environment Sediment Quality Guidelines for the Protection of Aquatic Life. Exceedances of these concentrations are shown in **bold** text.

* = Denotes that summary information does not include samples whose concentrations were less than the analytical detection limits.

< DL = less than the laboratory analytical detection limit.

N/A = not applicable, as statistic could not be calculated based on sample concentrations being less than the analytical detection limit.

Comparison of Sediment Concentrations to Applicable Criteria and Trends in Vertical Distribution

Dredge Basin

Over the vertical profile of the dredge basin dredge prism across the three sampling campaigns, 79 samples were analysed for metals and total PAHs and 102 samples were analysed for total PCBs. Of the 79 samples analysed for metals, exceedances of DAS LL or CCME ISQG criteria were observed for arsenic, cadmium, chromium, copper, and mercury, outlined as follows:

- Sample VC8-f collected at a depth of approximately 0.275 m below seabed had a cadmium level 0.67 µg/g, which exceeds the DAS LL criterion for cadmium of 0.6 µg/g;
- Sample BH16-53-03 collected at a depth of approximately 2 m below the seabed had a chromium level of 54 µg/g, which exceeds the CCME ISQG for chromium of 52.3 µg/g;
- Sample BH16-38-12 at a depth of approximately 24.8 m below seabed had a mercury level of 0.149 µg/g, which exceeds the CCME ISQG for mercury of 0.13 µg/g; and
- Five samples tested for arsenic and 45 samples tested for copper from various depths exceed their respective CCME ISQGs (see **Appendix IR3-25-B: Table IR3-25-B1** for specific sample depths and concentrations). Copper routinely exceeds the CCME ISQG in sediments entrained in the Fraser River and deposited on the delta due to naturally (i.e., of geologic origin) elevated concentrations of copper in the broader geographic area.

The elevated concentrations of these five parameters in the samples listed above were generally at a similar concentration to their respective CCME ISQG or DAS LL concentrations. No samples had parameter concentrations that approached or exceeded their respective CCME PEL concentrations.

Of the 79 samples analysed for total PAHs, sample BH16-43-01 collected from a depth of 0.5 m below seabed had a total PAH concentration of 6.87 µg/g, which exceeds the DAS LL criterion of 2.5 µg/g. This was the only exceedance for total PAHs, and all other samples had total PAH concentrations below the analytical detection limit. The elevated total PAH result for BH16-43-01 is highly localised, and likely reflects relict coal particulates associated with an accidental release of coal or deposition of coal dust from past Westshore Terminals operations, due to the proximity to this terminal (see Figure IR3-25-A1 in **Appendix IR3-25-A** for sample location).

Of the 102 samples analysed for total PCBs, no samples exceed the DAS LL, CCME ISQG, or CCME PEL criteria.

The vertical distributions of metal and total PCB concentrations within the dredge basin dredge prism are provided in Figures IR3-25-A3 to IR3-25-A10 in **Appendix IR3-25-A**[3]. The vertical

[3] For all vertical profile figures provided in **Appendix IR3-25-A**, samples whose concentrations were less than the analytical detection limits were graphed at the analytical detection limit.

profile of total PAHs is not provided as all samples except for one (sample BH16-43-01) exhibited a total PAH concentration lower than the detection limit.

To evaluate vertical concentration trends in sediments from the dredge basin, a linear regression was calculated for the concentration of each metal and total PCBs[4] in relation to depth of the sediment sample from the sediment surface. The results are summarised in **Table IR3-25-2**. A statistically significant linear relationship (α < 0.05) between sediment concentration and depth was observed for PCBs (p = 0.019) and cadmium (p=0.007), noting that a negative slope indicates a statistically significant decreasing concentration with depth below sediment surface.

Table IR3-25-2 Dredge Basin Area – Linear Regression Results for Metals and Total PCB Concentrations Relative to Sample Depth

Parameter	Number of Samples	p-value	Statistical Significance?	Slope	Intercept
Arsenic	79	0.32	No	-	-
Cadmium	79	0.007	Yes	-0.0056	0.21
Chromium	79	0.12	No	-	-
Copper	79	0.093	No	-	-
Lead	79	0.18	No	-	-
Mercury	79	0.76	No	-	-
Nickle	79	0.081	No	-	-
Zinc	79	0.088	No	-	-
Total PCBs	31	0.019	Yes	-0.0000061	0.000029

Tug Basin Expansion Area

Over the vertical profile of the tug basin expansion area dredge prism across the 2013 and 2016 campaigns, 40 samples were analysed for metals and total PAHs and 53 samples were analysed for total PCBs.

Of the 40 samples analysed for metals, exceedances of CCME ISQGs were observed for arsenic and copper in 10 samples and 15 samples, respectively (see **Appendix IR3-25-B**: Table IR3-25-B2 for specific sample depths and concentrations). As mentioned above, copper routinely exceeds the CCME ISQG concentration due to naturally elevated concentrations of copper in the broader geographic area. The elevated concentrations for arsenic and copper were generally at similar concentrations to their respective CCME ISQG. All samples analysed for total PAHs had concentrations below the analytical detection limit, noting that the detection limit was below the DAS LL criterion. Of the 53 samples analysed for total PCBs, no

[4] For PCBs, linear regressions were performed only on samples analysed for PCB congeners using highly sensitive analytical techniques, as all PCB aroclor results were below the detection limit. The sum of PCB congeners is equivalent to total PCBs.

sample exceeded the DAS LL or CCME ISQG criteria. No samples from the tug basin had parameter concentrations that approached or exceeded their respective CCME PEL concentrations.

The vertical distributions of metal and total PCB concentrations over the vertical profile of the tug basin expansion area dredge prism is provided in Figures IR3-25-A11 to IR3-25-A18 in **Appendix IR3-25-A**. The vertical profile of total PAHs is not included as all samples exhibited total PAH concentrations that were lower than the analytical detection limit.

As for the dredge basin, a linear regression was calculated to evaluate vertical concentration trends of metals and total PCBs[5] in sediments from the tug basin expansion area. The results are summarised in **Table IR3-25-3**. A statistically significant linear relationship ($\alpha < 0.05$) between sediment concentration and depth was observed for arsenic, lead, mercury, and total PCBs (i.e., statistically significant decrease in concentrations of these parameters with depth below sediment surface).

Table IR3-25-3 Tug Basin Expansion Area – Linear Regression Results for Metals and Total PCB Concentrations Relative to Sample Depth

Parameter	Number of Samples	p-value	Statistical Significance?	Slope	Intercept
Arsenic	40	0.00002	Yes	-0.60	7.0
Cadmium	40	0.15	No		
Chromium	40	0.49	No		
Copper	40	0.29	No		
Lead	40	0.000087	Yes	-0.39	5.2
Mercury	40	0.0098	Yes	-0.0028	0.041
Nickle	40	0.29	No		
Zinc	40	0.072	No		
ΣPCBs	31	0.00053	Yes	-0.00017	0.00032

The vertical trends for some parameters in the tug basin expansion area differed from the dredge basin area as there is greater enrichment in the upper sediments of finer-textured sediments and organic matter in tug basin area due to its location adjacent to the Roberts Bank causeway. Concentrations are higher in upper sediments for some parameters, since they preferentially adsorb to organic carbon and finer-textured sediments.

Existing Tug Basin Area

Within the area to be dredged within the existing tug basin (i.e., from the surface of the seabed at approximately -6.0 m CD to a maximum depth of -6.5 m CD), six samples were analysed as part of the 2016 program for metals, total PAHs, and total PCBs. Of the six samples analysed for metals, no samples exceeded the DAS LL or CCME ISQG criteria. For total PAH and total PCB concentrations, no samples exceeded their respective analytical

detection limits, noting that detection limits were below both the DAS LL and CCME ISQG criteria.

As the existing tug basin will only be dredged approximately 0.5 m, vertical distribution concentrations are not provided (i.e., the depth of material to be dredged is considered a single homogenous profile).

References

Hemmera. 2011. Sediment Assessment – Container Capacity Improvement Program, Terminal 2. Prepared for Port Metro Vancouver and WorleyParsons Canada Services Ltd.

Hemmera. 2017. Roberts Bank Terminal 2 Fall 2016 Disposal at Sea Criteria Sampling. Prepared for the Vancouver Fraser Port Authority.

Appendices

Appendix IR3-25-A Supporting Figures

Appendix IR3-25-B Supporting Tables

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APPENDIX IR3-25-A
SUPPORTING FIGURES

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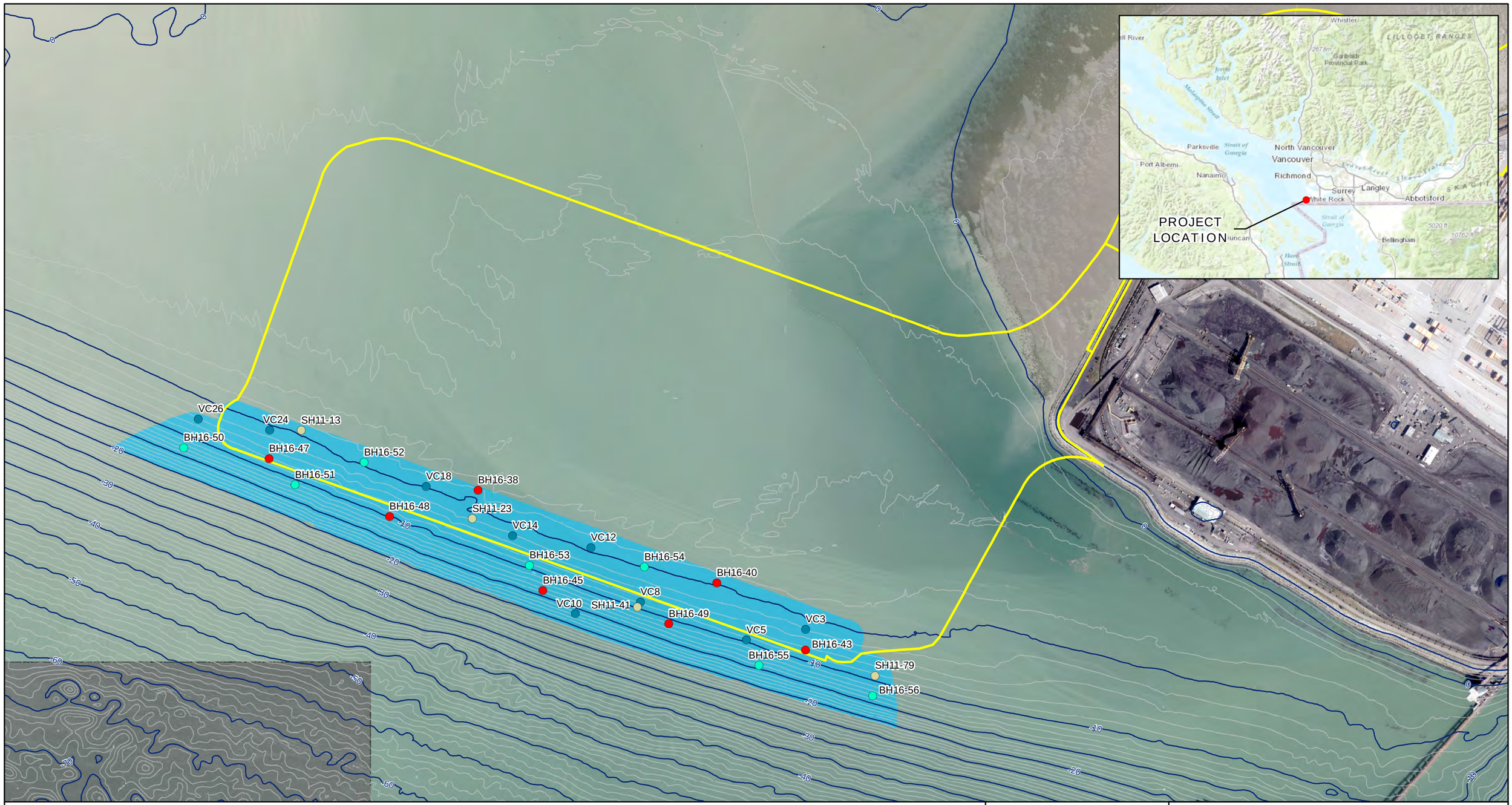

Legend

- HEMMERA 2016 DEEP BOREHOLE SAMPLING LOCATION
- HEMMERA 2016 SHALLOW CORE SAMPLING LOCATION
- HEMMERA 2013 SAMPLING LOCATION
- HEMMERA 2011 SAMPLING LOCATION
- RBT2 BOUNDARY
- DREDGE BASIN
- MAJOR CONTOUR (5 METRE INTERVAL)
- MINOR CONTOUR (1 METRE INTERVAL)

0 150 300
Metres

N

1:7,500

NAD 1983 UTM Zone 10N

PORT of vancouver

ROBERTS BANK TERMINAL 2

2011, 2013 AND 2016
DAS CRITERIA SAMPLING LOCATIONS
IN THE RBT2 DREDGE BASIN

DATE: 06/16/2017

FIG No. IR3-25-A1

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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ETB16-6
TB16-2
ETB16-5
TB16-3
TB16-1
ETB16-4
VC211
VC207
ETB16-3
VC209
VC205
VC201
ETB16-2
ETB16-1
VC202

Legend

- HEMMERA 2016 BOREHOLE SAMPLING LOCATION
- HEMMERA 2016 SHALLOW CORE SAMPLING LOCATION
- HEMMERA 2013 SAMPLING LOCATION
- MAJOR CONTOUR (5 METRE INTERVAL)
- MINOR CONTOUR (1 METRE INTERVAL)
- RBT2 BOUNDARY
- EXISTING TUG BASIN DREDGE TO -6.5 M CD
- PROPOSED TUG BASIN EXPANSION DREDGE TO -6.5 M CD

0 50 100
Metres

1:2,000

NAD 1983 UTM Zone 10N

N

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ROBERTS BANK TERMINAL 2

2013 AND 2016
DAS CRITERIA SAMPLING LOCATIONS
IN THE RBT2 TUG BASIN AREA

DATE: 06/16/2017

FIG No. IR3-25-A2

Figure IR3-25-A3 Vertical Distribution of Arsenic in Dredge Basin

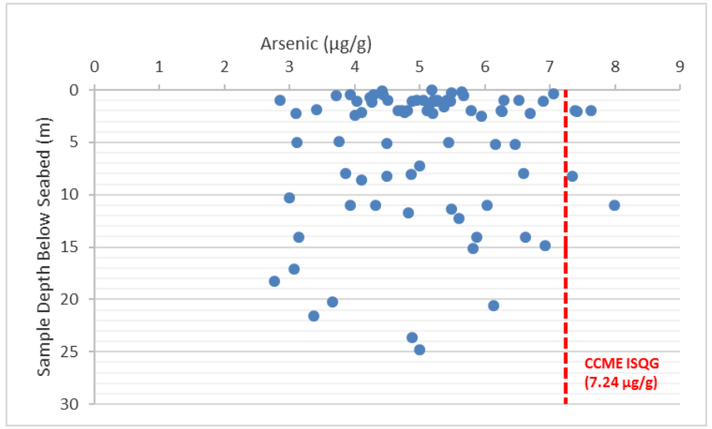


Figure IR3-25-A4 Vertical Distribution of Cadmium in Dredge Basin

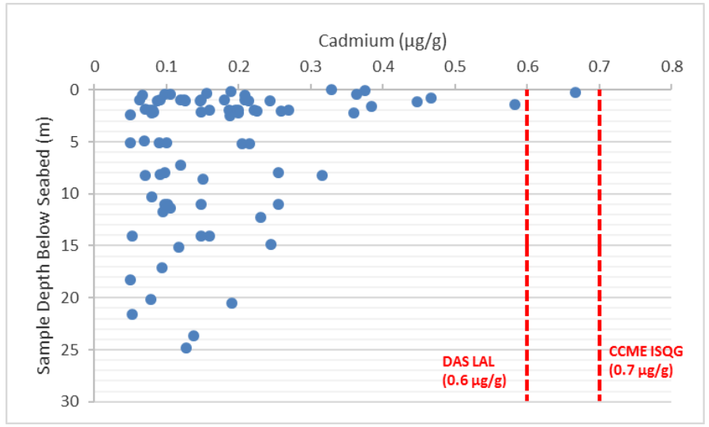


Figure IR3-25-A5 Vertical Distribution of Chromium in Dredge Basin

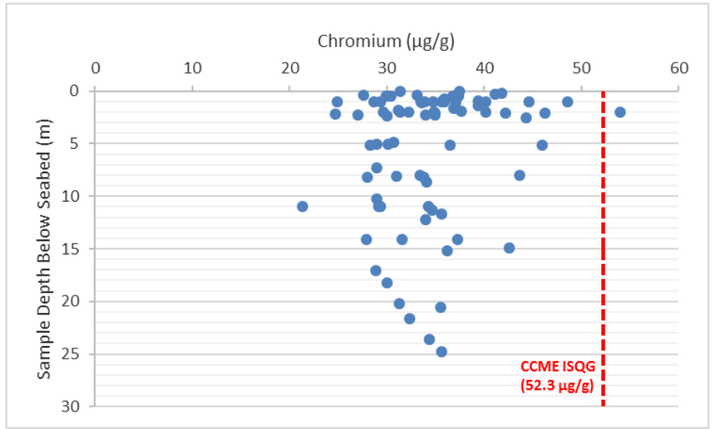


Figure IR3-25-A6 Vertical Distribution of Copper in Dredge Basin

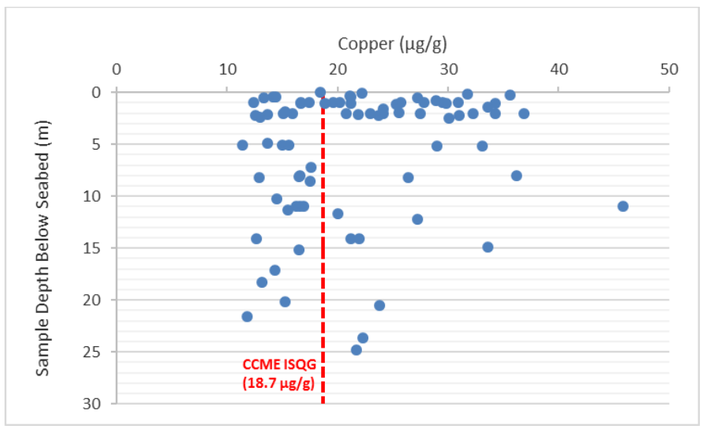


Figure IR3-25-A7 Vertical Distribution of Lead in Dredge Basin

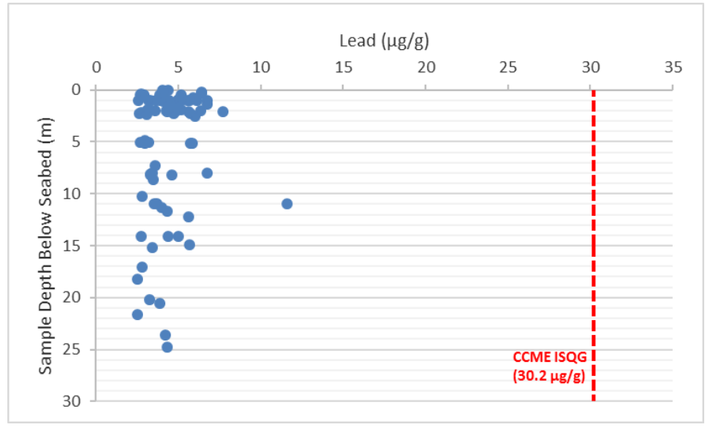


Figure IR3-25-A8 Vertical Distribution of Mercury in Dredge Basin

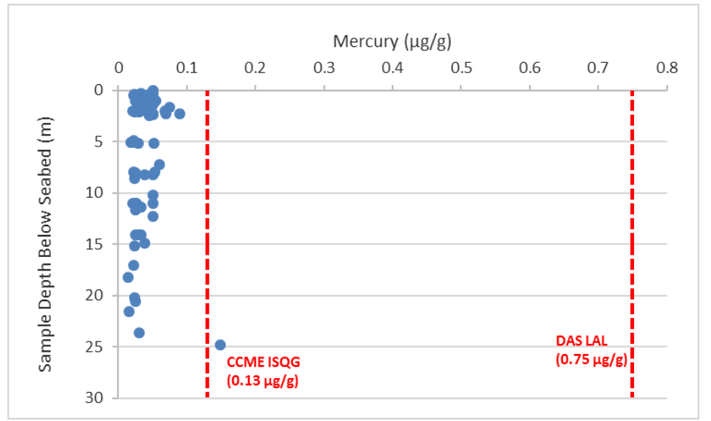


Figure IR3-25-A9 Vertical Distribution of Zinc in Dredge Basin

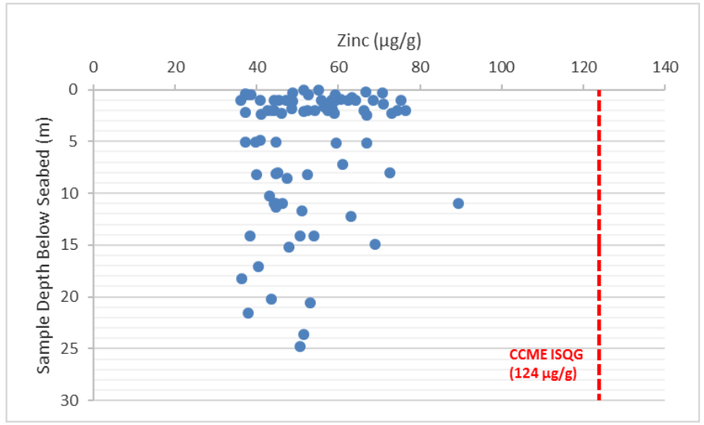


Figure IR3-25-A10 Vertical Distribution of Total PCBs in Dredge Basin

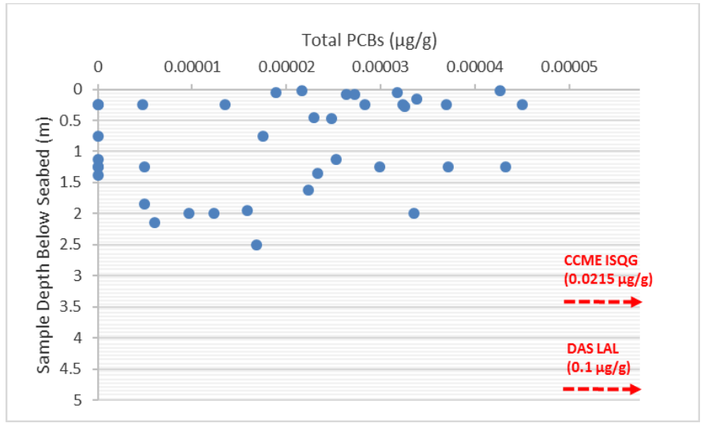


Figure IR3-25-A11 Vertical Distribution of Arsenic in Tug Basin Expansion Area

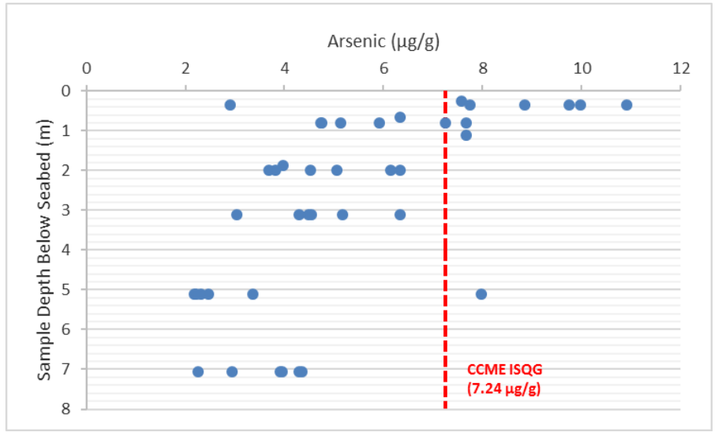


Figure IR3-25-A12 Vertical Distribution of Cadmium in Tug Basin Expansion Area

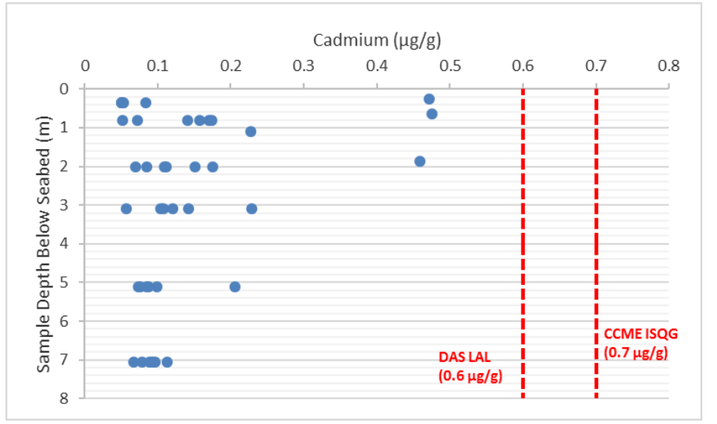


Figure IR3-25-A13 Vertical Distribution of Chromium in Tug Basin Expansion Area

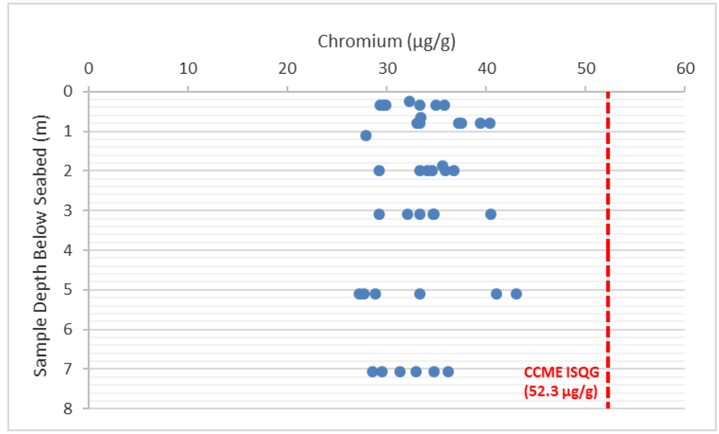


Figure IR3-25-A14 Vertical Distribution of Copper in Tug Basin Expansion Area

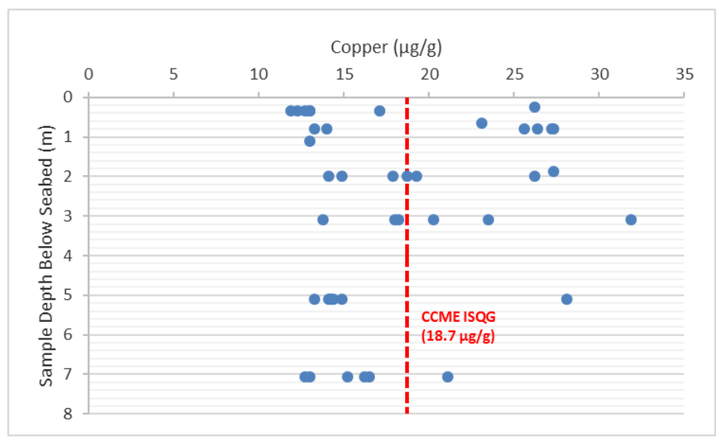


Figure IR3-25-A15 Vertical Distribution of Lead in Tug Basin Expansion Area

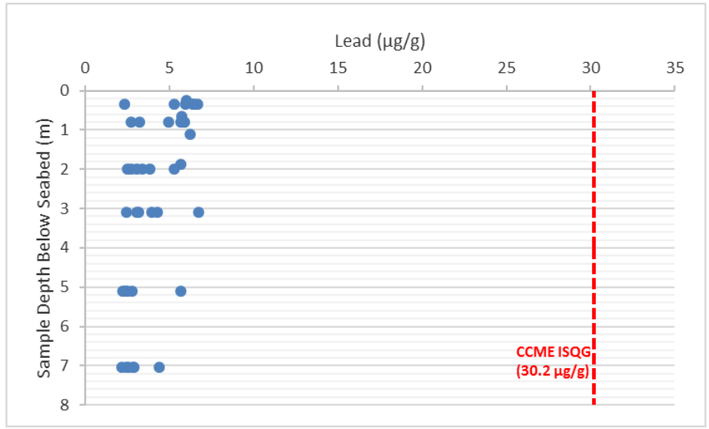


Figure IR3-25-A17 Vertical Distribution of Zinc in Tug Basin Expansion Area

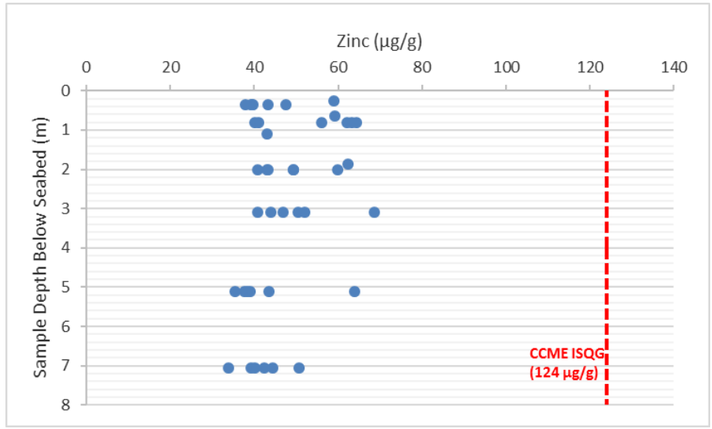


Figure IR4-25-A16 Vertical Distribution of Mercury in Tug Basin Expansion Area

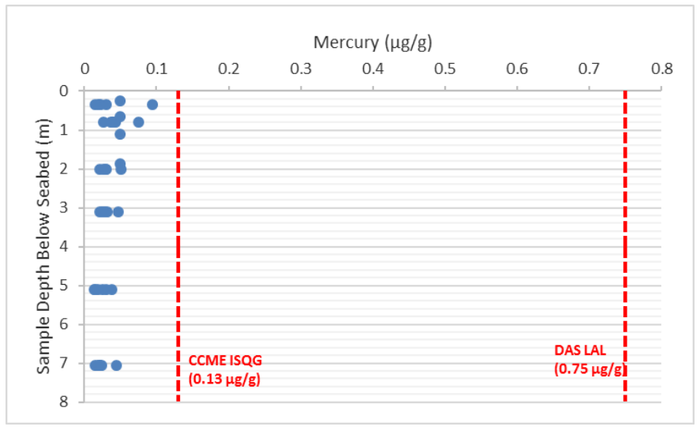
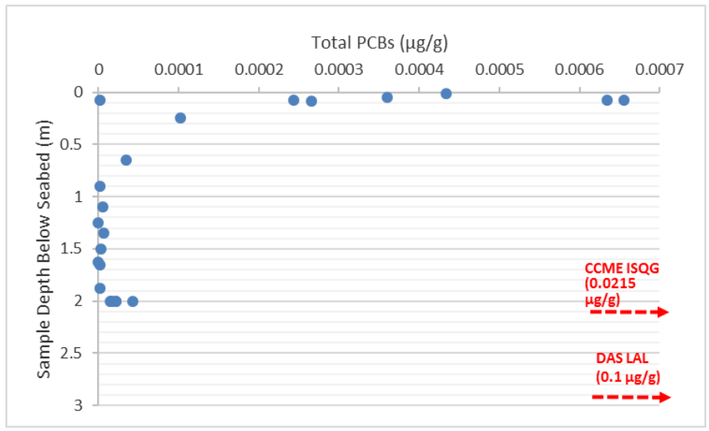


Figure IR3-25-A18 Vertical Distribution of Total PCBs in Tug Basin Expansion Area



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APPENDIX IR3-25-B
SUPPORTING TABLES

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Appendix IR3-25-B: Dredge Basin Sediment Analytical Data (Table IR3-25-B1)

						Hemmera 2011							
					Location ID:	SH11-13		SH11-23		SH11-41		SH11-79	
					Sample ID:	SH11-13-1*	SH11-13-2*	SH11-23-1*	SH11-23-2*	SH11-41-1*	SH11-41-2*	SH11-79-1*	SH11-79-2*
					Date Sampled:	11/05/2011	11/05/2011	11/05/2011	11/05/2011	11/05/2011	11/05/2011	09/05/2011	09/05/2011
					Sample Depth (m):	2-2.5	12-12.5	2-2.5	10-10.5	2-2.5	7-7.5	2.2-2.6	8-8.4
					Sample Depth Mid Point (m):	2.25	12.25	2.25	10.25	2.25	7.25	2.4	8.2
					Sample Locaton (GPS):	485855.034302/5429480.89527		486211.179929/5429297.4183		486553.858831/5429113.67527		487047.735485/5428971.15823	
Parameter	**CCME MW ISQG [3,4]**	**DAS LAL [5,6]**	**Detection Limit Hemmera 2011**	**Detection Limit EIS Appendix 9.6-B**	**Detection Limit Hemmera 2017**								
Grain Size													
Clay (<4 um) (%)			0.01	0.01	1	5.06	5.03	7.6	13	5.02	3.78	3.8	2.53
Silt (0.004-0.063 mm) (%)			0.01	0.01	1	11.4	6.26	18.1	37.2	15.48	12.56	10.48	9.69
Sand (0.063-2.00 mm) (%)			0.01	0.01	1	83.53	88.71	74.3	49.8	79.5	83.66	85.72	87.78
Gravel (>2.00 mm) (%)						<0.01	<0.01	<0.01	<0.01*	<0.01	<0.01	<0.01	<0.01
Organics													
Total Organic Carbon (%)			0.2	varies (~0.05)	0.05	0.35	1.5	2.5	0.2	0.15	0.3	0.16	0.16
Total Metals													
Arsenic (µg/g)	7.24		0.5	0.5	0.1	5.2	5.6	6.7	3	3.1	5	4	4.5
Cadmium (µg/g)	0.7	0.6	0.05	0.05	0.05	0.2	0.23	0.36	0.08	0.08	0.12	<0.05	0.07
Chromium (µg/g)	52.3		1	1	0.5	34	34	35	29	27	29	30	28
Copper (µg/g)	18.7		0.5	0.5	0.5	**23.7**	**27.2**	**31**	14.5	12.6	17.6	13	12.9
Lead (µg/g)	30.2		0.1	0.1	0.5	4.7	5.6	5.7	2.8	2.6	3.6	3.1	3.3
Mercury (µg/g)	0.13	0.75	0.05	0.05	0.005	0.07	<0.05	0.09	0.05	<0.05	0.06	<0.05	<0.05
Zinc (µg/g)	124		1	1	2	59	63	73	43	46	61	41	40
PAH													
Total PAH's (µg/g)		2.5	0.05	0.05	0.2	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
PCB													
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	0.03	varies	0.02	**<0.03**	**<0.03**	**<0.03**	**<0.03**	**<0.03**	**<0.03**	**<0.03**	**<0.03**

***Denotes % sand, silt, clay gradation was classified using alternative grain size parameters. The following grain size classification parameters were applied:**
Clay (<5 um) (%)
Silt (0.005-0.075 mm) (%)
Sand (0.075-4.75 mm) (%)
Gravel (>4.75 mm) (%)

Appendix IR3-25-B: Dredge Basin Sediment Analytical Data (Table IR3-25-B1)

						EIS Appendix 9.6-B										
					Location ID:	VC3		VC5								
					Sample ID:	VC3-1	VC3-3	VC5-ab	VC5-ae	VC5-af	VC5-ag	VC5-b	VC5-c	VC5-e	VC5-h	VC5-k	VC5-m
					Date Sampled:	13/08/2013		15/08/2013									
					Sample Depth (m):	0-0.5	1-1.5	0.01-0.02	0.04-0.05	0.05-0.075	0.075-0.1	0.1-0.2	0.2-0.3	0.4-0.5	0.7-0.8	1-1.25	1.5-1.75
					Sample Depth Mid Point (m):	0.25	1.25	0.015	0.045	0.0625	0.0875	0.15	0.25	0.45	0.75	1.125	1.625
					Sample Locaton (GPS):	123.179116666667/49.0143666666667		123.1808/49.0141666666667									
Parameter	**CCME MW ISQG [3,4]**	**DAS LAL [5,6]**	**Detection Limit Hemmera 2011**	**Detection Limit EIS Appendix 9.6-B**	**Detection Limit Hemmera 2017**												
Grain Size																	
Clay (<4 um) (%)			0.01	0.01	1	2.49	21.81	8.13	14.52		28.81	26.44		8.09		6.08	6.59
Silt (0.004-0.063 mm) (%)			0.01	0.01	1	9.83	55.18	25.59	45.40		70.93	70.59		24.25		33.20	29.37
Sand (0.063-2.00 mm) (%)			0.01	0.01	1	87.69	23.02	66.28	40.08		0.26	2.97		67.66		60.72	64.04
Gravel (>2.00 mm) (%)																	
Organics																	
Total Organic Carbon (%)			0.2	varies (~0.05)	0.05	0.33	2.5	0.41	0.6		0.51	0.58	0.69	0.49	0.66	0.57	0.45
Total Metals																	
Arsenic (µg/g)	7.24		0.5	0.5	0.1					4.42				4.44		4.26	5.37
Cadmium (µg/g)	0.7	0.6	0.05	0.05	0.05					0.375				0.364		0.447	0.384
Chromium (µg/g)	52.3		1	1	0.5					37.5				36.8		37.1	36.9
Copper (µg/g)	18.7		0.5	0.5	0.5					**22.2**				**21.2**		**25.3**	**24.1**
Lead (µg/g)	30.2		0.1	0.1	0.5					4.35				3.85		4.97	4.54
Mercury (µg/g)	0.13	0.75	0.05	0.05	0.005					<0.05				<0.05		<0.05	0.075
Zinc (µg/g)	124		1	1	2					55.1				52.6		59	56.5
PAH																	
Total PAH's (µg/g)		2.5	0.05	0.05	0.2					<0.050				<0.050		<0.050	<0.050
PCB																	
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	0.03	varies	0.02	0.0000135	0.0000371	0.0000426	0.0000189		0.0000263	0.0000338	0.0000283	0.0000229	0.0000175	0.0000253	0.0000223

Appendix IR3-25-B: Dredge Basin Sediment Analytical Data (Table IR3-25-B1)

						EIS Appendix 9.6-B										
	Location ID:					VC8									VC10	
	Sample ID:					VC8-ab	VC8-ac	VC8-ae	VC8-b	VC8-f	VC8-j	VC8-m	VC8-p	VC8-q	VC10-1	VC10-3
	Date Sampled:					13/08/2013									13/08/2013	
	Sample Depth (m):					0.01-0.02	0.02-0.03	0.04-0.05	0.05-0.1	0.25-0.3	0.45-0.5	0.7-0.8	1-1.25	1.25-1.5	0-0.5	1-1.5
	Sample Depth Mid Point (m):					0.015	0.025	0.045	0.075	0.275	0.475	0.75	1.125	1.375	0.25	1.25
	Sample Locaton (GPS):					123.183816666667/49.0148666666667									123.185666666667/49.01465	
Parameter	**CCME MW ISQG [3,4]**	**DAS LAL [5,6]**	**Detection Limit Hemmera 2011**	**Detection Limit EIS Appendix 9.6-B**	**Detection Limit Hemmera 2017**											
Grain Size																
Clay (<4 um) (%)			0.01	0.01	1			13.47	15.21	9.98	11.78	4.47	17.61	22.16	22.06	24.27
Silt (0.004-0.063 mm) (%)			0.01	0.01	1			37.95	52.54	36.50	46.78	24.44	68.03	65.58	62.99	73.38
Sand (0.063-2.00 mm) (%)			0.01	0.01	1			48.58	32.24	53.52	41.44	71.09	14.36	12.27	14.96	2.35
Gravel (>2.00 mm) (%)																
Organics																
Total Organic Carbon (%)			0.2	varies (~0.05)	0.05	0.69		2.2	0.76	1	0.74	0.93	0.72	0.72	0.99	0.79
Total Metals																
Arsenic (µg/g)	7.24		0.5	0.5	0.1		5.18			5.48		4.24		5.16		
Cadmium (µg/g)	0.7	0.6	0.05	0.05	0.05		0.328			**0.666**		0.466		0.583		
Chromium (µg/g)	52.3		1	1	0.5		31.4			41.1		35.9		39.4		
Copper (µg/g)	18.7		0.5	0.5	0.5		18.4			**35.6**		**28.9**		**33.6**		
Lead (µg/g)	30.2		0.1	0.1	0.5		4.05			6.39		5.92		6.77		
Mercury (µg/g)	0.13	0.75	0.05	0.05	0.005		<0.050			<0.050		<0.050		<0.050		
Zinc (µg/g)	124		1	1	2		51.4			70.9		63.3		71.1		
PAH																
Total PAH's (µg/g)		2.5	0.05	0.05	0.2		<0.050			<0.050		<0.050		<0.050		
PCB																
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	0.03	varies	0.02	0.0000216		0.0000317	0.0000272	0.0000325	0.0000248	0	0	0	0	0

Appendix IR3-25-B: Dredge Basin Sediment Analytical Data (Table IR3-25-B1)

						EIS Appendix 9.6-B									
					Location ID:	VC12		VC14		VC18		VC24		VC26	
					Sample ID:	VC12-1	VC12-3	VC14-1	VC14-3	VC18-1	VC18-3	VC24-1	VC24-3	VC26-1	VC26-3
					Date Sampled:	13/08/2013		12/08/2013		14/08/2013		14/08/2013		12/08/2013	
					Sample Depth (m):	0-0.5	1-1.5	0-0.5	1-1.5	0-0.5	1-1.5	0-0.5	1.2-1.5	0-0.5	1-1.5
					Sample Depth Mid Point (m):	0.25	1.25	0.25	1.25	0.25	1.25	0.25	1.35	0.25	1.25
					Sample Locaton (GPS):	123.185233333333/49.0158833333333		123.18745/49.0161		123.189916666667/49.0170166666667		123.194366666667/49.0180666666667		123.1964/49.0182666666667	
Parameter	**CCME MW ISQG [3,4]**	**DAS LAL [5,6]**	**Detection Limit Hemmera 2011**	**Detection Limit EIS Appendix 9.6-B**	**Detection Limit Hemmera 2017**										
Grain Size															
Clay (<4 um) (%)			0.01	0.01	1	11.65	5.70	18.83	18.71	1.18	17.63	3.63	17.50	8.63	10.06
Silt (0.004-0.063 mm) (%)			0.01	0.01	1	49.25	21.36	56.39	69.58	4.47	60.70	10.28	53.29	32.45	30.01
Sand (0.063-2.00 mm) (%)			0.01	0.01	1	39.10	72.94	24.77	11.71	94.35	21.67	86.09	29.21	58.92	59.93
Gravel (>2.00 mm) (%)															
Organics															
Total Organic Carbon (%)			0.2	varies (~0.05)	0.05	0.74	0.81	0.69	0.53	0.15	0.11	0.17	0.84	4.8	1.1
Total Metals															
Arsenic (µg/g)	7.24		0.5	0.5	0.1										
Cadmium (µg/g)	0.7	0.6	0.05	0.05	0.05										
Chromium (µg/g)	52.3		1	1	0.5										
Copper (µg/g)	18.7		0.5	0.5	0.5										
Lead (µg/g)	30.2		0.1	0.1	0.5										
Mercury (µg/g)	0.13	0.75	0.05	0.05	0.005										
Zinc (µg/g)	124		1	1	2										
PAH															
Total PAH's (µg/g)		2.5	0.05	0.05	0.2										
PCB															
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	0.03	varies	0.02	0.00000474	0.00000494	0	0	0.000045	0.0000299	0.0000323	0.0000233	0.0000369	0.0000432

Appendix IR3-25-B: Dredge Basin Sediment Analytical Data (Table IR3-25-B1)

						Hemmera 2017										Hemmera 2017							
	Location ID:					BH16-38										BH16-40							
	Sample ID:					BH16-38-01	BH16-38-02	BH16-38-03	BH16-38-06	BH16-38-07	BH16-38-08	BH16-38-09	BH16-38-10	BH16-38-11	BH16-38-12	BH16-40-01	BH16-40-02	BH16-40-05	BH16-40-06	BH16-40-08	BH16-40-09	BH16-40-10	BH16-40-11
	Date Sampled:					30/09/2016	30/09/2016	30/09/2016	30/09/2016	30/09/2016	30/09/2016	30/09/2016	30/09/2016	30/09/2016	30/09/2016	26/09/2016	26/09/2016	26/09/2016	26/09/2016	26/09/2016	26/09/2016	26/09/2016	26/09/2016
	Sample Depth (m):					0.3-0.5	0.9-1.1	1.8-1.9	5.0-5.2	8.5-8.7	11.6-11.8	15.10-15.2	18.2-18.3	21.4-21.8	24.6-25.0	0.9-1.2	2.0-2.3	5.0-5.3	7.9-8.5	11.1-11.6	14.6-15.2	20.4-20.7	23.5-23.8
	Sample Depth Mid Point (m):					0.4	1	1.85	5.1	8.6	11.7	15.15	18.25	21.6	24.8	1.05	2.15	5.15	8.2	11.35	14.9	20.55	23.65
	Sample Locaton (GPS):					5429356.603 / 486222.956										5429164.038 / 486718.781							
Parameter	**CCME MW ISQG [3,4]**	**DAS LAL [5,6]**	**Detection Limit Hemmera 2011**	**Detection Limit EIS Appendix 9.6-B**	**Detection Limit Hemmera 2017**																		
Grain Size																							
Clay (<4 um) (%)			0.01	0.01	1	2.5	2	2.1	1.9	6.3	8	2.1	1.4	2.3	9.7	3.8	3.8	11.3	7.6	5.7	9.6	4.3	5.3
Silt (0.004-0.063 mm) (%)			0.01	0.01	1	16.3	9.4	5.7	9.9	39.8	31.2	12.4	4.1	6.1	32.4	15.3	16	46	36.2	17.3	41.6	23.6	25.3
Sand (0.063-2.00 mm) (%)			0.01	0.01	1	81.3	88.6	92.1	88.2	54	60.8	85.5	94.5	91.6	57.8	80.9	80.3	42.7	56.3	77	48.7	72	69.4
Gravel (>2.00 mm) (%)						<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Organics																							
Total Organic Carbon (%)			0.2	varies (~0.05)	0.05	0.438	0.301	0.262	0.595	2.39	0.585	1.01	0.19	0.247	0.399	0.516	0.725	1.16	3.39	0.315	0.866	0.792	0.466
Total Metals																							
Arsenic (µg/g)	7.24		0.5	0.5	0.1	4.29	2.85	3.41	4.49	4.11	4.82	5.82	2.77	3.37	5	4.04	4.1	6.17	**7.35**	5.49	6.92	6.13	4.88
Cadmium (µg/g)	0.7	0.6	0.05	0.05	0.05	0.097	0.063	0.07	0.1	0.15	0.095	0.117	<0.050	0.053	0.127	0.087	0.082	0.205	0.315	0.105	0.245	0.191	0.138
Chromium (µg/g)	52.3		1	1	0.5	27.6	24.9	31.2	28.3	34.1	35.6	36.2	30	32.4	35.6	28.7	24.7	36.5	33.8	34.7	42.6	35.5	34.4
Copper (µg/g)	18.7		0.5	0.5	0.5	14.2	12.4	15.3	15	17.5	**20**	16.5	13.2	11.8	**21.7**	16.7	13.7	**29**	**26.4**	15.5	**33.6**	**23.8**	**22.3**
Lead (µg/g)	30.2		0.1	0.1	0.5	2.73	2.58	3.19	2.99	3.45	4.31	3.41	2.49	2.54	4.33	3.18	2.75	5.73	4.61	3.96	5.66	3.86	4.23
Mercury (µg/g)	0.13	0.75	0.05	0.05	0.005	0.024	0.0244	0.037	0.0241	0.0242	0.0252	0.0232	0.0145	0.015	**0.149**	0.0255	0.0234	0.0295	0.0389	0.0326	0.0386	0.0251	0.0307
Zinc (µg/g)	124		1	1	2	37.3	36.1	48.6	44.7	47.4	51.1	47.9	36.2	37.9	50.5	40.9	37.1	59.4	52.3	44.6	69	53.1	51.4
PAH																							
Total PAH's (µg/g)		2.5	0.05	0.05	0.2	<0.20	<0.20	<0.20	<0.037	<0.037	<0.037	<0.037	<0.037	<0.037	<0.20	<0.20	<0.20	<0.037	<0.037	<0.037	<0.037	<0.037	<0.20
PCB																							
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	0.03	varies	0.02	<0.020	<0.020	0.000005	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	0.000006	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020

Appendix IR3-25-B: Dredge Basin Sediment Analytical Data (Table IR3-25-B1)

						Hemmera 2017									Hemmera 2017						
	Location ID:					BH16-43									BH16-45						
	Sample ID:					BH16-43-01	BH16-43-02	BH16-43-04	BH16-43-07	BH16-43-08	BH16-43-09	BH16-43-10	BH16-43-11	BH16-43-12	BH16-45-01	BH16-45-02	BH16-45-04	BH16-45-07	BH16-45-08	BH16-45-09	BH16-45-10
	Date Sampled:					16/09/2016	16/09/2016	16/09/2016	16/09/2016	16/09/2016	16/09/2016	16/09/2016	16/09/2016	16/09/2016	10/09/1916	10/09/1916	10/09/1916	10/09/1916	10/09/2016	10/09/2016	10/09/2016
	Sample Depth (m):					0.3 - 0.7	0.9 - 1.0	1.9 - 2.1	5.0 - 5.1	7.9 - 8.0	10.9 - 11.1	14.1 - 14.3	16.9 - 17.0	20.1- 21.0	0.10-0.30	0.90-1.20	2.40-2.60	6.40-6.50	7.90-8.00	10.90-11.10	13.70-13.80
	Sample Depth Mid Point (m):					0.5	0.95	2	5.05	7.95	11	14.2	16.95	20.55	0.2	1.05	2.5	6.45	7.95	11	13.75
	Sample Locaton (GPS):					5429024.217 / 486903.277									5429148.5 / 486357.6						
Parameter	**CCME MW ISQG** [3,4]	**DAS LAL** [5,6]	**Detection Limit Hemmera 2011**	**Detection Limit EIS Appendix 9.6-B**	**Detection Limit Hemmera 2017**																
Grain Size																					
Clay (<4 um) (%)			0.01	0.01	1	2.6	5.3	8.3	4	4.9	1.8	7.3	8.4	4.9	10.9	12.8	9.46	2.93	2.63	1.96	1.44
Silt (0.004-0.063 mm) (%)			0.01	0.01	1	10.5	26.9	22.6	17.7	25	2.8	29.8	43.6	27.2	49.4	57	50.7	13.7	13.3	9.24	6.16
Sand (0.063-2.00 mm) (%)			0.01	0.01	1	86.9	67.8	69.1	78.3	70	95.5	63	48.1	68	39.6	30.1	39.8	83.4	84.1	88.8	92.4
Gravel (>2.00 mm) (%)						<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	0.13	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Organics																					
Total Organic Carbon (%)			0.2	varies (~0.05)	0.05	0.264	1.03	0.45	1.07						0.829	0.614	0.525			0.407	
Total Metals																					
Arsenic (µg/g)	7.24		0.5	0.5	0.1	3.71	6.29	4.66	5.45						5.65	5.25	5.95			7.99	
Cadmium (µg/g)	0.7	0.6	0.05	0.05	0.05	0.066	0.209	0.077	0.09						0.189	0.214	0.188			0.255	
Chromium (µg/g)	52.3		1	1	0.5	30.4	39.4	31.4	29						41.8	48.6	44.3			21.3	
Copper (µg/g)	18.7		0.5	0.5	0.5	13.3	27.8	15.1	15.6						31.8	34.3	30.1			45.8	
Lead (µg/g)	30.2		0.1	0.1	0.5	2.67	4.97	3.14	3.2						6.43	6.77	5.99			11.6	
Mercury (µg/g)	0.13	0.75	0.05	0.05	0.005	0.024	0.0396	0.0283	0.0249						0.0487	0.0429	0.0446			0.0512	
Zinc (µg/g)	124		1	1	2	38.5	60.6	42.7	39.6						66.8	75.3	67			89.5	
PAH																					
Total PAH's (µg/g)		2.5	0.05	0.05	0.2	6.87	<0.20	<0.20	<0.20						<0.20	<0.20	<0.20			<0.20	
PCB																					
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	0.03	varies	0.02	<0.020	<0.020	0.0000335	<0.020						<0.020	<0.020	0.0000168			<0.020	

Appendix IR3-25-B: Dredge Basin Sediment Analytical Data (Table IR3-25-B1)

						Hemmera 2017								
					Location ID:	BH16-47								
					Sample ID:	BH16-47-01	BH16-47-02	BH16-47-04	BH16-47-08	BH16-47-09	BH16-47-10	BH16-47-11	BH16-47-12	BH16-47-13
					Date Sampled:	22/10/2016	22/10/2016	22/10/2016	22/10/2016	22/10/2016	22/10/2016	22/10/2016	22/10/2016	22/10/2016
					Sample Depth (m):	0.4-0.6	0.9-1.1	1.9-2.1	4.8-5.0	7.9-8.1	10.9-11.1	20.1-20.3	14.0-14.2	17.0-17.2
					Sample Depth Mid Point (m):	0.5	1	2	4.9	8	11	20.2	14.1	17.1
					Sample Locaton (GPS):	485031.3653/5429355.8957								
Parameter	**CCME MW ISQG [3,4]**	**DAS LAL [5,6]**	**Detection Limit Hemmera 2011**	**Detection Limit EIS Appendix 9.6-B**	**Detection Limit Hemmera 2017**									
Grain Size														
Clay (<4 um) (%)			0.01	0.01	1	8.5	3.2	6.3	2.6	6.4	3.8	2.6	5	2.4
Silt (0.004-0.063 mm) (%)			0.01	0.01	1	39.8	11.8	27.7	10	25.7	14.7	9.2	23.8	8
Sand (0.063-2.00 mm) (%)			0.01	0.01	1	51.7	85	66	87.4	67.9	81.6	88.2	71.2	89.7
Gravel (>2.00 mm) (%)						<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Organics														
Total Organic Carbon (%)			0.2	varies (~0.05)	0.05	1.33	0.419	0.777	0.223	0.489	0.256	0.25	0.569	0.253
Total Metals														
Arsenic (µg/g)	7.24		0.5	0.5	0.1	5.67	5.06	4.81	3.76	3.86	4.32	3.66	5.88	3.07
Cadmium (µg/g)	0.7	0.6	0.05	0.05	0.05	0.208	0.091	0.159	0.069	0.098	0.101	0.078	0.148	0.094
Chromium (µg/g)	52.3		1	1	0.5	37.4	33.5	34.9	30.7	33.4	29.2	31.3	37.3	28.9
Copper (µg/g)	18.7		0.5	0.5	0.5	27.2	17.4	23	13.7	16.6	16.6	15.3	22	14.3
Lead (µg/g)	30.2		0.1	0.1	0.5	5.18	3.33	4.25	2.97	3.43	3.62	3.24	4.39	2.82
Mercury (µg/g)	0.13	0.75	0.05	0.05	0.005	0.0416	0.0294	0.0319	0.0221	0.0226	0.0216	0.0233	0.0248	0.0219
Zinc (µg/g)	124		1	1	2	59.3	45.3	52.4	40.8	45.1	44.2	43.6	54.1	40.4
PAH														
Total PAH's (µg/g)		2.5	0.05	0.05	0.2	<0.20	<0.20	<0.20	<0.037	<0.037	<0.037	<0.037	<0.037	<0.20
PCB														
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	0.03	varies	0.02	<0.020	<0.020	0.0000123	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020

Appendix IR3-25-B: Dredge Basin Sediment Analytical Data (Table IR3-25-B1)

						Hemmera 2017							Hemmera 2017						
					Location ID:	BH16-48							BH16-49						
					Sample ID:	BH16-48-01	BH16-48-02	BH16-48-04	BH16-48-07	BH16-48-08	BH16-48-09	BH16-48-10	BH16-49-01	BH16-49-02	BH16-49-04	BH16-49-07	BH16-49-08	BH16-49-09	BH16-49-10
					Date Sampled:	12/10/2016	12/10/2016	12/10/2016	12/10/2016	12/10/2016	12/10/2016	12/10/2016	18/10/2016	18/10/2016	18/10/2016	18/10/2016	18/10/2016	18/10/2016	18/10/2016
					Sample Depth (m):	0.4-0.5	1.0-1.2	1.9-2.1	5.0-5.1	8.0-8.2	10.9-11.1	14.0-14.2	0.3-0.4	0.9-1.1	1.8-2.1	5.1-5.2	7.9-8.1	10.9-11.1	14.0-14.2
					Sample Depth Mid Point (m):	0.45	1.1	2	5.05	8.1	11	14.1	0.35	1	1.95	5.15	8	11	14.1
					Sample Locaton (GPS):	5429302.014 / 486038.683							5429078.994 / 486619.237						
Parameter	**CCME MW ISQG [3,4]**	**DAS LAL [5,6]**	**Detection Limit Hemmera 2011**	**Detection Limit EIS Appendix 9.6-B**	**Detection Limit Hemmera 2017**														
Grain Size																			
Clay (<4 um) (%)			0.01	0.01	1	4	3	2	2.7	3.5	4.6	1.9	7.5	7.1	9.5	10.8	12.5	5.6	5
Silt (0.004-0.063 mm) (%)			0.01	0.01	1	18.6	15.7	11	12.5	19.6	20.8	9.4	36.2	43.9	44.2	56.4	46.4	23.3	18.9
Sand (0.063-2.00 mm) (%)			0.01	0.01	1	77.4	81.3	87	84.8	76.9	74.6	88.7	56.3	49	46.3	32.8	41.2	71.1	76.2
Gravel (>2.00 mm) (%)						<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Organics																			
Total Organic Carbon (%)			0.2	varies (~0.05)	0.05	1.16	0.732	2	0.257	0.335	0.297	0.182	1.41	0.682	0.639	0.896	0.915	1.6	0.801
Total Metals																			
Arsenic (µg/g)	7.24		0.5	0.5	0.1	3.93	5.47	**7.38**	3.11	4.87	3.93	3.14	7.06	5.27	5.79	6.47	6.6	6.04	6.63
Cadmium (µg/g)	0.7	0.6	0.05	0.05	0.05	0.105	0.147	0.269	<0.050	0.091	0.097	0.052	0.156	0.18	0.186	0.215	0.255	0.148	0.16
Chromium (µg/g)	52.3		1	1	0.5	29.9	33.6	29.6	30.1	31	34.3	27.9	33.1	35.6	37.7	46	43.7	29.4	31.6
Copper (µg/g)	18.7		0.5	0.5	0.5	14.4	**18.9**	**20.8**	11.4	16.5	16.3	12.7	**21.1**	**25.7**	**25.6**	**33.1**	**36.2**	16.9	**21.2**
Lead (µg/g)	30.2		0.1	0.1	0.5	2.91	4.11	3.6	2.69	3.31	3.68	2.74	4.11	5.17	5.19	5.86	6.74	3.54	4.98
Mercury (µg/g)	0.13	0.75	0.05	0.05	0.005	0.0218	0.0397	0.0406	0.0184	0.0246	0.0255	0.0333	0.0328	0.0367	0.0383	0.0517	0.0526	0.0269	0.0291
Zinc (µg/g)	124		1	1	2	37.7	48.8	43.8	37.2	44.8	46.3	38.4	48.7	58.4	58.5	67	72.7	44.7	50.6
PAH																			
Total PAH's (µg/g)		2.5	0.05	0.05	0.2	<0.20	<0.20	<0.20	<0.20	<0.037	<0.037	<0.037	<0.20	<0.20	<0.20	<0.037	<0.20	<0.037	<0.037
PCB																			
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	0.03	varies	0.02	<0.020	<0.020	0.0000097	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	0.0000158	<0.020	<0.020	<0.020	<0.020

Appendix IR3-25-B: Dredge Basin Sediment Analytical Data (Table IR3-25-B1)

						Hemmera 2017											
	Location ID:					BH16-50		BH16-51		BH16-52		BH16-53		BH16-54		BH16-55		BH16-56	
	Sample ID:					BH16-50-01	BH16-50-04	BH16-51-01	BH16-51-04	BH16-52-01	BH16-52-03	BH16-53-01	BH16-53-03	BH16-54-01	BH16-54-03	BH16-55-01	BH16-55-03	BH16-56-01	BH16-56-03
	Date Sampled:					22/10/2016	22/10/2016	22/10/2016	22/10/2016	22/10/2016	22/10/2016	22/10/2016	22/10/2016	18/10/2016	18/10/2016	18/10/2016	18/10/2016	18/10/2016	18/10/2016
	Sample Depth (m):					0.9-1.1	1.9-2.1	0.9-1.1	2.0-2.2	0.9-1.1	1.9-2.1	0.9-1.1	1.9-2.1	1.0-1.1	2.0-2.1	1.0-1.1	2.0-2.1	0.9-1.1	1.9-2.1
	Sample Depth Mid Point (m):					1	2	1	2.1	1	2	1	2	1.05	2.05	1.05	2.05	1	2
	Sample Locaton (GPS):					5429444.984 / 485611.767		5429368.125 / 485842.702		5429414.451/ 485986.367		5429200.449 / 486329.919		5429197.4 / 486568.435		5428992.815 / 486806.749		5428929.561 / 487042.507	
Parameter	**CCME MW ISQG [3,4]**	**DAS LAL [5,6]**	**Detection Limit Hemmera 2011**	**Detection Limit EIS Appendix 9.6-B**	**Detection Limit Hemmera 2017**														
Grain Size																			
Clay (<4 um) (%)			0.01	0.01	1	7.5	7.7	3.4	6.3	3.8	3.6	12.9	11.6	9.3	14.2	7.2	13.5	4.5	3.4
Silt (0.004-0.063 mm) (%)			0.01	0.01	1	38.5	32.8	17.4	28.1	17.2	18	52.9	51.5	44.4	52.1	28.4	51.9	19.9	13.2
Sand (0.063-2.00 mm) (%)			0.01	0.01	1	54	59.6	79.1	65.6	79.1	78.4	34.2	36.9	46.3	33.7	64.4	34.6	75.6	83.4
Gravel (>2.00 mm) (%)						<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Organics																			
Total Organic Carbon (%)			0.2	varies (~0.05)	0.05	1.22	0.897	0.367	0.687	1.15	1.93	0.553	0.599	1.33	0.95	0.449	0.628	0.594	0.406
Total Metals																			
Arsenic (µg/g)	7.24		0.5	0.5	0.1	5.42	5.11	4.51	4.77	5.21	6.25	6.52	**7.63**	6.9	**7.41**	4.88	6.27	4.95	4.73
Cadmium (µg/g)	0.7	0.6	0.05	0.05	0.05	0.21	0.195	0.12	0.148	0.148	0.2	0.211	0.222	0.243	0.259	0.126	0.225	0.125	0.081
Chromium (µg/g)	52.3		1	1	0.5	40.2	34.9	33.9	35	34.8	40.2	44.6	**54**	35.7	42.2	35.9	46.3	29.4	32.3
Copper (µg/g)	18.7		0.5	0.5	0.5	**29.5**	**24.1**	**19.6**	**21.9**	**20.2**	**27.5**	**30.9**	**36.9**	**29.8**	**34.3**	**21.2**	**32.3**	16.7	15.9
Lead (µg/g)	30.2		0.1	0.1	0.5	5.53	4.51	3.91	4.33	4	4.89	6.12	6.36	5.69	7.69	4.43	5.64	3.65	3.09
Mercury (µg/g)	0.13	0.75	0.05	0.05	0.005	0.0411	0.0426	0.0282	0.0307	0.0547	0.0423	0.0418	0.0414	0.0417	0.0456	0.0264	0.0687	0.0269	0.0216
Zinc (µg/g)	124		1	1	2	64.1	54.3	48.4	51.6	47.1	57.4	68.6	74.4	62.3	76.5	55.9	66.2	44.3	44.3
PAH																			
Total PAH's (µg/g)		2.5	0.05	0.05	0.2	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
PCB																			
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	0.03	varies	0.02	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020

Appendix B: Tug Basin Expansion Area Sediment Analytical Data (Table IR3-25-B2)

					EIS Appendix 9.6-B									
				Location ID:	VC201								VC202	
				Sample ID:	VC201-b	VC201-e	VC201-g	VC201-i	VC201-m	VC201-q	VC201-s	VC201-t	VC202-1	VC202-3
				Date Sampled:	16/08/2013	16/08/2013	16/08/2013	16/08/2013	16/08/2013	16/08/2013	16/08/2013	16/08/2013	16/08/2013	16/08/2013
				Sample Depth (m):	0.01-0.02	0.04-0.05	0.075-0.1	0.2-0.3	0.6-0.7	1-1.2	1.5-1.75	1.75-2	0-0.15	1.2-1.8
				Sample Depth Mid Point (m):	0.015	0.045	0.0875	0.25	0.65	1.1	1.625	1.875	0.075	1.5
				Sample Locaton (GPS):	489047.188/5430126.531								489078.81/5430096.824	
Parameter	**CCME MW ISQG [3,4]**	**DAS LL [5,6]**	**Detection Limits EIS Appendix 9.6-B**	**Detection Limits Hemmera 2017**										
Grain Size														
Clay (<4 um) (%)			varies	1	15.1		14.6	7.7	10.2	22.5	12	20.6	16	12.9
Silt (0.004-0.063 mm) (%)			varies	1	65.2		62.8	31	39.5	58.3	60.9	65.1	68.9	52.2
Sand (0.063-2.00 mm) (%)			varies	1	19.7		22.5	61.3	50.3	19.2	27.1	14.3	15.1	34.9
Gravel (>2.00 mm) (%)				1										
Organics														
Total Organic Carbon (%)			0.05	0.05	1.6	1.4	1.3	0.52	0.91	0.16	0.47	0.43	2.3	0.46
Total Metals														
Arsenic (µg/g)	7.24		0.5	0.1				**7.57**	6.34	**7.67**		3.97		
Cadmium (µg/g)	0.7	0.6	0.05	0.05				0.472	0.475	0.227		0.459		
Chromium (µg/g)	52.3		1	0.5				32.3	33.4	27.9		35.6		
Copper (µg/g)	18.7		0.5	0.5				**26.2**	**23.1**	13		**27.3**		
Lead (µg/g)	30.2		0.1	0.5				5.99	5.72	6.21		5.69		
Mercury (µg/g)	0.13	0.75	0.05	0.005				<0.050	<0.050	<0.050		<0.050		
Zinc (µg/g)	124		1	2				58.9	59.1	43.1		62.3		
PAH														
Total PAH's (µg/g)		2.5	0.05	0.2				<0.050	<0.050	<0.050		<0.050		
PCB														
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	varies	0.02	0.000434	0.00036	0.000266	0.000102	0.000034	0.00000575	0	0.0000022	0.000655	0.00000273

Appendix B: Tug Basin Expansion Area Sediment Analytical Data (Table IR3-25-B2)

					EIS Appendix 9.6-B							Hemmera 2017					
	Location ID:				VC205		VC207		VC209		VC211	ETB16-1					
	Sample ID:				VC205-1	VC205-3	VC207-1	VC207-3	VC209-1	VC209-3	VC211-2	ETB16-1-01	ETB16-1-02	ETB16-1-03	ETB16-1-04	ETB16-1-06	ETB16-1-07
	Date Sampled:				16/08/2013	16/08/2013	16/08/2013	16/08/2013	16/08/2013	16/08/2013	16/08/2013	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016
	Sample Depth (m):				0-0.15	1.2-1.5	0-0.15	1-1.5	0-0.15	1.5-1.8	0.8-1	0.3-0.4	0.7-0.9	1.9-2.1	3.0-3.2	5.0-5.2	7.0-7.1
	Sample Depth Mid Point (m):				0.075	1.35	0.075	1.25	0.075	1.65	0.9	0.35	0.8	2	3.1	5.1	7.05
	Sample Locaton (GPS):				489075.238/5430139.445		489078.956/5430170.934		489106.954/5430157.910		04.568/5430183.853	5430093.371/489046.078					
Parameter	**CCME MW ISQG** [3,4]	**DAS LL** [5,6]	**Detection Limits EIS Appendix 9.6-B**	**Detection Limits Hemmera 2017**													
Grain Size																	
Clay (<4 um) (%)			varies	1	14.4		9.5	3.4	12.9	13.3	3.5	2.6	11.7	2.6	10.9	3.1	2.5
Silt (0.004-0.063 mm) (%)			varies	1	54.8		47.9	9.4	54.4	54.7	7.5	7.9	46.3	17.8	51.4	13.8	10.2
Sand (0.063-2.00 mm) (%)			varies	1	30.8		42.5	87.2	32.7	32	89	89.3	42	79.6	37.7	83.1	87.2
Gravel (>2.00 mm) (%)				1								<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Organics																	
Total Organic Carbon (%)			0.05	0.05	0.81	0.44	1.4	0.16	0.89	0.35	0.36	0.188	0.471	0.274	0.605	0.277	0.217
Total Metals																	
Arsenic (µg/g)	7.24		0.5	0.1								**9.74**	**7.25**	3.69	5.17	3.37	3.91
Cadmium (µg/g)	0.7	0.6	0.05	0.05								0.053	0.174	0.085	0.12	0.076	0.078
Chromium (µg/g)	52.3		1	0.5								29.7	40.4	34.1	34.8	41	36.2
Copper (µg/g)	18.7		0.5	0.5								12.7	**27.2**	14.9	**20.3**	14.9	13
Lead (µg/g)	30.2		0.1	0.5								5.95	5.82	2.71	3.92	2.75	2.43
Mercury (µg/g)	0.13	0.75	0.05	0.005								0.0224	0.0399	0.0294	0.0289	0.0153	0.0184
Zinc (µg/g)	124		1	2								39.2	64.4	43.2	50.5	43.6	39.2
PAH																	
Total PAH's (µg/g)		2.5	0.05	0.2								<0.20	<0.20	<0.20	<0.20	<0.037	<0.037
PCB																	
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	varies	0.02	0.000243	0.00000651	0.000634	0	0.00000196	0.0000014	0.00000218	<0.020	<0.020	0.0000146	<0.020	<0.020	<0.020

Appendix B: Tug Basin Expansion Area Sediment Analytical Data (Table IR3-25-B2)

					Hemmera 2017						Hemmera 2017						Hemmera 2017					
				Location ID:	ETB16-2						ETB16-3						ETB16-4					
				Sample ID:	ETB16-2-01	ETB16-2-03	ETB16-2-04	ETB16-2-05	ETB16-2-06	ETB16-2-07	ETB16-3-01	ETB16-3-02	ETB16-3-03	ETB16-3-04	ETB16-3-05	ETB16-3-07	ETB16-4-01	ETB16-4-03	ETB16-4-04	ETB16-4-05	ETB16-4-06	ETB16-4-07
				Date Sampled:	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016
				Sample Depth (m):	0.3-0.4	0.7-0.9	1.9-2.1	3.0-3.2	5.0-5.2	7.0-7.1	0.3-0.4	0.7-0.9	1.9-2.1	3.0-3.2	5.0-5.2	7.0-7.1	0.3-0.4	0.7-0.9	1.9-2.1	3.0-3.2	5.0-5.2	7.0-7.1
				Sample Depth Mid Point (m):	0.35	0.8	2	3.1	5.1	7.05	0.35	0.8	2	3.1	5.1	7.05	0.35	0.8	2	3.1	5.1	7.05
				Sample Locaton (GPS):	5430117.943/489003.82						5430165.649/489092.606						5430190.511/489043.225					
Parameter	**CCME MW ISQG [3,4]**	**DAS LL [5,6]**	**Detection Limits EIS Appendix 9.6-B**	**Detection Limits Hemmera 2017**																		
Grain Size																						
Clay (<4 um) (%)			varies	1	2.4	12.7	3.6	12.5	1.1	3.1	9	11	2.3	1.3	1.6	3.6	2.2	6.5	9.9	6.1	1.7	2.4
Silt (0.004-0.063 mm) (%)			varies	1	5.8	50	16.7	61.8	5	13.7	33.7	51.6	9.7	5.6	7.2	17.3	5.6	33.2	48.6	33.9	8	9.9
Sand (0.063-2.00 mm) (%)			varies	1	90.7	37.3	79.8	25.7	93.9	83.2	57.3	37.4	88	93.1	91.2	79.1	92.1	60.3	41.5	60	90.3	87.8
Gravel (>2.00 mm) (%)				1	1.1	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Organics																						
Total Organic Carbon (%)			0.05	0.05	0.152	0.465	0.322	0.831	0.13	0.256	0.461	0.571	0.25	0.206	0.185	0.287	0.16	0.471	0.672	0.517	0.207	0.234
Total Metals																						
Arsenic (µg/g)	7.24		0.5	0.1	**10.9**	5.14	3.82	6.33	2.18	4.35	**7.75**	5.91	4.52	3.03	2.32	4.29	**9.98**	**7.66**	6.34	4.55	2.47	3.96
Cadmium (µg/g)	0.7	0.6	0.05	0.05	<0.050	0.17	0.07	0.229	0.087	0.089	0.084	0.158	0.112	0.057	0.074	0.113	<0.050	0.141	0.175	0.142	0.099	0.092
Chromium (µg/g)	52.3		1	0.5	33.3	37.2	29.2	40.5	27.2	32.9	34.9	39.4	35.9	33.3	33.3	34.8	29.3	37.5	36.8	34.7	28.9	31.3
Copper (µg/g)	18.7		0.5	0.5	13	**26.4**	14.1	**31.9**	14.2	16.5	17.1	**27.3**	**19.3**	13.8	14.1	**21.1**	12.3	**25.6**	**26.2**	**23.5**	14.4	16.2
Lead (µg/g)	30.2		0.1	0.5	6.39	5.89	2.5	6.71	2.36	2.89	5.25	5.66	3.82	2.43	2.37	4.37	6.47	4.93	5.3	4.25	2.47	2.85
Mercury (µg/g)	0.13	0.75	0.05	0.005	0.0945	0.0396	0.0216	0.0464	0.0256	0.044	0.0309	0.0431	0.0286	0.0216	0.0142	0.0242	0.0201	0.0369	0.0508	0.0321	0.0189	0.021
Zinc (µg/g)	124		1	2	43.3	62.1	40.8	68.6	38.4	44.4	47.5	63.3	49.3	40.7	37.6	50.7	39.7	56	59.9	52.1	39	42.4
PAH																						
Total PAH's (µg/g)		2.5	0.05	0.2	<0.20	<0.20	<0.20	<0.20	<0.037	<0.037	<0.20	<0.20	<0.20	<0.20	<0.037	<0.037	<0.20	<0.20	<0.20	<0.20	<0.037	<0.037
PCB																						
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	varies	0.02	<0.020	<0.020	0.0000163	<0.020	<0.020	<0.020	<0.020	<0.020	0.0000222	<0.020	<0.020	<0.020	<0.020	<0.020	0.0000158	<0.020	<0.020	<0.020

Appendix B: Tug Basin Expansion Area Sediment Analytical Data (Table IR3-25-B2)

					Hemmera 2017						Hemmera 2017					
	Location ID:				ETB16-5						ETB16-6					
	Sample ID:				ETB16-5-01	ETB16-5-02	ETB16-5-03	ETB16-5-04	ETB16-5-06	ETB16-5-07	ETB16-6-01	ETB16-6-02	ETB16-6-03	ETB16-6-05	ETB16-6-06	ETB16-6-07
	Date Sampled:				16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016
	Sample Depth (m):				0.3-0.4	0.7-0.9	1.9-2.1	3.0-3.2	5.0-5.2	7.0-7.1	0.3-0.4	0.7-0.9	1.9-2.1	3.0-3.2	5.0-5.2	7.0-7.1
	Sample Depth Mid Point (m):				0.35	0.8	2	3.1	5.1	7.05	0.35	0.8	2	3.1	5.1	7.05
	Sample Locaton (GPS):				5430289.533/489104.318						5430305.809/489258.05					
Parameter	**CCME MW ISQG [3,4]**	**DAS LL [5,6]**	**Detection Limits EIS Appendix 9.6-B**	**Detection Limits Hemmera 2017**												
Grain Size																
Clay (<4 um) (%)			varies	1	2.1	3.3	3.5	1.5	<1.0	1.5	1.2	9.7	2	7.5	10.6	2
Silt (0.004-0.063 mm) (%)			varies	1	6.5	11.7	20.2	7.5	4.8	7	4.6	50.7	10	33.7	37.7	16.2
Sand (0.063-2.00 mm) (%)			varies	1	91.4	84.9	76.4	90.9	94.4	91.5	94.2	39.5	88	58.8	51.7	81.8
Gravel (>2.00 mm) (%)				1	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Organics																
Total Organic Carbon (%)			0.05	0.05	0.161	0.171	0.749	0.195	0.134	0.12	0.098	0.883	0.214	0.758	0.409	0.214
Total Metals																
Arsenic (µg/g)	7.24		0.5	0.1	**8.85**	4.73	5.05	4.3	2.22	2.25	2.9	4.76	6.15	4.48	**7.97**	2.94
Cadmium (µg/g)	0.7	0.6	0.05	0.05	<0.050	0.052	0.109	0.104	0.085	0.067	0.052	0.072	0.151	0.108	0.206	0.096
Chromium (µg/g)	52.3		1	0.5	29.9	33	34.6	32.1	27.7	28.6	35.8	33.3	33.3	29.2	43	29.5
Copper (µg/g)	18.7		0.5	0.5	13	13.3	**18.7**	18.2	13.3	12.7	11.9	14	17.9	18	**28.1**	15.2
Lead (µg/g)	30.2		0.1	0.5	6.67	3.2	3.38	3.17	2.23	2.17	2.32	2.7	3.06	3.04	5.68	2.56
Mercury (µg/g)	0.13	0.75	0.05	0.005	0.02	0.0261	0.0268	0.0235	0.0306	0.0149	0.0156	0.0748	0.03	0.0262	0.0382	0.0214
Zinc (µg/g)	124		1	2	39.4	40.2	49.3	46.9	35.5	33.9	37.8	41	43.1	44	63.9	40.1
PAH																
Total PAH's (µg/g)		2.5	0.05	0.2	<0.20	<0.20	<0.20	<0.20	<0.037	<0.037	<0.20	<0.20	<0.20	<0.20	<0.037	<0.037
PCB																
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	varies	0.02	<0.020	<0.020	0.0000221	<0.020	<0.020	<0.020	<0.020	<0.020	0.0000429	<0.020	<0.020	<0.020

Appendix B: Tug Basin Sediment Analytical Data (Table IR3-25-B3)

			Hemmera 2017					
	Location ID:		TB16-1		TB16-1		TB16-1	
	Sample ID:		TB16-1-01	TB16-1-02	TB16-2-01	TB16-2-02	TB16-3-01	TB16-3-02
	Date Sampled:		16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016	16/10/2016
	Sample Depth (m):		0.3-0.4	0.9-1.1	0.3-0.4	0.9-1.1	0.3-0.4	0.9-1.1
	Sample Depth Mid Point (m):		0.35	1	0.35	1	0.35	1
	Sample Locaton (GPS):		5430244.531/489162.155		5430297.7/489194.513		5430269.375/489238.909	
Parameter	**CCME MW ISQG [3,4]**	**DAS LL [5,6]**	**Detection Limit**					
Grain Size								
Clay (<4 um) (%)			1	1.2	1.3	1.2	1.5	1.3	1.1
Silt (0.004-0.063 mm) (%)			1	2.9	3.3	3.7	4.8	2.2	3
Sand (0.063-2.00 mm) (%)			1	94.4	93.9	94.2	92.4	96.5	95.9
Gravel (>2.00 mm) (%)			1	1.5	1.5	<1.0	1.3	<1.0	<1.0
Organics								
Total Organic Carbon (%)			0.05	0.195	0.219	0.184	0.21	0.092	0.215
Total Metals								
Arsenic (µg/g)	7.24		0.1	3.37	3.73	3.46	3.74	3.78	4.21
Cadmium (µg/g)	0.7	0.6	0.05	<0.050	<0.050	0.053	<0.050	0.07	0.069
Chromium (µg/g)	52.3		0.5	28.9	24.2	22.4	23.2	26.7	28.5
Copper (µg/g)	18.7		0.5	10.8	10.9	10.4	10.5	14.6	13.3
Lead (µg/g)	30.2		0.5	2.32	2.17	2.13	2.26	2.7	2.4
Mercury (µg/g)	0.13	0.75	0.005	0.0156	0.0219	0.0177	0.0191	0.0194	0.0172
Zinc (µg/g)	124		2	35.1	36.3	35.1	35.3	38.2	36.6
PAH								
Total PAH's (µg/g)		2.5	0.2	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
PCB								
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	0.02	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020

Notes

(1) All values are reported as µg/g unless otherwise noted
(2) - = No standard or not analyzed
(3) CCME = Canadian Council of Ministers of the Environment, Canadian Environmental Quality Guidelines, 1999, updated to November 30, 2011
(4) CCME MW ISQG = Chapter 6, Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, Summary Tables, Table 2 Marine, Interim Sediment Quality Guidelines, Update 2002
(5) DAS = Canadian Environmental Protection Act, Disposal at Sea Regulations, SOR/2001-275, including amendments up to SOR/2003-295, s.1(F)
(6) DAS LAL = Section 4, Mechanisms for Screening, Lower Action Levels

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IR3-26 Surficial Geology and Marine Sediment – Contaminant Levels in Sediment: Copper Level Comparisons

Information Source(s)

EIS Volume 2: Section 9.6, Appendix 9.6-B

Context

As stated by the Proponent in Section 9.6 of the EIS, copper levels in Project activity areas are not considered to be contaminated relative to natural conditions. Although Appendix 9.6-B identified that the elevated copper sediment concentrations likely reflect naturally occurring concentrations rather than recent anthropogenic inputs, this conclusion cannot be verified by looking at the values shown in Table 9.6-4 of Section 9.6. To validate this conclusion, it is necessary to do a valid statistical test using the data collected on copper concentrations.

Information Request

Using the original data presented in Section 9.6 of the EIS and any new data obtained from IR3-25 above, carry out a statistical test to evaluate the hypothesis that there is no difference in copper concentrations between the dredge basin, the tug basin, Fraser River dredgeate, and the Proponent's candidate DaS areas.

VFPA Response

To inform the assessment of potential changes to sediment quality as a result of the Project, copper sediment concentrations were obtained from sediments sampled in the proposed dredge basin, tug basin, and discharge area[1] locations, and Fraser River maintenance dredging areas in the navigational channel, as explained in IR3-27. **Table IR3-26-1** summarises the 2011, 2013, and 2016 sampling campaigns conducted in these areas and the locations where copper concentration data for these areas are provided.

[1] The discharge area for decant water from the containment dykes during infilling is no longer referred to as the Roberts Bank candidate disposal at sea area for the reasons explained in the Preamble provided at the beginning of this response package.

Table IR3-26-1 Sediment Sampling Summary for Copper Concentrations

Sampling Area	Sampling Campaigns	Data Location
Dredge Basin	2011 – Sub-surface sediments 2013 – Surface and sub-surface sediments 2016 – Near surface sediments	Appendix IR3-25-B: Table IR3-25-B1
Tug Basin	2013 – Surface and sub-surface sediments 2016 – Near surface sediments	Appendix IR3-25-B: Tables IR3-25-B2 and IR3-25-B3
Fraser River Maintenance Dredging Area	2013 – Surface sediments	Appendix IR3-27-A: Tables IR3-27-A1 and IR3-27-A2
Discharge Area	2013 – Surface sediments	Appendix IR3-27-A: Tables IR3-27-A1 and IR3-27-A2

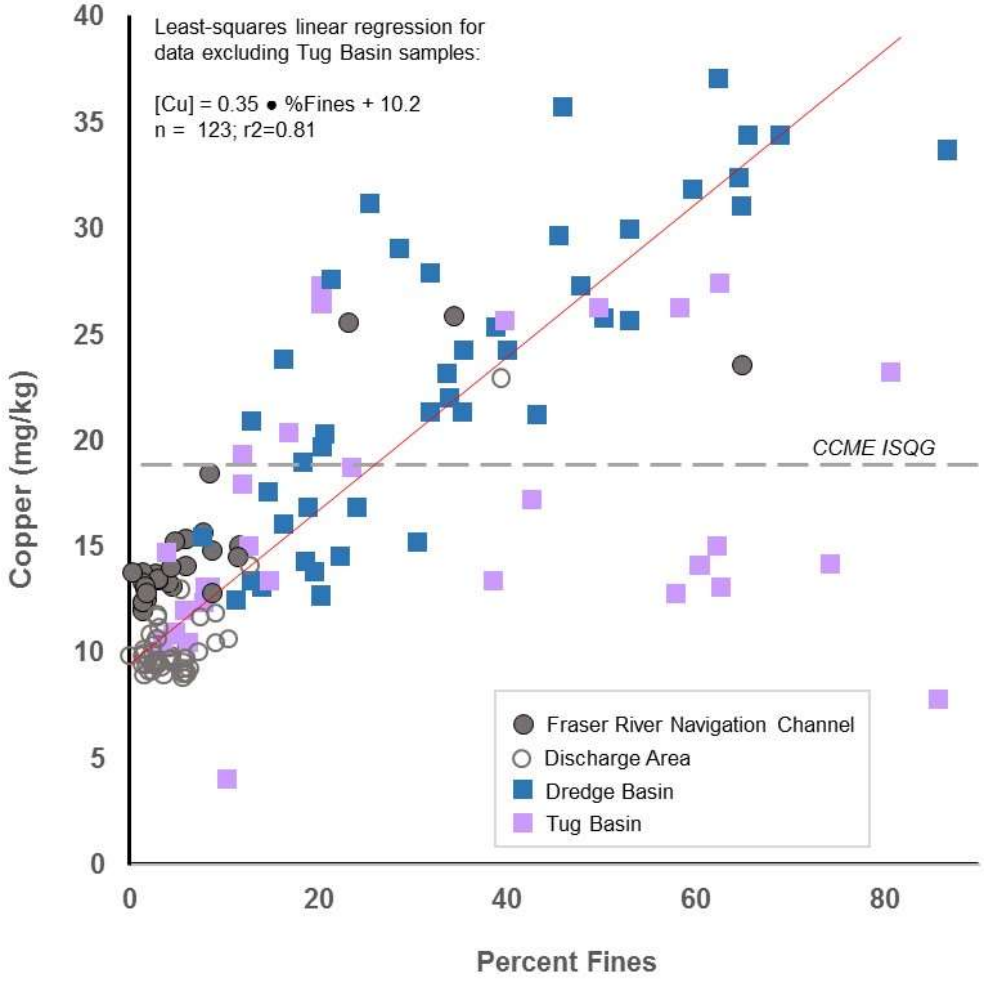
The results of statistical evaluations to test the hypothesis that there is no difference in copper concentrations between the dredge basin, tug basin, the discharge area, and Fraser River locations are presented below.

Statistical Evaluation

As described in EIS Section 9.6.6.2, a strong relationship exists between metals and the amount of fines (and total organic carbon) in sediments. The trend of higher copper concentrations with finer-grained sediments was illustrated in EIS Figure 9.6-5. Based on this known association, an analysis of this relationship was conducted for copper concentrations in sediment from the dredge basin, tug basin, discharge area, and the Fraser River. The dredge basin, the discharge area, and Fraser River exhibit a consistent relationship between copper concentration and percent fines (i.e., silt and clay sized particles less than 63 µm (micrometres)), as shown in **Figure IR3-26-1**. Based on 123 sediment samples from these three locations, sediment texture (as percent fines) was shown to be a highly significant predictor of copper concentration ($p << 0.01$) in this dataset, and hence the co-variation of copper and percent fines was taken into consideration prior to statistically comparing copper concentrations between the three areas.

The tug basin sediment samples depart from the relationship (i.e., copper concentrations do not increase with increasing percent fines content), as shown in **Figure IR3-26-1**. This is likely due to the constrained supply of sediment from Fraser River discharge to the inter-causeway area as a result of the Roberts Bank causeway (refer to IR3-28 for more information on spatial trends being influenced by the Fraser River plume at Roberts Bank). The generally lower copper concentrations in finer textured sediments within the tug basin area in comparison with the other three areas may also indicate a greater influence of detrital organic matter from local primary and secondary production, or alternatively greater scavenging of copper from the water and surficial sediments based on uptake in eelgrass and other locally dominant biota. Based on the lack of co-variation between copper and percent fines in tug basin sediments, data from the tug basin were excluded from further statistical analyses.

Figure IR3-26-1 Co-variation Between Sediment Copper Concentration and Percent Fines



Copper concentration data from the dredge basin, discharge area, and Fraser River were further evaluated using an Analysis of Covariance (ANCOVA) to evaluate possible differences in copper concentration in sediments between these three areas. After adjusting for co-variations with texture (standardised to a mean value of all $\log_{10}$-transformed percent fines data), the mean copper concentrations for each of the Fraser River maintenance dredge areas in the navigational channel, discharge area, and dredge basin, were 16.2 milligrams per kilogram (mg/kg), 11.5 mg/kg, and 17.4 mg/kg, respectively[2]. The results of the ANCOVA indicated that the three areas are statistically significantly different (for ANCOVA output data, refer to **Appendix IR3-26-A**), even though their copper concentrations follow the same general trendline as illustrated in **Figure IR3-26-1**, and have small differences when comparing the mean copper concentrations for these areas. The small but statistically significant differences in texture-adjusted copper concentrations between discharge area and

[2] After adjusting for the relationship with sediment texture, mean copper concentrations in sediments from the dredge basin, discharge area, and Fraser River were lower than the Canadian Council of Ministers of the Environment interim sediment quality guideline for copper of 18.7 mg/kg.

Fraser River sediments likely reflect differences in the proportion of sediment delivered via settling of the Fraser River discharge plume and other particulate source types (e.g., particles of organic and inorganic matter, plankton). The dredge basin sediments are similar to the Fraser River sediments with regard to copper concentrations and co-variance with sediment texture (samples from these two areas had similar texture-normalised average copper concentrations of 17.4 mg/kg and 16.2 mg/kg, respectively).

Overall, the evaluation of copper concentrations between areas, and in relation to sediment texture as an important co-variate, reinforces the understanding that copper concentrations in sediments are a reflection of the potential for the settling and retention of finer textured sediments. Percent fines content in sediments accounted for 81% of the observed variation in copper concentrations across samples analysed from the dredge basin, discharge area, and Fraser River. Copper concentrations in sediments, if textural variations in sediment are accounted for, will generally reflect concentrations in sediments from the Fraser River discharge plume within closer proximity to the mouth of the Fraser River (e.g., on Sturgeon Bank and Roberts Bank), and an increasing influence of other particulate sources (including different copper sources) farther away (e.g., on Boundary Bay).

Appendices

Appendix IR3-26-A ANCOVA Statistical Analysis Output

APPENDIX IR3-36-A
ANCOVA STATISTICAL ANALYSIS OUTPUT

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Appendix IR3-26-A: ANCOVA Statistical Analysis Output

ANCOVA Single Factor

	SS	df	MS	F	p-value
Covariate	0.489031926	1	0.489031926	71.65829539	7.75902E-14
Between	0.566436695	2	0.283218348	41.50024351	2.12117E-14
Within	0.812115316	119	0.006824498		
Total	4.02646471	122			

	mean	adj mean	adj mean back-transformed
Fraser River	1.158479605	1.209165516	16.18696829
Discharge Area	1.000669636	1.060105074	11.48431442
Dredge Basin	1.344013425	1.239540187	17.35961891

Homogeneity of Slopes Test

R-sq Full	0.861245486
R-sq Red	0.798305617
df1	2
df2	117
F	26.53594627
p-value	3.13956E-10

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IR3-27 Surficial Geology and Marine Sediment – Contaminant Levels in Sediment: Sediment Data

Information Source(s)

EIS Volume 2: Section 9.6, Appendix 9.6-B

Context

Table 9.6-4 of the EIS presented the analytical results of sediment samples collected in 2013 for contaminant analyses as ranges of values. Table 5-1 of Appendix 9.6-B of the EIS presented the statistical summary of the sediment chemistry results, and included averages for contaminants. Table 9.6-4 and Table 5-1 showed exceedances of either Disposal at Sea (DAS) regulations reference criteria or Canadian Council of Ministers of the Environment interim sediment quality guidelines (CCME ISQG) for arsenic, cadmium, and copper by at least some of the sediment samples. However, neither table displays variance measures. In the case of parameters with smaller sample sizes and showing exceedances, such as for arsenic and cadmium, all the data points should be shown to evaluate whether or not exceedances represent outliers.

Contrary to the first paragraph of Section 5.1 of Appendix 9.6-B, Appendix C does not show the complete sediment analytical data for metals or PAHs.

Information Request

Provide a table that includes the following:

- all the parameters measured in Table 5-1;
- data from the dredge basin, tug basin, ITP, Fraser River maintenance dredging sites, and Roberts Bank candidate DAS areas;
- sample size, mean, minimum, maximum and standard deviation for each of the above;
- the method detection limit for each parameter; and
- a comparison with the more stringent criteria between the CCME ISQG or DAS regulations.

For arsenic and cadmium, provide a table showing all the individual data points and the locations where they were collected.

Provide the complete sediment analytical data for metals and PAHs to complete the information in Appendix C of Appendix 9.6-B.

VFPA Response

The concentrations of parameters listed in EIS Appendix 9.6-B in Table 5-1, and other relevant information, are provided for the dredge basin, tug basin, Fraser River maintenance dredging sites, and discharge area receiving decant water from the containment dykes (formerly referred to as the Roberts Bank candidate disposal at sea (DAS) area, as explained in the

Preamble at the beginning of this response package). Information for the intermediate transfer pit (ITP) is not provided, as the ITP is no longer proposed for use as a temporary storage site for Fraser River sand, as outlined in the Preamble.

The VFPA conducted sampling and analysis of sediments[1], including the following:

- Sub-surface sediments from the dredge basin area in 2011;
- Surface and sub-surface sediments from the dredge basin and tug basin areas in 2013;
- Surface sediments from the Fraser River maintenance dredging sites and the discharge area in 2013; and
- Near surface and deeper sediments within and beyond the extent of the areas to be dredged (i.e., dredge prisms) in the dredge basin and tug basin areas in fall 2016.

Table IR3-27-1 provides the requested statistical summaries (sample size, mean, maximum, minimum, and standard deviation) for the sampling campaigns for all parameters listed in Table 5-1 of EIS Appendix 9.6-B for sediments from the Fraser River maintenance dredging sites and the discharge area. Table IR3-25-1 in IR3-25 provides statistical summaries for sediments from the dredge basin and tug basin areas. The summary statistic tables provide comparisons to the Environment and Climate Change Canada (ECCC) Disposal at Sea Regulations Lower Level (DAS LL) concentrations and the Canadian Council of Ministers of the Environment (CCME) Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, including the Interim Marine Sediment Quality Guidelines (ISQGs) and the Probable Effects Levels (PELs). Exceedances are shown in bold text.

Table IR3-27-1 Fraser River Maintenance Dredging Sites and Discharge Area - Summary Statistics for the 2013 Sediment Sampling Campaigns

Parameter	Screening Criteria			Fraser River Maintenance Dredging Sites	Discharge Area
	DAS LL	CCME ISQG	CCME PEL		
Sand (percent)					
No. of samples				30	50
Minimum				35.2	60.8
Mean				92.2	95.1
Maximum				99.6	99.8
Standard Deviation				12.9	5.59
Silt (percent)					
No. of samples				30	50
Minimum				0.4	0.1

[1] Sediment sampling information and results for the 2011, 2013, and 2016 campaigns are detailed in Hemmera 2011, EIS Appendix 9.6-B, and Hemmera 2017, respectively. The specific objectives and scope of each campaign varied; however, all sample collection and analytical methodologies were conducted in accordance with best practices. The earlier sampling campaigns focused on establishing existing conditions in surface and sub-surface sediments to characterise physical parameters, metal concentrations, and contaminant levels (e.g., polychlorinated biphenyls (PCBs)), and the most recent sampling campaign in 2016 focused on characterising at-depth sediments within and beyond the extent of the dredging at the dredge basin (dredging depth to -26.7 m chart datum (CD)) and tug basin (dredging depth to -6.5 m CD) areas.

Parameter	Screening Criteria			Fraser River Maintenance Dredging Sites	Discharge Area
	DAS LL	CCME ISQG	CCME PEL		
Mean				6.6	4.0
Maximum				47.6	31.4
Standard Deviation				9.58	4.5
Clay (percent)					
No. of samples				30	50
Minimum				0.1	0.1
Mean				3.7	1.4
Maximum				17.3	7.9
Standard Deviation				4.61	1.52
TOC (percent)					
No. of samples				30	50
Minimum				0.05	0.05
Mean				0.12	0.08
Maximum				0.67	0.21
Standard Deviation				0.13	0.04
Arsenic (µg/g)		7.24	41.6		
No. of samples				30	50
Minimum				1.93	3.05
Mean				2.92	4.43
Maximum				4.86	7.07
Standard Deviation				0.65	0.67
Cadmium (µg/g)	0.6	0.7	4.2		
No. of samples				30	50
Minimum				0.14	0.06
Mean				0.20	0.13
Maximum				0.40	0.32
Standard Deviation				0.05	0.04
Copper (µg/g)		18.7	108		
No. of samples				30	50
Minimum				11.9	8.67
Mean				14.7	10.2
Maximum				**25.8**	**22.8**
Standard Deviation				3.7	2.11
Chromium (µg/g)		52.3	160		
No. of samples				30	50
Minimum				21.5	22.2
Mean				29.5	29.5
Maximum				49.6	37.5
Standard Deviation				5.98	3.70
Lead (µg/g)		30.2	112		
No. of samples				30	50
Minimum				2.24	2.02
Mean				2.90	2.72
Maximum				5.47	5.13
Standard Deviation				0.86	0.49

Parameter	Screening Criteria			Fraser River Maintenance Dredging Sites	Discharge Area
	DAS LL	CCME ISQG	CCME PEL		
Mercury (µg/g)	0.75	0.13	0.70		
No. of samples				30	50
Minimum				<0.050	<0.05
Mean				0.050	<0.05
Maximum				0.054	<0.05
Standard Deviation				N/A	N/A
Zinc (µg/g)		124	271		
No. of samples				30	50
Minimum				34.0	36.2
Mean				41.2	41.0
Maximum				60.0	60.6
Standard Deviation				6.33	3.57
Total PAHs (µg/g)	2.5				
No. of samples				0	27
Minimum				N/A	<0.050
Mean				N/A	<0.050
Maximum				N/A	<0.050
Standard Deviation				N/A	N/A
Total PCBs (µg/g)	0.1	0.0215	0.189		
No. of samples				30	27
Minimum				0.0000036	0
Mean				0.0000388	0.00002
Maximum				0.000246	0.00015
Standard Deviation				0.000052	0.000028

Notes: Disposal at Sea Regulations Lower Level (DAS LL) concentrations as per Section 4 of the *Disposal at Sea Regulations*. Interim Marine Sediment Quality Guidelines (CCME ISQG) and Probable Effects Levels (CCME PEL) as per Canadian Council of the Ministers of the Environment Sediment Quality Guidelines for the Protection of Aquatic Life. Exceedances of these concentrations are shown in **bold** text.
N/A = not applicable, as statistic could not be calculated based on sample concentrations being less than the analytical detection limit or no analytical information available.

As requested, the complete dataset for sediments analysed from the Fraser River maintenance dredging sites and the discharge area are provided in Tables IR3-27-A1 and IR3-27-A2 of **Appendix IR3-27-A**, along with applicable analytical detection limits. In Appendix IR3-25-B, Tables IR3-25-B1 to IR3-25-B3 provide the requested parameters for sediment samples analysed from the dredge basin and tug basin areas, along with applicable analytical detection limits. For arsenic and cadmium, these tables provide all the individual data points and sample location coordinates.

As shown in **Appendix IR3-27-A**: Table IR3-27-A1, three samples from the Fraser River maintenance dredging sites (FR1-1, FR27-1, and FR29-1 with copper concentrations of 25.8 micrograms per gram (µg/g), 23.4 µg/g, and 25.5 µg/g, respectively) and one sample from the discharge area (DAS47 with a copper concentration of 22.8 µg/g) exceeded the CCME ISQG for copper of 18.7 µg/g. These elevated concentrations are not considered to be outliers, as copper routinely exceeds the CCME ISQG in sediments entrained in the Fraser

River and deposited on the delta due to naturally (i.e., of geologic origin) elevated concentrations of copper in the broader geographic area. All other sample parameters were below DAS LL and CCME ISQG criteria. All parameter concentrations in the sediment samples were far lower than their respective CCME PEL criteria.

Sampling locations within the Fraser River maintenance dredging sites and the discharge area for metals (including arsenic and cadmium), total polycyclic aromatic hydrocarbons (PAHs) (for the discharge area only), and total PCBs are shown in EIS Appendix 9.6-B Figure 4-4 and Figure IR3-27-B1 in **Appendix IR3-27-B**, while sampling locations within the dredge basin and tug basin areas are shown in IR3-25 Appendix IR3-25-A (Figures IR3-25-A1 and IR3-25-A2).

References

Hemmera. 2011. Sediment Assessment – Container Capacity Improvement Program, Terminal 2. Prepared for Port Metro Vancouver and WorleyParsons Canada Services Ltd.

Hemmera. 2017. Roberts Bank Terminal 2 Fall 2016 Disposal at Sea Criteria Sampling. Prepared for Vancouver Fraser Port Authority.

Appendices

Appendix IR3-27-A Supporting Tables

Appendix IR3-27-B Supporting Figures

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APPENDIX IR3-27-A
SUPPORTING TABLES

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Appendix IR3-27-A: Fraser River Maintenance Dredging Sites Analytical Data (Table IR3-27-A1)

			Location ID:	FR001	FR002	FR003	FR004	FR005	FR006	FR007	FR008
			Sample ID:	FR1-1	FR2-1	FR3-1	FR4-1	FR5-1	FR6-1	FR7-1	FR8-1
			Date Sampled:	28/11/2013	28/11/2013	41606	41606	41606	41606	41606	41606
			Sample Depth (m):	0-0.15	0-0.15	0-0.15	0-0.15	0-0.15	0-0.15	0-0.15	0-0.15
			Sample Depth Mid Point (m):	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
			Sample Locaton (GPS x coordinate):	483069.3405	483549.9966	483985.6769	484404.801	484837.823	485254.8398	485637.9671	486068.8069
			Sample Locaton (GPS y coordinate):	5441904.888	5441886.428	5441732.644	5441576.458	5441362.662	5441172.066	5440980.904	5440804.99
Parameter	**CCME MW ISQG [3,4]**	**DAS LL [5,6]**	**Detection Limit**								
Grain Size											
Clay (<4 um) (%)			0.01	8.8	1.6	1.7	<0.010	<0.010	<0.010	1	<0.010
Silt (0.004-0.063 mm) (%)			0.01	25.6	3	<0.010	4.3	2.8	1.6	7	6.1
Sand (0.063-2.00 mm) (%)			0.01	65.6	95.5	98.3	95.9	97.6	98.7	92	94.3
Gravel (>2.00 mm) (%)											
Organics											
Total Organic Carbon (%)			0.05	0.33	0.11	0.056	0.058	0.053	0.093	0.091	0.068
Total Metals											
Arsenic (µg/g)	7.24		0.5	4.4	2.86	2.74	2.95	2.79	2.97	3.19	2.79
Cadmium (µg/g)	0.7	0.6	0.05	0.303	0.166	0.228	0.194	0.183	0.164	0.203	0.151
Chromium (µg/g)	52.3		1	32	29.7	32.2	27	26.6	28.1	27	29.7
Copper (µg/g)	18.7		0.5	25.8	13	12.3	13.2	13.6	13.7	15.5	14
Lead (µg/g)	30.2		0.1	5.47	2.7	2.53	2.54	2.4	2.76	2.85	2.59
Mercury (µg/g)	0.13	0.75	0.05	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Zinc (µg/g)	124		1	60	39.7	38.9	39.8	38.8	38.7	41.9	40.3
PCB											
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	varies	0.000147	0.0000735	0.0000089	0.00000923	0.00000853	0.00000884	0.0000269	0.0000135

Appendix IR3-27-A: Fraser River Maintenance Dredging Sites Analytical Data (Table IR3-27-A1)

			Location ID:	FR009	FR010	FR011	FR012	FR013	FR014	FR015
			Sample ID:	FR9-1	FR10-1	FR11-1	FR12-1	FR13-1	FR14-1	FR15-1
			Date Sampled:	41606	41606	41606	41606	41606	41606	41606
			Sample Depth (m):	0-0.15	0-0.15	0-0.15	0-0.15	0-0.15	0-0.15	0-0.15
			Sample Depth Mid Point (m):	0.075	0.075	0.075	0.075	0.075	0.075	0.075
			Sample Locaton (GPS x coordinate):	486467.052	486792.8405	487223.7008	487664.5039	488109.1995	488566.1752	488999.723
			Sample Locaton (GPS y coordinate):	5440647.05	5440430.392	5440218.531	5440032.695	5439895.522	5439745.334	5439631.471
Parameter	**CCME MW ISQG [3,4]**	**DAS LL [5,6]**	**Detection Limit**							
Grain Size										
Clay (<4 um) (%)			0.01	<0.010	2.4	<0.010	2.6	<0.010	<0.010	<0.010
Silt (0.004-0.063 mm) (%)			0.01	1.6	6.1	6.1	9.1	3.1	3.2	4.4
Sand (0.063-2.00 mm) (%)			0.01	98.9	91.4	94.3	88.3	97.2	96.9	95.6
Gravel (>2.00 mm) (%)										
Organics										
Total Organic Carbon (%)			0.05	0.052	0.08	0.15	0.13	0.064	0.051	0.089
Total Metals										
Arsenic (µg/g)	7.24		0.5	2.67	3.26	3.29	2.56	3.18	2.8	2.71
Cadmium (µg/g)	0.7	0.6	0.05	0.193	0.239	0.144	0.227	0.183	0.161	0.186
Chromium (µg/g)	52.3		1	26.3	29.3	28.8	29.8	28.6	41.8	25.8
Copper (µg/g)	18.7		0.5	12	18.4	15.2	14.9	13.3	13.4	13.9
Lead (µg/g)	30.2		0.1	2.41	3.59	2.89	2.86	2.64	2.5	2.82
Mercury (µg/g)	0.13	0.75	0.05	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Zinc (µg/g)	124		1	37.9	47.7	43.6	40	41.5	43.8	38.9
PCB										
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	varies	0.0000465	0.0000176	0.0000716	0.0000418	0.0000281	0.0000148	0.0000388

Appendix IR3-27-A: Fraser River Maintenance Dredging Sites Analytical Data (Table IR3-27-A1)

			Location ID:	FR016	FR017	FR018	FR019	FR020	FR021	FR022	FR023	FR024
			Sample ID:	FR16-1	FR17-1	FR18-1	FR19-1	FR20-1	FR21-1	FR22-1	FR23-1	FR24-1
			Date Sampled:	41606	41606	41606	41606	41606	41606	41606	41606	20/11/2013
			Sample Depth (m):	0-0.15	0-0.15	0-0.15	0-0.15	0-0.15	0-0.15	0-0.15	0-0.15	0-0.15
			Sample Depth Mid Point (m):	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
			Sample Locaton (GPS x coordinate):	489469.3928	489922.0887	490394.2566	490895.2228	491422.3897	491869.3503	492459.5683	493012.6797	493945.3076
			Sample Locaton (GPS y coordinate):	5439531.303	5439492.625	5439483.855	5439470.52	5439612.139	5439829.834	5440049.647	5440307.107	5440690.054
Parameter	**CCME MW ISQG [3,4]**	**DAS LL [5,6]**	**Detection Limit**									
Grain Size												
Clay (<4 um) (%)			0.01	<0.010	<0.010	<0.010	<0.010	<0.010	1.4	<0.010	<0.010	<0.010
Silt (0.004-0.063 mm) (%)			0.01	1.6	1.8	1.6	1.9	1.6	7.3	1.6	0.4	1.7
Sand (0.063-2.00 mm) (%)			0.01	98.5	98.2	98.7	98.2	98.6	91.2	98.6	99.6	98.5
Gravel (>2.00 mm) (%)												
Organics												
Total Organic Carbon (%)			0.05	0.061	<0.05	<0.05	0.05	0.058	0.16	<0.50	<0.50	0.057
Total Metals												
Arsenic (µg/g)	7.24		0.5	2.7	2.67	2.53	2.3	2.42	2.36	1.93	2.1	2.53
Cadmium (µg/g)	0.7	0.6	0.05	0.177	0.21	0.176	0.182	0.18	0.203	0.196	0.195	0.227
Chromium (µg/g)	52.3		1	21.6	35.4	33.6	27.6	24.5	25.2	24.3	28.4	21.5
Copper (µg/g)	18.7		0.5	11.9	12.9	13.2	12.4	12.3	14.7	12.3	13.7	13
Lead (µg/g)	30.2		0.1	2.27	2.36	2.39	2.26	2.28	2.53	2.24	2.31	2.31
Mercury (µg/g)	0.13	0.75	0.05	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Zinc (µg/g)	124		1	34	40.5	40.9	34.8	35.6	38.8	34.9	36.6	35.6
PCB												
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	varies	0.0000117	0.00000834	0.00000803	0.00000364	0.0000173	0.000117	0.0000153	0.00000572	0.0000104

Appendix IR3-27-A: Fraser River Maintenance Dredging Sites Analytical Data (Table IR3-27-A1)

			Location ID:	FR025	FR026	FR027	FR028	FR029	FR030
			Sample ID:	FR25-1	FR26-1	FR27-1	FR28-1	FR29-1	FR30-1
			Date Sampled:	41606	41606	41606	41606	28/11/2013	28/11/2013
			Sample Depth (m):	0-0.15	0-0.15	0-0.15	0-0.15	0-0.15	0-0.15
			Sample Depth Mid Point (m):	0.075	0.075	0.075	0.075	0.075	0.075
			Sample Locaton (GPS x coordinate):	494919.2391	482567.242	482112.5339	481701.7957	481303.2121	480894.682
			Sample Locaton (GPS y coordinate):	5441326.676	5441758.502	5441591.868	5441308.638	5441007.278	5440701.367
Parameter	**CCME MW ISQG [3,4]**	**DAS LL [5,6]**	**Detection Limit**						
Grain Size									
Clay (<4 um) (%)			0.01	0.1	1.4	17.3	2.9	4.4	3
Silt (0.004-0.063 mm) (%)			0.01	1.9	7.4	47.6	8.6	19	1.9
Sand (0.063-2.00 mm) (%)			0.01	98	91.2	35.2	88.5	76.6	95.1
Gravel (>2.00 mm) (%)									
Organics									
Total Organic Carbon (%)			0.05	0.076	0.08	0.67	0.12	0.25	0.067
Total Metals									
Arsenic (µg/g)	7.24		0.5	2.27	3.17	4.36	3.13	4.86	3.1
Cadmium (µg/g)	0.7	0.6	0.05	0.139	0.202	0.298	0.165	0.401	0.182
Chromium (µg/g)	52.3		1	21.6	28.8	36.6	27	36.4	49.6
Copper (µg/g)	18.7		0.5	12.7	12.7	**23.4**	14.4	**25.5**	15.1
Lead (µg/g)	30.2		0.1	2.3	2.98	5.11	2.84	5.11	2.86
Mercury (µg/g)	0.13	0.75	0.05	<0.050	<0.050	<0.050	<0.050	0.054	<0.050
Zinc (µg/g)	124		1	36.2	38.2	58.2	39.8	57.7	43.4
PCB									
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	varies	0.00000493	0.0000321	0.000246	0.0000269	0.0000894	0.0000118

Appendix IR3-27-A: Discharge Area Analytical Data (Table IR3-27-A2)

			Location ID:	DAS001	DAS002	DAS003	DAS004	DAS005	DAS006	DAS007	DAS008
			Sample ID:	DAS1-1	DAS2-1	DAS3-1	DAS4-1	DAS5-1	DAS6-1	DAS7-1	DAS8-1
			Date Sampled:	20/11/2013	20/11/2013	20/11/2013	20/11/2013	20/11/2013	21/11/2013	21/11/2013	21/11/2013
			Sample Depth (m):	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01
			Sample Depth Mid Point (m):	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
			Sample Locaton (GPS x coordinate):	484535.3705	485032.8053	487032.0348	487289.1122	484281.5351	484798.3468	485302.6216	485792.0198
			Sample Locaton (GPS y coordinate):	5427865.22	5427856.075	5427858.456	5427857.677	5428106.978	5428104.427	5428108.628	5428110.874
Parameter	**CCME MW ISQG [3,4]**	**DAS LAL [5,6]**	**Detection Limit**								
Grain Size											
Clay (<4 um) (%)			0.01	3	2.5	<0.010	1.1	<0.010	<0.010	<0.010	<0.010
Silt (0.004-0.063 mm) (%)			0.01	6.2	3.2	1.8	2	1.6	2.6	3	1.4
Sand (0.063-2.00 mm) (%)			0.01	90.8	94.2	98.6	96.8	98.6	97.5	97	98.7
Gravel (>2.00 mm) (%)											
Organics											
Total Organic Carbon (%)			0.05	0.19	0.076	0.074	0.065	0.078	0.068	0.066	<0.05
Total Metals											
Arsenic (µg/g)	7.24		0.5	4.73	4.39	4.18	3.75	4.21	4.2	3.94	4.1
Cadmium (µg/g)	0.7	0.6	0.05	0.115	0.11	0.067	0.073	0.084	0.143	0.097	0.144
Chromium (µg/g)	52.3		1	31.8	28.3	26.5	25.1	27.9	29.9	31.4	37.5
Copper (µg/g)	18.7		0.5	11.7	9.39	9.24	10.5	8.8	8.97	9.28	9.72
Lead (µg/g)	30.2		0.1	3.3	2.51	2.28	2.02	2.48	2.51	2.66	2.34
Mercury (µg/g)	0.13	0.75	0.05	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Zinc (µg/g)	124		1	45.8	40.5	40.5	40.1	40.8	39.3	40.5	40.3
PAH											
Total PAH's (µg/g)		2.5	0.05		<0.050		<0.050	<0.050			
PCB											
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	varies		0.0000319		0	0.00000582			

Appendix IR3-27-A: Discharge Area Analytical Data (Table IR3-27-A2)

			Location ID:	DAS009	DAS010	DAS011	DAS012	DAS013	DAS014	DAS015	DAS016
			Sample ID:	DAS9-1	DAS10-1	DAS11-1	DAS12-1	DAS13-1	DAS14-1	DAS15-1	DAS16-1
			Date Sampled:	20/11/2013	20/11/2013	20/11/2013	20/11/2013	20/11/2013	20/11/2013	20/11/2013	20/11/2013
			Sample Depth (m):	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01
			Sample Depth Mid Point (m):	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
			Sample Locaton (GPS x coordinate):	486284.8146	486790.5533	487283.4727	487529.3188	487775.0432	488788.687	484048.8585	484534.4276
			Sample Locaton (GPS y coordinate):	5428106.855	5428112.484	5428109.665	5428106.329	5428103.003	5428103.272	5428366.289	5428358.059
Parameter	**CCME MW ISQG [3,4]**	**DAS LAL [5,6]**	**Detection Limit**								
Grain Size											
Clay (<4 um) (%)			0.01	0.9	1.1	2.7	0.2	0.1	2.5	0.1	1.6
Silt (0.004-0.063 mm) (%)			0.01	1.8	3.5	3.3	1.8	1.6	3.5	1.4	3
Sand (0.063-2.00 mm) (%)			0.01	97.3	95.4	94	98.1	98.3	94	98.5	95.4
Gravel (>2.00 mm) (%)											
Organics											
Total Organic Carbon (%)			0.05	0.061	0.068	0.07	0.075	0.081	0.073	0.072	0.09
Total Metals											
Arsenic (µg/g)	7.24		0.5	4.36	3.84	3.55	4.24	3.47	4.66	4.28	3.85
Cadmium (µg/g)	0.7	0.6	0.05	0.059	0.109	0.136	0.128	0.155	0.093	0.063	0.106
Chromium (µg/g)	52.3		1	37.2	35.6	26.1	24.9	29.7	24.3	33.6	33
Copper (µg/g)	18.7		0.5	9.29	9.73	9.54	8.99	9.82	8.89	9.28	9.38
Lead (µg/g)	30.2		0.1	2.41	2.27	2.19	2.61	2.95	2.52	2.63	2.56
Mercury (µg/g)	0.13	0.75	0.05	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Zinc (µg/g)	124		1	40	43.3	37.8	39.1	38.3	39.1	41.1	41.1
PAH											
Total PAH's (µg/g)		2.5	0.05			<0.050	<0.050			<0.050	<0.050
PCB											
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	varies			0.000014	0.0000101			0.0000119	0.000151

Appendix IR3-27-A: Discharge Area Analytical Data (Table IR3-27-A2)

			Location ID:	DAS017	DAS018	DAS019	DAS020	DAS021	DAS022	DAS023	DAS025	DAS026	DAS027
			Sample ID:	DAS17-1	DAS18-1	DAS19-1	DAS20-1	DAS21-1	DAS22-1	DAS23-1	DAS25-1	DAS26-1	DAS27-1
			Date Sampled:	21/11/2013	21/11/2013	21/11/2013	20/11/2013	20/11/2013	20/11/2013	20/11/2013	20/11/2013	21/11/2013	21/11/2013
			Sample Depth (m):	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01
			Sample Depth Mid Point (m):	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
			Sample Locaton (GPS x coordinate):	485042.4601	485545.8185	486036.164	486534.5833	487031.6266	487543.1752	488045.3424	483793.3852	484285.6444	484784.9875
			Sample Locaton (GPS y coordinate):	5428362.966	5428351.998	5428351.855	5428363.963	5428362.039	5428360.497	5428360.689	5428616.411	5428611.29	5428611.381
Parameter	**CCME MW ISQG [3,4]**	**DAS LAL [5,6]**	**Detection Limit**										
Grain Size													
Clay (<4 um) (%)			0.01	<0.010	<0.010	0.1	2.4	<0.010	1.5	2.9	0.1	0.5	0.3
Silt (0.004-0.063 mm) (%)			0.01	3.4	3.1	2.1	3.4	3.1	1.6	0.1	<0.010	6	2.8
Sand (0.063-2.00 mm) (%)			0.01	96.6	97.1	97.9	94.1	97.2	96.9	97	99.8	93.5	95.7
Gravel (>2.00 mm) (%)													
Organics													
Total Organic Carbon (%)			0.05	0.055	0.067	0.072	0.08	0.072	0.073	0.083	0.063	0.073	0.051
Total Metals													
Arsenic (µg/g)	7.24		0.5	4.23	4.02	4.7	3.92	3.94	4.01	3.05	4.35	4.01	4.12
Cadmium (µg/g)	0.7	0.6	0.05	0.141	0.103	0.16	0.15	0.138	0.112	0.164	0.062	0.136	0.162
Chromium (µg/g)	52.3		1	29.5	33.6	24.8	26.9	31.2	27.8	22.2	33.6	26.8	27.5
Copper (µg/g)	18.7		0.5	9.19	9.5	9.54	8.88	9.52	11.5	11.6	9.67	9.1	10.5
Lead (µg/g)	30.2		0.1	2.52	2.38	2.65	2.39	2.42	2.44	2.24	2.68	2.46	2.8
Mercury (µg/g)	0.13	0.75	0.05	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Zinc (µg/g)	124		1	38.7	40.7	39.2	39.2	38.7	38.5	36.2	41.9	38.1	41.1
PAH													
Total PAH's (µg/g)		2.5	0.05	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050			
PCB													
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	varies	0.00000576	0.0000131	0.0000144	0.0000129	0.0000245	0.0000169	0.0000178			

Appendix IR3-27-A: Discharge Area Analytical Data (Table IR3-27-A2)

			Location ID:	DAS028	DAS029	DAS030	DAS031	DAS032	DAS033	DAS034	DAS035	DAS036	DAS037
			Sample ID:	DAS28-1	DAS29-1	DAS30-1	DAS31-1	DAS32-1	DAS33-1	DAS34-1	DAS35-1	DAS36-1	DAS37-1
			Date Sampled:	21/11/2013	21/11/2013	22/11/2013	22/11/2013	21/11/2013	20/11/2013	21/11/2013	21/11/2013	22/11/2013	22/11/2013
			Sample Depth (m):	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01
			Sample Depth Mid Point (m):	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
			Sample Locaton (GPS x coordinate):	485285.1836	485782.8161	486294.9409	486790.7748	487296.1828	483542.1825	484037.239	484534.4864	485038.3078	485547.8712
			Sample Locaton (GPS y coordinate):	5428611.515	5428610.218	5428604.298	5428615.324	5428603.583	5428860.42	5428860.826	5428860.345	5428857.296	5428859.466
Parameter	**CCME MW ISQG [3,4]**	**DAS LAL [5,6]**	**Detection Limit**										
Grain Size													
Clay (<4 um) (%)			0.01	1.6	<0.010	0.7	0.5	<0.010	1.6	0.4	1.3	<0.010	0.5
Silt (0.004-0.063 mm) (%)			0.01	7.5	1.7	2.6	3.9	3.6	0.7	4.2	1.8	3.2	2.1
Sand (0.063-2.00 mm) (%)			0.01	90.9	98.3	96.8	95.7	96.4	97.7	95.4	96.9	97.3	97.4
Gravel (>2.00 mm) (%)													
Organics													
Total Organic Carbon (%)			0.05	0.11	0.061	<0.05	0.074	0.061	0.091	0.083	0.08	0.066	0.053
Total Metals													
Arsenic (µg/g)	7.24		0.5	4.51	5.26	4.68	7.07	4.22	4.06	4.75	4.28	3.66	5.99
Cadmium (µg/g)	0.7	0.6	0.05	0.157	0.149	0.174	0.097	0.159	0.123	0.157	0.164	0.12	0.146
Chromium (µg/g)	52.3		1	25	33.9	27.1	26.6	29	29.1	26.6	24.7	35	24.8
Copper (µg/g)	18.7		0.5	10.3	10	11	10.1	8.73	10.7	9.58	10.5	9.43	9.36
Lead (µg/g)	30.2		0.1	2.67	2.63	2.38	3.51	2.68	2.7	2.73	2.55	2.62	2.9
Mercury (µg/g)	0.13	0.75	0.05	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Zinc (µg/g)	124		1	40.6	41.8	39.9	46.5	38.7	43.3	40.3	40.6	39.1	39.8
PAH													
Total PAH's (µg/g)		2.5	0.05				<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
PCB													
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	varies				0.0000184	0.00000968	0.0000124	0.000046	0.00000299	0.0000153	0.0000141

Appendix IR3-27-A: Discharge Area Analytical Data (Table IR3-27-A2)

			Location ID:	DAS038	DAS039	DAS040	DAS041	DAS042	DAS043	DAS044	DAS045	DAS046	DAS047
			Sample ID:	DAS38-1	DAS39-1	DAS40-1	DAS41-1	DAS42-1	DAS43-1	DAS44-1	DAS45-1	DAS46-1	DAS47-1
			Date Sampled:	22/11/2013	21/11/2013	21/11/2013	21/11/2013	22/11/2013	22/11/2013	21/11/2013	21/11/2013	21/11/2013	22/11/2013
			Sample Depth (m):	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01	0-0.02
			Sample Depth Mid Point (m):	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	1.005
			Sample Locaton (GPS x coordinate):	486037.8188	486540.0467	483786.3174	484283.773	484780.1324	485285.1698	485784.7012	483542.1825	484036.8408	484538.4168
			Sample Locaton (GPS y coordinate):	5428864.326	5428857.713	5429117.422	5429112.47	5429107.567	5429111.948	5429108.238	5428860.42	5429357.926	5429352.43
Parameter	**CCME MW ISQG [3,4]**	**DAS LAL [5,6]**	**Detection Limit**										
Grain Size													
Clay (<4 um) (%)			0.01	0.3	<0.010	0.1	<0.010	<0.010	0.8	0.3	0.2	2.5	
Silt (0.004-0.063 mm) (%)			0.01	2.2	5.7	5.9	2.6	4.4	5.5	5.4	2.3	10.2	
Sand (0.063-2.00 mm) (%)			0.01	97.5	94.4	94	97.4	98.9	93.7	94.3	97.6	87.2	
Gravel (>2.00 mm) (%)													
Organics													
Total Organic Carbon (%)			0.05	0.06	0.066	<0.05	0.056	0.07	0.068	0.058	0.08	0.16	0.21
Total Metals													
Arsenic (µg/g)	7.24		0.5	5.01	3.99	4.66	4.37	4.63	4.94	4.1	5.09	5.44	
Cadmium (µg/g)	0.7	0.6	0.05	0.154	0.116	0.155	0.114	0.11	0.102	0.145	0.172	0.174	
Chromium (µg/g)	52.3		1	27.1	30.8	35.7	32.7	31.7	27.5	30	27.1	32.2	
Copper (µg/g)	18.7		0.5	10.2	9.12	9.61	9.3	9.44	8.87	8.67	9.92	14	
Lead (µg/g)	30.2		0.1	2.79	2.49	2.76	2.65	2.83	2.86	2.67	2.79	3.84	
Mercury (µg/g)	0.13	0.75	0.05	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	
Zinc (µg/g)	124		1	40.1	38.8	41.5	40.2	39.6	39.2	38.5	39.9	46.9	
PAH													
Total PAH's (µg/g)		2.5	0.05	<0.050						<0.050	<0.050	<0.050	
PCB													
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	varies	0.00000467						0.00000994	0.0000124	0.0000391	0.00000952

Appendix IR3-27-A: Discharge Area Analytical Data (Table IR3-27-A2)

			Location ID:	DAS047	DAS048	DAS049	DAS050	DAS051
			Sample ID:	DAS47-2	DAS48-1	DAS49-1	DAS50-1	DAS51-1
			Date Sampled:	22/11/2013	21/11/2013	21/11/2013	21/11/2013	21/11/2013
			Sample Depth (m):	0-0.05	0-0.01	0-0.01	0-0.01	0-0.01
			Sample Depth Mid Point (m):	0.025	0.005	0.005	0.005	0.005
			Sample Locaton (GPS x coordinate):	485031.3653	483784.1043	484282.98	483536.9877	484048.3985
			Sample Locaton (GPS y coordinate):	5429355.896	5429611.192	5429606.978	5429861.674	5429859.81
Parameter	**CCME MW ISQG [3,4]**	**DAS LAL [5,6]**	**Detection Limit**					
Grain Size								
Clay (<4 um) (%)			0.01	7.9	0.4	2.3	1.5	4
Silt (0.004-0.063 mm) (%)			0.01	31.4	7	3.1	9.1	3.5
Sand (0.063-2.00 mm) (%)			0.01	60.8	92.6	94.6	89.4	92.6
Gravel (>2.00 mm) (%)								
Organics								
Total Organic Carbon (%)			0.05		0.087	0.11	0.19	0.11
Total Metals								
Arsenic (µg/g)	7.24		0.5	5.02	4.78	4.46	5.41	4.96
Cadmium (µg/g)	0.7	0.6	0.05	0.322	0.15	0.211	0.18	0.164
Chromium (µg/g)	52.3		1	32.4	26.3	30.2	33	29
Copper (µg/g)	18.7		0.5	**22.8**	9.93	12.8	10.5	11.5
Lead (µg/g)	30.2		0.1	5.13	2.81	3.35	3.16	3.3
Mercury (µg/g)	0.13	0.75	0.05	<0.050	<0.050	<0.050	<0.050	<0.050
Zinc (µg/g)	124		1	60.6	41.2	43.9	43.9	43.4
PAH								
Total PAH's (µg/g)		2.5	0.05	<0.050				<0.050
PCB								
Total Polychlorinated Biphenyls (µg/g)	0.0215	0.1	varies					0.0000185

Notes

(1) All values are reported as µg/g unless otherwise noted
(2) - = No standard or not analyzed
(3) CCME = Canadian Council of Ministers of the Environment, Canadian Environmental Quality Guidelines, 1999, updated to November 30, 2011
(4) CCME MW ISQG = Chapter 6, Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, Summary Tables, Table 2 Marine, Interim Sediment Quality Guidelines, Update 2002
(5) DAS = Canadian Environmental Protection Act, Disposal at Sea Regulations, SOR/2001-275, including amendments up to SOR/2003-295, s.1(F)
(6) DAS LL = Section 4, Mechanisms for Screening, Lower Action Levels

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APPENDIX IR3-27-B
SUPPORTING FIGURES

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Path: O:\!\1200-\1246\EIS_INFORMATION_REQUEST\SIR3_27\mxd\RBT2_IR3_27_B1_DischargeSampling_170424.mxd

Legend

- DISCHARGE SITE SAMPLING LOCATIONS
- RBT2 DISCHARGE AREA
- RBT2 BOUNDARY
- DREDGE BASIN
- BATHYMETRY (5 M INTERVAL, M CD)
- U.S.A.-CANADA BORDER

0 300 600
Metres

N

1:15,000

NAD 1983 UTM Zone 10N

PORT of vancouver

ROBERTS BANK TERMINAL 2

2013 RBT2 DISCHARGE AREA SAMPLING LOCATIONS

DATE:	FIG No.
05/31/2017	IR3-27-B1

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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IR3-28 Surficial Geology and Marine Sediment – Contaminant Levels in Sediment: Spatial Trends

Information Source(s)

EIS Volume 2: Appendix 9.6-A

Context

In Table 13 of Appendix 9.6-A of the EIS, the Proponent compared the analytical results for various contaminant parameters against CCME sediment quality guidelines. The results in the table identified that there were some exceedances of arsenic, chromium, copper, mercury, and several PAHs at Roberts Bank. Although there are numerous maps included in Appendix 9.6-A to demonstrate the spatial distribution of various parameters, there are no maps indicating the location of samples of arsenic, chromium, copper, mercury, and PAHs that were found to be in exceedance of the CCME guidelines.

Information Request

Using the sample data input into Table 13 of Appendix 9.6-A of the EIS, provide maps indicating the location and concentrations of all individual samples found to exceed CCME Sediment Quality Guidelines for the Roberts Bank area.

Provide a discussion of the exceedance(s) of arsenic, chromium, copper, mercury and PAHs, and describe any spatial trends observed in the Roberts Bank area.

VFPA Response

Using the sample data input into Table 13 of Appendix 9.6-A of the EIS, provide maps indicating the location and concentrations of all individual samples found to exceed CCME Sediment Quality Guidelines for the Roberts Bank area.

Table 13 of EIS Appendix 9.6-A provided summary statistics for surface sediment samples collected from 10 field sampling campaigns conducted at Roberts Bank, Sturgeon Bank, and Boundary Bay during the period of April 2012 to September 2013 and subsequently analysed for arsenic, chromium, copper, mercury, and polycyclic aromatic hydrocarbons (PAHs). Table 13 of EIS Appendix 9.6-A also provided comparisons to Canadian Council of Ministers of the Environment (CCME) Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, including the Interim Marine Sediment Quality Guidelines (ISQGs) and the Probable Effects Levels (PELs). Surface sediment sampling locations for each sampling campaign were indicated in Figure 10 of EIS Appendix 9.6-A.

Figures IR3-28-A1 to IR3-28-A5 in **Appendix IR3-28-A** show the locations of all samples analysed for arsenic, chromium, copper, mercury, and PAHs, respectively, with the locations of individual samples found to exceed the CCME ISQGs (and CCME PELs outlined, where

relevant)[1]. The associated parameter concentration at each location with an exceedance is also provided.

Provide a discussion of the exceedance(s) of arsenic, chromium, copper, mercury and PAHs, and describe any spatial trends observed in the Roberts Bank area.

Sediment Concentrations Based on Sediment Texture and Organic Content

In general, the spatial distribution of some elements (e.g., metals such as arsenic and copper, PAHs) is proportional to total organic carbon (TOC) content in sediment, which is highly correlated with percent fines[2] in sediment (as shown in Figure 11 of EIS Appendix 9.6-A). Finer-textured sediment and TOC provide a strong sorptive phase for these elements[3]. Figure IR3-28-A6 in **Appendix IR3-28-A** shows the percent TOC concentrations for Roberts Bank, Sturgeon Bank, and Boundary Bay analysed from 2012 to 2013 sampling campaigns. The percentage of TOC (and percent fines) in surface sediment is higher on average on the Sturgeon Bank and Roberts Bank tidal flats compared to the Boundary Bay tidal flat, as illustrated in Figure IR3-28-A6 in **Appendix IR3-28-A** and shown in **Table IR3-28-1**.

Table IR3-28-1 Mean Values (%) for Sediment Size Fractions and Total Organic Carbon

Parameter	Boundary Bay	Roberts Bank	Sturgeon Bank
Percent Sand (63 µm to 2000 µm)	88.8	61.3	63.1
Percent Silt (4 µm to 63 µm)	9.23	31.3	30.0
Percent Clay (less than 4 µm)	1.92	6.92	6.87
Percent Total Organic Carbon	0.30	0.51	0.40

Source: Information from Tables 9 and 10 from EIS Appendix 9.6-A.

The spatial distribution of fine sediments and TOC in the Fraser River estuary is related to the influence of the Fraser River discharge plume. Overall, higher TOC content and exceedances of arsenic, chromium, copper, mercury, or PAHs were more frequently observed at Roberts Bank and Sturgeon Bank in comparison to Boundary Bay. TOC content (and associated parameter concentrations) also varied across the Sturgeon Bank and Roberts Bank tidal flats in an onshore-offshore direction, with higher TOC content and parameter exceedances being

[1] Figures IR3-28-A1 to IR3-28-A4 in **Appendix IR3-28-A** show exceedances of individual samples compared to the respective CCME ISQG value for arsenic, chromium, copper, and mercury, respectively, and not both CCME ISQG and CCME PEL values, as the CCME ISQG values are lower than the CCME PEL values for these parameters of interest (see Table 12 of EIS Appendix 9.6-A for specific CCME Sediment Quality Guideline values). Since the CCME PEL value was exceeded for the PAH 2-Methylnaphthalene in one sample, Figure IR3-28-A5 in **Appendix IR3-28-A** shows exceedances of individual samples compared to both CCME ISQG and CCME PELs.

[2] Fine material (comprised of silt and clay) has an effective particle diameter of less than 63 µm (micrometres).

[3] The strong sorptive phase for the substance of interest is a result of (i) greater amounts of charged molecules on the sediment particle surface that attract metals/metalloids based on ionic and Van der Waals interactions, and (ii) higher amounts of sediment organic matter, which in turn provide a strong sorptive phase.

associated with areas on the seabed and tidal flat that are more quiescent with regard to tidal and wind-generated bottom currents (i.e., these areas have greater retention of finer-textured sediments due to lower wave and current energies). Additional information on the spatial trends of exceedances is provided below for the parameters of interest.

Spatial Trends for Arsenic and Copper Exceedances

Of the 520 surface sediment samples analysed, the spatial distributions for the 61 arsenic and 166 copper exceedances are shown in Figures IR3-28-A1 and IR3-28-A3 in **Appendix IR3-28-A**, respectively. The exceedances reflect geochemical focusing of these naturally occurring trace elements onto organic rich fine silts and clays within the Fraser River discharge plume and the ongoing sedimentation of fines contained in the plume to more quiescent tidal flat and subtidal seabed areas at Sturgeon Bank and Roberts Bank.

Spatial Trends for Chromium and Mercury Exceedances

As shown in Figures IR3-28-A2 and IR3-28-A4 in **Appendix IR3-28-A**, for chromium and mercury, respectively, concentrations are higher in the upper tidal flats at Roberts Bank and Sturgeon Bank, largely due to the correlation with percent fines. Spatial trends were not observed for chromium or mercury exceedances observed at Roberts Bank. Only three of 520 samples exceeded the respective CCME ISQG for mercury and only one sample exceeded the respective CCME ISQG for chromium. The exceedances are spatially discrete and are considered to be anomalous based on the larger sediment quality data set.

Spatial Trends for Polycyclic Aromatic Hydrocarbon

The spatial distribution of individual PAH exceedances (see table inset in Figure IR3-28-A5 in **Appendix IR3-28-A** for the list of 13 PAHs analysed) also reflects an association with higher percent fines and TOC in more quiescent tidal flat and subtidal areas. Incidences of CCME ISQG exceedances in sediment samples for individual PAHs, however, were greater at Roberts Bank than at Sturgeon Bank or Boundary Bay. This observed spatial pattern of PAHs reflects the re-suspension and settlement re-distribution of historically deposited coal particulates in more quiescent areas of Roberts Bank (i.e., greater accumulations of finer-textured PAH-containing particulates from settled coal dust in areas that are prone to accumulation of finer-textured, organic rich sediments).

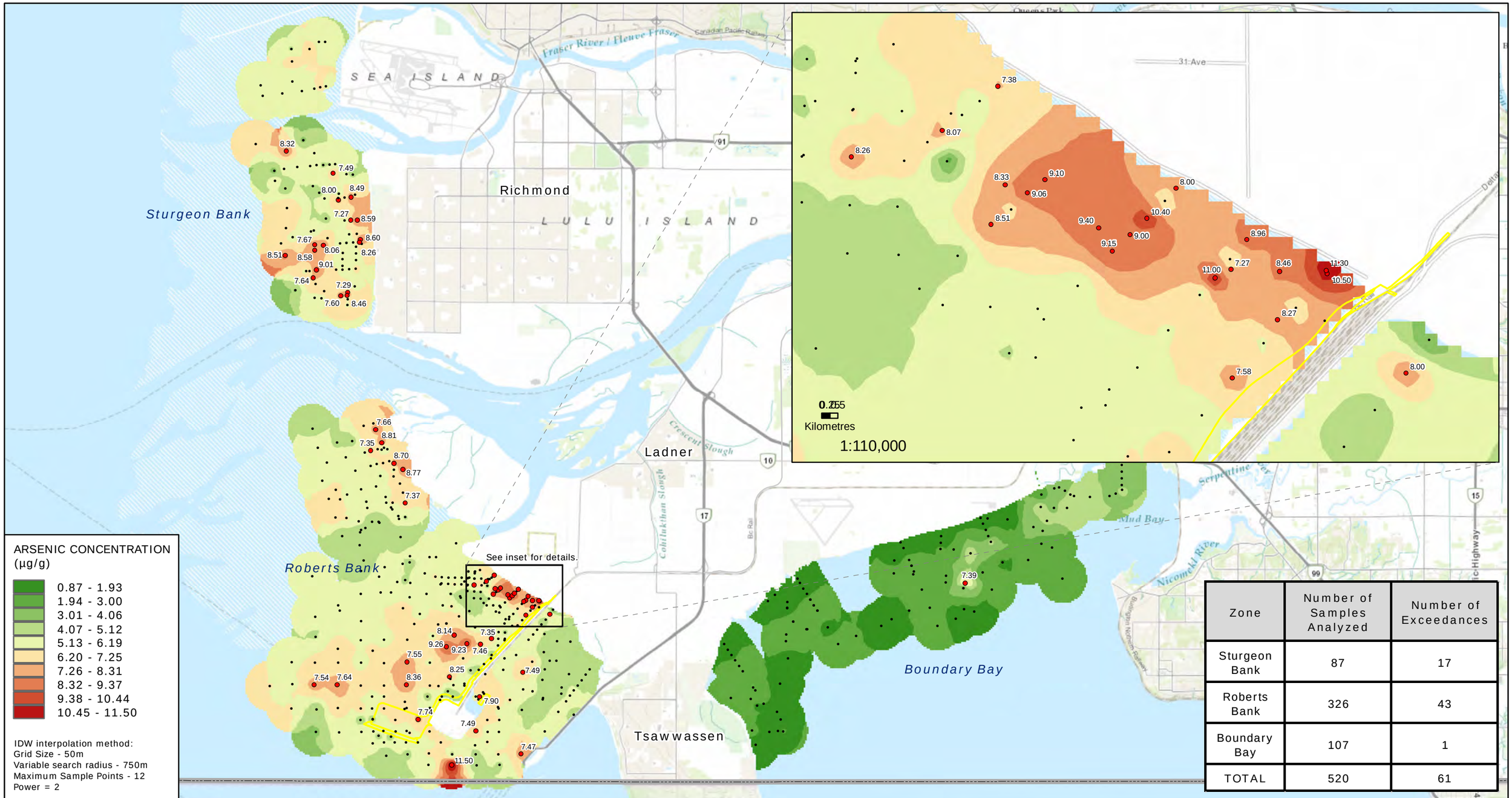
One sample located in the turning basin with a concentration of 0.217 µg/g (micrograms per gram) for 2-methylenapthalene exceeded the CCME PEL of 0.201 µg/g. This area has the highest percentage of coal and TOC observed at Roberts Bank (refer to EIS Figure 9.6-7 and Figure IR3-28-A6 in **Appendix IR3-28-A**, respectively).

Appendices

Appendix IR3-28-A Supporting Figures

APPENDIX IR3-28-A
SUPPORTING FIGURES

Path: O:\!1200-\1246\EIS_INFORMATION_REQUEST\SIR3_28\mxd\IR3_28_1_MetalsExceedances_Arsenic_170307.mxd



ARSENIC CONCENTRATION (µg/g)

0.87 - 1.93
1.94 - 3.00
3.01 - 4.06
4.07 - 5.12
5.13 - 6.19
6.20 - 7.25
7.26 - 8.31
8.32 - 9.37
9.38 - 10.44
10.45 - 11.50

IDW interpolation method:
Grid Size - 50m
Variable search radius - 750m
Maximum Sample Points - 12
Power = 2

Zone	Number of Samples Analyzed	Number of Exceedances
Sturgeon Bank	87	17
Roberts Bank	326	43
Boundary Bay	107	1
TOTAL	520	61

Legend

7.55 ARSENIC CONCENTRATION (µg/g)

SAMPLE LOCATION MEETS APPLICABLE CCME ISQGS FOR ARSENIC

SAMPLE LOCATION EXCEEDS APPLICABLE CCME ISQGS FOR ARSENIC

Canadian Council of Ministers of the Environment (CCME) Interim Sediment Quality Guidelines (ISQGs) for Arsenic = 7.24 µg/g

BOUNDARY OF PROJECT AREA

CANADA-U.S.A. BORDER

0 2 4
Kilometres
1:110,000
NAD 1983 UTM Zone 10N

N

PORT of vancouver

ROBERTS BANK TERMINAL 2

LOCATION OF CCME ISQGs EXCEEDANCES FOR METALS - ARSENIC

DATE: 06/20/2017

FIG No. IR3-28-1

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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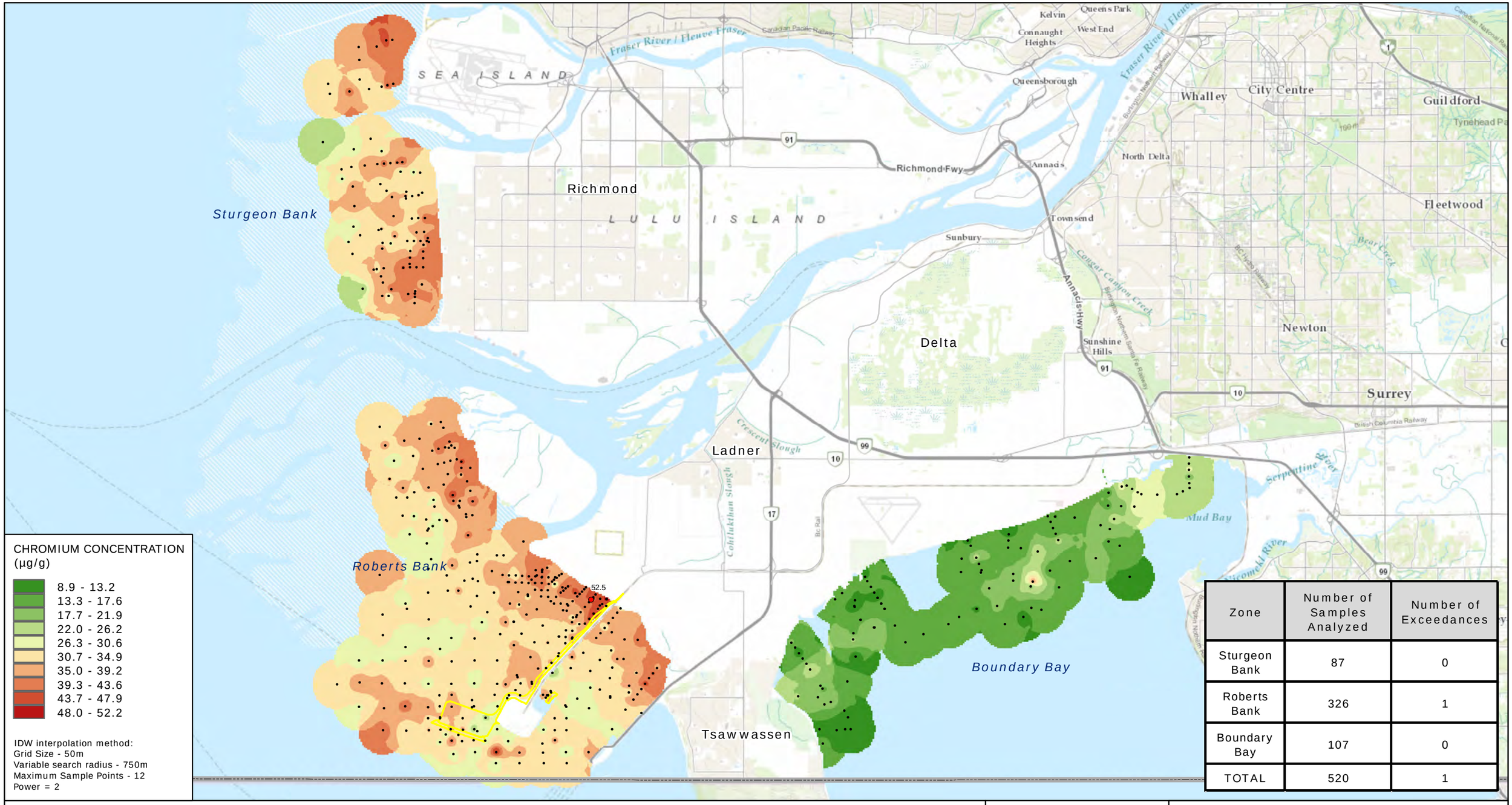

CHROMIUM CONCENTRATION (µg/g)

8.9 - 13.2
13.3 - 17.6
17.7 - 21.9
22.0 - 26.2
26.3 - 30.6
30.7 - 34.9
35.0 - 39.2
39.3 - 43.6
43.7 - 47.9
48.0 - 52.2

IDW interpolation method:
Grid Size - 50m
Variable search radius - 750m
Maximum Sample Points - 12
Power = 2

Zone	Number of Samples Analyzed	Number of Exceedances
Sturgeon Bank	87	0
Roberts Bank	326	1
Boundary Bay	107	0
TOTAL	520	1

Legend

52.5 CHROMIUM CONCENTRATION (µg/g)

SAMPLE LOCATION MEETS APPLICABLE CCME ISQGS FOR CHROMUIM

SAMPLE LOCATION EXCEEDS APPLICABLE CCME ISQGS FOR CHROMIUM

Canadian Council of Ministers of the Environment (CCME) Interim Sediment Quality Guidelines (ISQGs) for Chromium = 52.3 µg/g

BOUNDARY OF PROJECT AREA

CANADA-U.S.A. BORDER

0 2 4
Kilometres

1:110,000

NAD 1983 UTM Zone 10N

N

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ROBERTS BANK TERMINAL 2

LOCATION OF CCME ISQGs EXCEEDANCES FOR METALS - CHROMIUM

DATE: 06/20/2017

FIG No. IR3-28-2

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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Sturgeon Bank

SEA ISLAND

Fraser River / Fleuve Fraser

Richmond

LULU ISLA

Ladner

Roberts Bank

Boundary Bay

Tsawwassen

See inset for details.

Colinkhan Slough

Robertson Rd

Tamboline Slough

Sawage Rd

Westham Island Rd

Tamboline Rd

Wellington Point Park

Trim Rd

River Rd W

40 St

41-B St

34 St

33 A Ave

Delta

Nicomekl River

0 1 2
Kilometres
1:45,000

COPPER CONCENTRATION (µg/g)

2.8 - 12.1
12.2 - 21.5
21.6 - 30.9
31.0 - 40.3
40.4 - 49.7
49.8 - 59.1
59.2 - 68.5
68.6 - 77.9
78.0 - 87.3
87.4 - 96.7

IDW interpolation method:
Grid Size - 50m
Variable search radius - 750m
Maximum Sample Points - 12
Power = 2

Zone	Number of Samples Analyzed	Number of Exceedances
Sturgeon Bank	87	33
Roberts Bank	326	132
Boundary Bay	107	1
TOTAL	520	166

Legend

21.1 COPPER CONCENTRATION (µg/g)

SAMPLE LOCATION MEETS APPLICABLE CCME ISQGS FOR COPPER

SAMPLE LOCATION EXCEEDS APPLICABLE CCME ISQGS FOR COPPER

Canadian Council of Ministers of the Environment (CCME) Interim Sediment Quality Guidelines (ISQGs) for Copper = 18.7 µg/g

BOUNDARY OF PROJECT AREA

CANADA-U.S.A. BORDER

0 2 4
Kilometres
1:110,000

N

NAD 1983 UTM Zone 10N

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ROBERTS BANK TERMINAL 2

LOCATION OF CCME ISQGs EXCEEDANCES FOR METALS - COPPER

DATE: 06/20/2017

FIG No. IR3-28-3

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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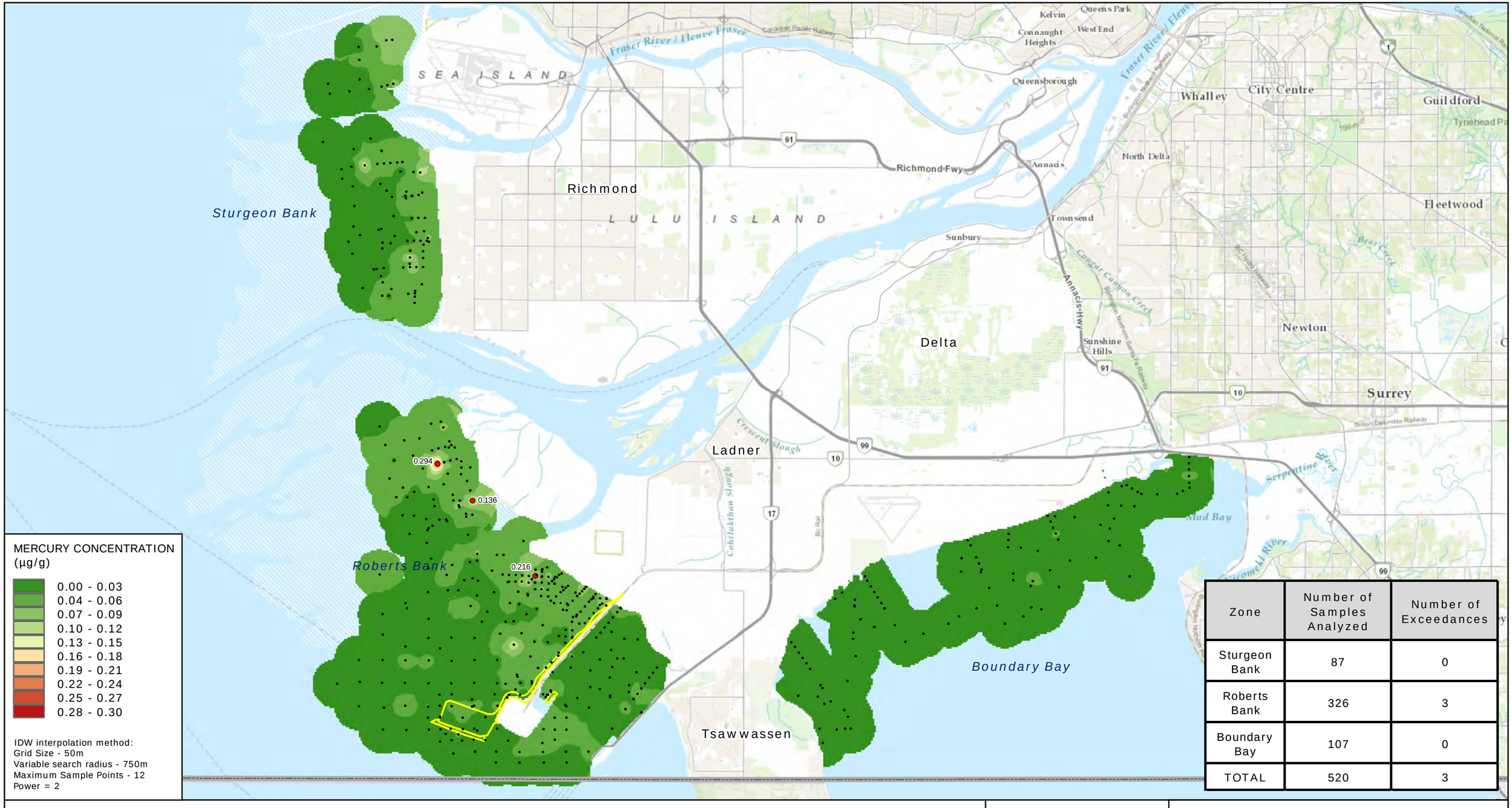

MERCURY CONCENTRATION (µg/g)

- 0.00 - 0.03
- 0.04 - 0.06
- 0.07 - 0.09
- 0.10 - 0.12
- 0.13 - 0.15
- 0.16 - 0.18
- 0.19 - 0.21
- 0.22 - 0.24
- 0.25 - 0.27
- 0.28 - 0.30

IDW interpolation method:
Grid Size - 50m
Variable search radius - 750m
Maximum Sample Points - 12
Power = 2

Zone	Number of Samples Analyzed	Number of Exceedances
Sturgeon Bank	87	0
Roberts Bank	326	3
Boundary Bay	107	0
TOTAL	520	3

Legend

52.5 MERCURY CONCENTRATION (µg/g)

SAMPLE LOCATION MEETS APPLICABLE CCME ISQGS FOR MERCURY

SAMPLE LOCATION EXCEEDS APPLICABLE CCME ISQGS FOR MERCURY

Canadian Council of Ministers of the Environment (CCME) Interim Sediment Quality Guidelines (ISQGs) for Mercury = 0.13 µg/g

BOUNDARY OF PROJECT AREA

CANADA-U.S.A. BORDER

0 2 4
Kilometres

1:110,000

NAD 1983 UTM Zone 10N

N

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ROBERTS BANK TERMINAL 2

LOCATION OF CCME ISQGs EXCEEDANCES FOR METALS - MERCURY

DATE: 06/20/2017

FIG No. IR3-28-4

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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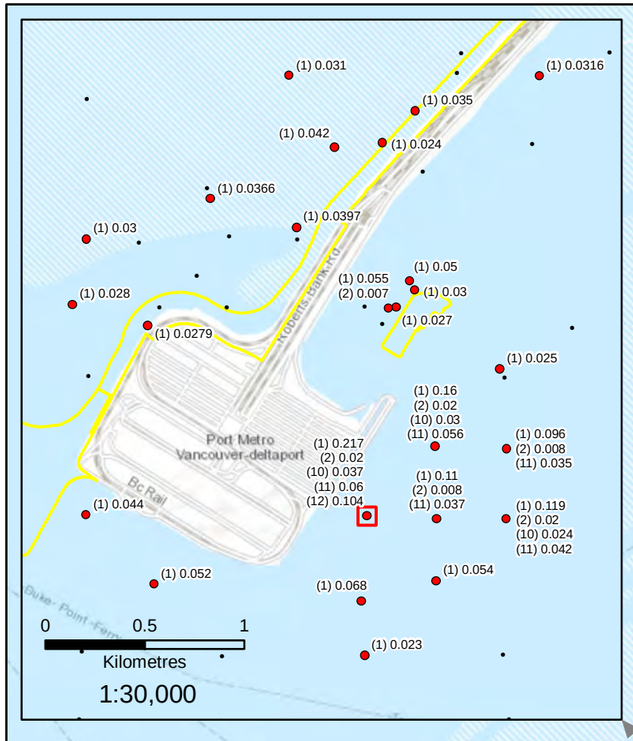

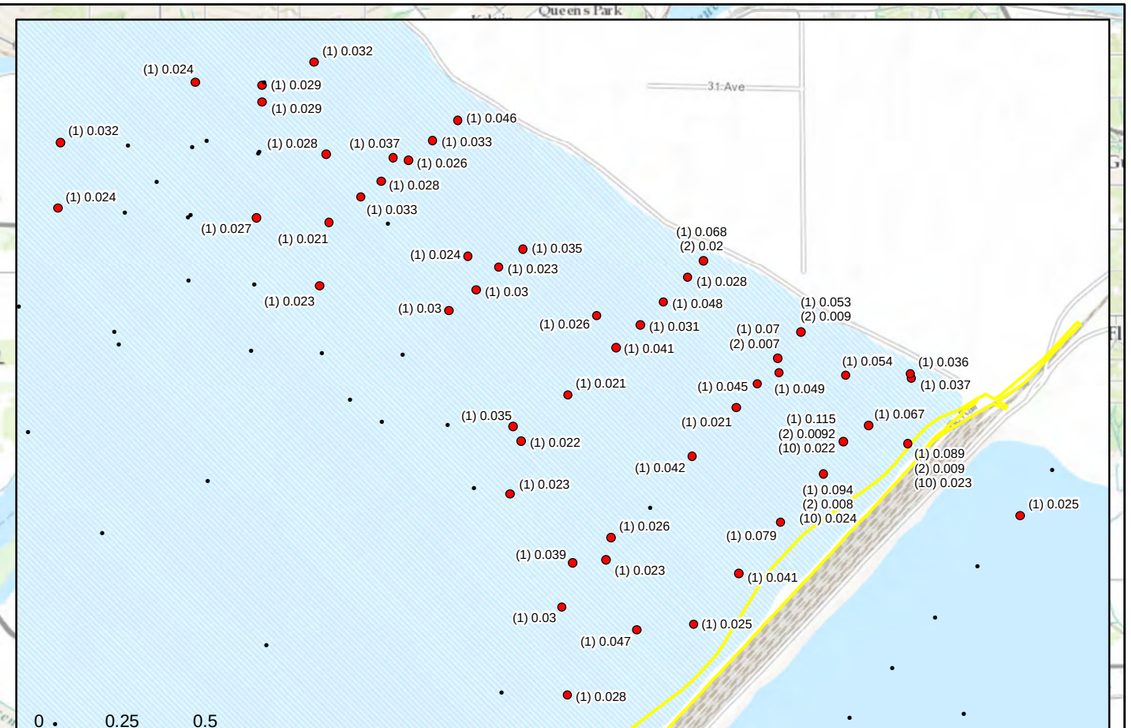

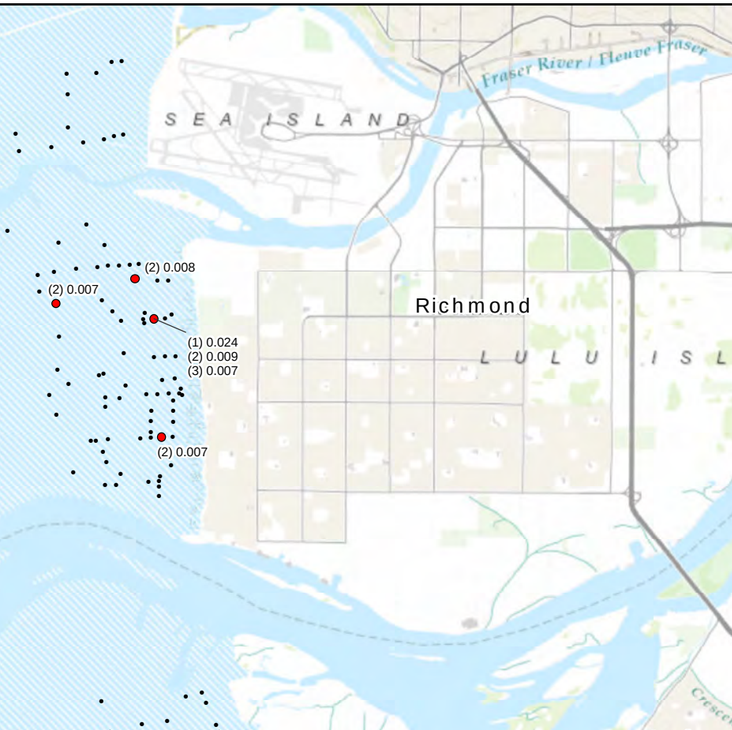

PAH ID	PAH Name	CCME ISQG (µg/g)	Number of Exceedances Recorded	CCME PEL (µg/g)	Number of Exceedances Recorded
1	2-Methylnaphthalene	0.0202	83	0.201	1
2	Acenaphthene	0.00671	16	0.0889	0
3	Acenaphthylene	0.00587	2	0.128	0
4	Anthracene	0.0469	0	0.245	0
5	Benzo(a)anthracene	0.0748	1	0.693	0
6	Benzo(a)pyrene	0.0888	1	0.763	0
7	Chrysene	0.108	1	0.846	0
8	Dibenz(a,h)anthracene	0.00622	3	0.135	0
9	Fluoranthene	0.113	1	1.494	0
10	Fluorene	0.0212	6	0.144	0
11	Naphthalene	0.0346	5	0.391	0
12	Phenanthrene	0.0867	2	0.544	0
13	Pyrene	0.153	1	1.398	0

Zone	Number of Sample Locations Analyzed	Number of Sample Locations with an Exceedance
Sturgeon Bank	87	4
Roberts Bank	326	83
Boundary Bay	107	2
TOTAL	520	89

Legend

(1) 0.03 (PAH ID) PAH CONCENTRATION (µg/g)

SAMPLE LOCATION MEETS APPLICABLE CCME ISQGS FOR ALL PAHS

SAMPLE LOCATION EXCEEDS APPLICABLE CCME ISQGS FOR ONE OR MORE PAHS

SAMPLE LOCATION EXCEEDS APPLICABLE CCME PELS FOR ONE OR MORE PAHS

BOUNDARY OF PROJECT AREA

CANADA-U.S.A. BORDER

See table above for PAH IDs and Canadian Council of Ministers of the Environment (CCME) Interim Sediment Quality Guidelines (ISQGs) and Probable Effect Levels (PELs) for PAHs

0 2 4
Kilometres
1:110,000
NAD 1983 UTM Zone 10N

N

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ROBERTS BANK TERMINAL 2

LOCATION OF CCME ISQG AND PEL EXCEEDANCES FOR POLYCYCLIC AROMATIC HYDROCARBONS (PAHs)

DATE: 06/20/2017

FIG No. IR3-28-5

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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Sturgeon Bank

Roberts Bank

Boundary Bay

SEA ISLAND

LULU ISLAND

Fraser River / Fleuve Fraser

Richmond

Delta

Ladner

Tsawwassen

Surrey

Whalley

City Centre

Guildford

Fleetwood

Newton

North Delta

Queensborough

Annacis

Townsend

Sunbury

Sunshine Hills

Kelvin

Queens Park

Connaught Heights

West End

Richmond Fwy

Annacis Hwy

Cougar Canyon Creek

Bear Creek

Crescent Slough

Cobble Hill Slough

Serpentine River

Nicomekl River

Mud Bay

South Surrey

White Rock

West Side

Oxford Hills

East Side

West Beach

Victoria Hill

Columbia

East Beach

Semiahmoo Bay

Canadian Pacific Railway

Canadian National Railway

Burlington Northern Santa Fe Railway

BC Hydro Railway

British Columbia Railway

Bc Rail

TOC CONCENTRATION (%)

- 0.05 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0
- 1.0 - 1.2
- 1.2 - 1.4
- 1.4 - 1.6
- > 1.6

IDW interpolation method:
Grid Size - 50m
Variable search radius - 750m
Maximum Sample Points - 12
Power = 2

Legend

- TOC CONCENTRATION BELOW DETECTION LIMIT (MODELLED AT 0.05%)
- TOC CONCENTRATION AT OR ABOVE DETECTION LIMIT (0.10%)
- BOUNDARY OF PROJECT AREA
- CANADA-U.S.A. BORDER

0 2 4
Kilometres

1:110,000

NAD 1983 UTM Zone 10N

N

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ROBERTS BANK TERMINAL 2

LOCATION OF TOC SAMPLES

DATE: 06/20/2017

FIG No. IR3-28-6

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

IR3-29 Surficial Geology and Marine Sediment – DDT Levels in Sediment

Information Source(s)

EIS Volume 2: Sections 9.6 and 9.7, Appendices 9.6-A, 9.6-B, and 14-D

Context

In Section 9.7 of the EIS, the Proponent stated that PAHs, PCBs, dichlorodiphenyltrichloroethane (DDT), and other persistent toxic contaminants are highly hydrophobic contaminants, and they preferentially associate with sediments. The Proponent indicated that the most appropriate method for evaluating the presence of these substances in the local study area is through the collection and analysis of surficial sediment samples. Although information on PAHs and PCBs was presented in Section 9.6, Appendix 9.6-A, and other Sections, there is no description of DDT baseline levels in the local study area.

Information Request

Provide a description of DDT levels in sediment in the local study area.

Describe whether there are any activities from Project construction or operation that would result in the mobilization of DDT, and that are likely to result in a measurable change to DDT levels in sediment in the local study area.

VFPA Background Information

The VFPA has conducted field studies in the Fraser River estuary to characterise marine sediments in the local study area (LSA[1]). Physical and chemical data for persistent organic pollutants (POPs) presented in the EIS Section 9.6, EIS Appendices 9.6-A and 9.6-B, IR3-25, and the existing body of scientific knowledge has been relied upon in developing this response. POPs, including polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenals (PCBs), dichlorodiphenyltrichloroethane (DDT), and others, are synthetic chemicals resistant to environmental degradation, are strongly hydrophobic[2], and are locally and globally distributed through atmospheric and aquatic transport.

For context to support the response provided below, DDT is a pesticide that came into use in the mid-1940s. Due to concerns over bioaccumulation in apex predators[3] and associated ecotoxicology effects, extensive studies and management actions were implemented worldwide starting in the late 1970s. Local use of DDT historically occurred within B.C., and

[1] The LSA for the assessment of surficial geology and marine sediment encompasses the Fraser River estuary, including intertidal and subtidal areas at Sturgeon Bank, Boundary and Mud bays, and Roberts Bank (see EIS Figure 9.6-1).
[2] Hydrophobic means repelling, tending not to combine with, or unable to dissolve in water.
[3] An apex predator is a predator residing at the top of a food chain upon which no other creatures prey.

sources to the Fraser River estuary included agricultural runoff, industrial effluent discharges, as well as sewage treatment plant effluent. Use of DDT and its environmental daughter products (dichlorodiphenyldichloroethylene (DDE) and dichlorodiphenyldichloroethane (DDD)) were banned in Canada in 1985, but atmospheric deposition still occurs globally due the ongoing use for controlling insect vectors in some countries.

VFPA Response

A description of DDT levels in the LSA is provided below. As information on DDT levels in the LSA is limited, information previously provided on PCB levels in the LSA is provided below as a proxy for DDT levels in the LSA. The spatial distribution of detectable PCBs are a suitable proxy for the spatial distribution of DDT in the LSA, as these substances have similar physical and chemical properties (e.g., hydrophobic), distribution mechanisms, and had similar global production levels[4]. The information provided below validates the assertion that no measurable changes in concentrations of globally distributed DDT are anticipated to result from Project activities.

Levels and Distribution of DDT in the Local Study Area

The Canadian Council of Ministers of the Environment (CCME) Interim Sediment Quality Guidelines for the Protection of Aquatic Life (ISQGs) for DDT, DDE, and DDD (CCME 1999) references work carried out in the Fraser River basin by Swain and Walton (1988). This guidance document concluded that total DDT concentrations measured in Fraser River estuary sediments between 1980 and 1987 have decreased. Concentrations were less than 1 µg/kg (micrograms per kilogram), with some elevated concentrations (up to 8.1 µg/kg) in Boundary Bay. The CCME ISQG for DDT is 1.19 µg/kg in the marine and estuarine environment.

The relationship between POPs, including DDT, and total organic carbon (TOC) and finer-textured sediments (i.e., clay and silt-sized particles) is important to understand the spatial distribution of DDT in the LSA. Since POPs preferentially adsorb to organic carbon and finer-textured sediments, detectable DDT in surface sediments in an estuarine environment (as found in the LSA) are primarily found in areas of finer-textured organic-rich sediments. Statistically significant relationships between grain size and TOC, and grain size and PCB concentrations within the LSA are illustrated in Figures 5-3 through 5-5 of EIS Appendix 9.6-B[5]. Greater accumulations of TOC and increased percentages of clay are generally observed in low wave and low current energy environments such as nearshore intertidal areas, as shown in EIS Figure 9.6-4. Similarly, Figure 18 of EIS Appendix 9.6-A shows higher percentages of TOC in the LSA in the upper intertidal zones of Sturgeon Bank and Roberts Bank, and east of the Deltaport Terminal. Due to the association with organic

[4] The total historical global production of DDT and PCBs is estimated to be in the range of 1.3 million tonnes (Breivik et al. 2007) and 1.8 million tonnes (ATSDR 2002), respectively.
[5] Statistically significant inter-relationships were observed between percent fines in surficial sediments and TOC content (R^2=0.87), and PCB concentrations (R^2=0.69) in the LSA. PCB concentrations are representative of the POP group of chemicals.

carbon and finer-textured sediments, DDT levels would also be expected to be higher in these upper intertidal areas.

The vertical distribution of POPs was also evaluated, based on radioisotopic (210Pb) age dating of sediments collected from the proposed RBT2 dredge basin. The study results revealed that sediments from depths greater than approximately 0.3 m to 1 m were deposited more than 60 years ago (see Section 5-5 of EIS Appendix 9.6-B for more information). These results support the timing of global production, as well as usage bans of PCBs and DDT. Based on this sediment dating information, and depending on the location within the LSA, sediments from depths greater than 1 m to 2 m are not expected to contain PCBs or DDT, since deeper deposits pre-date the initiation of production of such chemicals.

Project-related Mobilisation of Sediment in the Local Study Area

The key Project activities in the LSA that have the potential to result in the mobilisation of sediment will only occur during the construction phase and include the following:

1) Dredging of the dredge basin area, and re-use of dredgeate as general fill resulting in the discharge of supernatant containing fines;
2) Dredging to expand the tug basin area, and re-use of dredgeate as general fill resulting in the discharge of supernatant containing fines; and
3) Use of dredged Fraser River sands as general fill, resulting in the discharge of supernatant containing fines.

The potential for the mobilisation of sediments to result in a measurable change to DDT levels in the LSA will depend on area-specific sediment characteristics, such as sediment grain size and TOC content, as explained above.

Sediment samples collected in 2013 and 2016[6] by the VFPA were analysed for PCBs using analytical techniques designed to achieve very low detection limits (for complete dataset, refer to IR3-25). The maximum total PCB concentration was 0.000655 µg/g (micrograms per gram) and all samples were well below the PCB ISQG of 0.0215 µg/g (see Table IR3-25-1 in IR3-25). Using PCB levels as a proxy, levels of DDT in the LSA are not expected to measurably change due to resuspension by Project construction activities and subsequent deposition for the following reasons:

- Detectable concentrations of POPs in the LSA are spatially distributed with finer-textured organic-rich sediments, generally in the upper intertidal zone. At Roberts Bank, Project activities with the potential to mobilise large volumes of sediments are not planned in this zone (i.e., dredging of the dredge basin area will occur in the subtidal zone; dredging to expand the tug basin area, while located in the intertidal zone, will not result in the movement of large volumes of sediment);
- The bulk of the material to be excavated for terminal development and tug basin expansion are planned to depths of -26.7 m chart datum (CD) and -6.5 m CD,

[6] In 2016 for the dredge basin and tug basin areas, sediments were collected and analysed to characterise deeper sediments within each dredge prism to inform the detailed design phase.

respectively. Deeper sediments (i.e., below 1 m to 2 m deep, depending on location) do not contain POPs as anthropogenic influences are limited to more recently-deposited surface sediments;

- While sediment samples from Project areas (within the LSA) and the lower Fraser River have not been analysed for DDT specifically, the VFPA has conducted analysis of sediments from these areas for other POPs (e.g., PCBs, PAHs). Sediment in Project areas and the lower Fraser River show no appreciable sediment contamination (refer to EIS Section 9.6.6.3 and IR3-25 for more information). Concentrations of POPs are the same in potentially disturbed surficial sediments as those that already occur in suspended sediment from the Fraser River and in sediment deposits in the LSA; and
- There are no local sources of POPs in the LSA (except for PAHs in areas influenced by coal deposition from Westshore Terminals[7]). Hence, resuspended and deposited sediments from dredging and discharge activities during Project construction will have the same or lower DDT levels than surface sediment concentrations in depositional areas in the LSA. Settled sediments from the dredging of deeper sediments that contain no DDT may result in lower surface DDT concentrations than existing concentrations in surface sediments, which may be influenced by atmospheric deposition.

References

Agency for Toxic Substances & Disease Registry (ATSDR). 2002. Toxicological Profile: for DDT, DDE, and DDE. Agency for Toxic Substances and Disease Registry, September 2002. Available at https://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=81&tid=20. Accessed March 2017.

Breivik, K., A. Sweetman, J. M. Pacyna, and K. C. Jones. 2007. Towards a Global Historical Emission Inventory for Selected PCB Congeners -- A Mass Balance Approach: 3, An Update. Science of The Total Environment 377, 296-307.

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EVS Consultants Ltd. (EVS)-Golder Associates Ltd. (Golder). 2004. Water Quality Report: Roberts Bank Expansion Project. Technical Report, Submitted to Vancouver Port Authority by EVS Environment Consultants, a Member of the Golder Group of Companies, Vancouver, B.C.

Swain, L. G., and D. G. Walton. 1988. Fraser River Estuary Monitoring, Report on the 1987 Benthos and Sediment Monitoring Program. Fraser River Harbour Commission and B.C. Ministry of Environment, New Westminster, B.C.

[7] Detailed sampling and analysis of sediment samples and biota was completed for PAHs since this was a different case than the larger suite of persistent organic pollutants; PAHs are known to have been introduced to Roberts Bank sediments because of the historical release of coal dust from the Westshore Terminals.

IR3-30 Surficial Geology and Marine Sediment – Sediment Dispersion Modeling: Modelling of Fines

Information Source(s)

EIS Volume 2: Appendix 9.6-C

Context

As stated by the Proponent in Appendix 9.6-C of the EIS:

- the amount of dredge basin dredgeate solids that would not be retained by the containment cells and would be discharged through disposal at sea was assumed to be 15%; and
- this estimate is based on previous experience and assumes the residence time for dredgeate liquids in the containment cell to be relatively short.

The sediment dispersion modelling assumed 15% non-retention rate and also carried out further simulations using much lower non-retention rates, but did not use higher non-retention rates. Table 5.3.2 of Appendix 9.6-C provided a summary of containment cell settling efficiency. The table indicated that the settling efficiency of "fines only" varies from 71% to 87%. The use of higher non-retention rates in the sediment dispersion modeling would represent more conservative estimates.

Information Request

Re-run the sediment dispersion modeling for the discharge of unsettled fines from the dredge basin at a depth of -45 m CD and using a nonretention rate of 30%. Compare these results with the previous modeling results that used a non-retention rate of 15%, and a depth of -45 m CD.

Provide figures similar to that of Figure 5.4.1 to 5.4.7 of Appendix 9.6-C for the above analysis, ensuring that the entire extent of the plume is visible on the maps.

VFPA Response

In response to the request to re-run the sediment dispersion modelling for the discharge of unsettled fines from the dredge basin at a depth of -45 m chart datum (CD) and using a non-retention rate of 30%, the following information explains that unsettled fines have been modelled up to a 71.8% fine sediment non-retention rate (and therefore, previous modelling encompassed the requested modelling of unsettled fines using a non-retention rate of 30%). EIS Appendix 9.6-C describes the results for sediment dispersion modelling for two non-retention rate scenarios at a depth of -45 m CD, including a simulated 3% overall (i.e., for both fine and coarse sediment) non-retention rate and an assumed 15% overall non-retention rate.

The following information clarifies details provided in the context of this information request regarding Table 5.3.2 of EIS Appendix 9.6-C. A settling efficiency of 71% to 72% listed in Table 5.3.2 refers specifically to imports of Fraser River sand (referred to as 'ITP (intermediate transfer pit)' sediment source in the table). The 'dredge basin and VEF' sediment source material (from dredging of the dredge basin and fallout (referred to as VEF, which are vibro-replacement expressed fines)) has a simulated settling efficiency of 86% to 87%, as shown in Table 5.3.2.

In responding to this request, it is helpful to explain the differences between non-retention rates (i.e., the proportion of material that will not settle within the containment area and will be discharged as decant water). Three types of non-retention rates are described in this response: coarse sediment, fine sediment, and overall non-retention rates. The non-retention rate of coarse sediment (i.e., midpoint grain size greater than 200 µm (micrometres)) is typically low given its particle size (i.e., most material is retained within the area of deposition). Compared to coarse material, the non-retention rate of fine sediment (i.e., midpoint grain size less than 43 µm) will be higher as smaller particles will remain in suspension for longer. The overall non-retention rate is defined as the combined coarse and fine fraction that is predicted not to settle in a containment cell and is a function of the relative proportions of coarse and fine sediment in the total volume of material to be placed in a containment cell. It is this overall non-retention rate on which the 3% and 15% dispersion modelling was undertaken. This is further explained below.

Simulated 3% Overall Non-retention Rate

A three-dimensional numerical model was used to estimate the non-retention rate of sediments (i.e., based on 'best-case' basin settling efficiency) during infilling of the containment cells for terminal land development. Based on simulations for both the east and west containment basins, the overall (i.e., fine and coarse sediment) non-retention rate was 2.9% and 2.7%, respectively. The 2.9% and 2.7% overall non-retention rates correspond to 13.5% and 12.7% fine sediment non-retention rates (**Table IR3-30-1**). Using the east basin as an example provided in **Table IR3-30-1**, coarse sediment makes up 79.1% of the inflow sediment, while fine sediment comprises the remaining 20.9% of the total inflow sediment. Coarse sediment had a simulated non-retention rate of 0.06% and fine sediment had a simulated non-retention rate of 13.5%. That is, 99.94% of the coarse material and 86.5% of the fine material is predicted to settle within the east basin. Based on the higher overall non-retention rate (2.9%), sediment dispersion modelling was undertaken at a 3% non-retention rate, which represents a non-retention rate of 13.5% for unsettled fines (**Table IR3-30-1**).

Table IR3-30-1 Summary of Simulated Containment Cell Settling Efficiency for Dredge Basin Material for Best-case Overall Non-retention Rate

Containment Cell	Coarse Sediment		Fine Sediment		Overall Non-retention Rate
	Non-retention Rate	% of Inflow Sediment	Non-retention Rate	% of Inflow Sediment	
East Basin	0.06%	79.1%	13.5%	20.9%	2.9%[a]
West Basin	0.05%	79.1%	12.7%	20.9%	2.7%[b]

Notes: Calculations to determine the overall non-retention rate are as follows:

a. 2.9% overall non-retention rate = (0.06% coarse non-retention x 79.1% coarse content) + (13.5% fines non-retention x 20.9% fines content)

b. 2.7% overall non-retention rate = (0.05% coarse non-retention x 79.1% coarse content) + (12.7% fines non-retention x 20.9% fines content)

Assumed 15% Overall Non-retention Rate

Sediment dispersion modelling was also conducted for an assumed maximum overall 15% non-retention rate (i.e., worst-case scenario). For this modelling scenario, if the fines content of the inflow sediment was less than 15%, it was assumed that the overall non-retention rate was equal to the fine sediment content, and if the fines fraction is greater than 15%, then some fines will be retained. For both the east and west basins, the overall fines content of the dredge basin material is 20.9% (i.e., greater than 15%), as shown in **Table IR3-30-2**, and an overall non-retention rate of 15% (comprised of finest 15% of the inflow material) was assumed for sediment dispersion modelling. The resulting overall (i.e., fine and coarse sediment) non-retention rate used for sediment dispersion modelling was 15%, which corresponds to a 71.8% fine sediment non-retention rate (**Table IR3-30-2**).

Table IR3-30-2 Summary of Assumed Containment Cell Settling Efficiency for Worst-case Overall Non-retention Rate for Dredge Basin Material

Containment Cell	Coarse Sediment		Fine Sediment		Overall Non-retention Rate
	Non-retention Rate	% of Inflow Sediment	Non-retention Rate	% of Inflow Sediment	
East Basin	0.0%	79.1%	71.8%	20.9%	15%[a]
West Basin	0.0%	79.1%	71.8%	20.9%	15%[a]

Note: a. Calculation to determine the 15% overall non-retention rate = (0.0% coarse non-retention x 79.1% coarse content) + (71.8% fines non-retention x 20.9% fines content)

In summary, the above two scenarios represent a range of *overall* non-retention rates for the discharge of unsettled fines from the dredge basin from 2.7% to 15%, corresponding to a range of fine sediment non-retention rates from 12.7% to 71.8%, respectively. The modelling conducted thereby encompassed the requested modelling of unsettled fines from the dredge basin at a depth of -45 m CD and using a non-retention rate of 30%. **Table IR3-30-3** summarises the discharge scenarios from the discharge of unsettled fines from the dredge

basin and their corresponding non-retention rates. The corresponding simulations are described in EIS Appendix 9.6-C.

Table IR3-30-3 Summary of Sediment Dispersion Modelling Scenarios for Dredge Basin Material and Information Provided in EIS Appendix 9.6-C

Containment Cell	Scenario	EIS Appendix 9.6-C Section	EIS Appendix 9.6-C Figures	Coarse Non-retention Rate	Fine Non-retention Rate	Overall Non-retention Rate
East Basin	Simulated 3% Best-case Non-retention	5.4.2	5.4.9 to 5.4.22	0.06%	13.5%	2.9%
	Assumed 15% Worst-case Non-retention	5.4.1	5.4.1 to 5.4.7	0.0%	71.8%	15%
West Basin	Simulated 3% Best-case Non-retention	5.4.2	5.4.9 to 5.4.22	0.05%	12.7%	2.7%
	Assumed 15% Worst-case Non-retention	5.4.1	5.4.1 to 5.4.7	0.0%	71.8%	15%

IR3-31 Surficial Geology and Marine Sediment – Sediment Dispersion Modeling: Model Depths

Information Source(s)

EIS Volume 2: Appendix 9.6-C

Context

In Appendix 9.6-C of the EIS, the Proponent carried out sediment dispersion modeling for the discharge of supernatant water using both 3% and 15% non-retention rates. The Proponent indicated that it also used the 3% non-retention rate for additional simulations at outfalls depths of 60 metres and 75 metres. It is not clear why the Proponent did not carry out additional simulations that used a non-retention rate of 15% at depths of 60 metres and 75 metres.

Information Request

Provide a rationale for why the 15% non-retention was not used in additional simulations using outfall depths of 60 metres and 75 metres.

VFPA Response

Three outfall depths were modelled for the 3% non-retention scenario, as the description of the outfall location had not yet been confirmed prior to the commencement of modelling. As per EIS Section 4.4.1.8, the outfall of the pipeline is anticipated to be located at the -45 m chart datum (CD) level (determined after modelling that deeper outfalls can pose operational challenges). At the time modelling was conducted, the 15% non-retention rate scenario was not simulated at -60 m and -75 m CD, as the simulation at -45 m represents a worst-case dispersion scenario. This rationale is explained in more detail below.

EIS Appendix 9.6-C presents the total suspended sediment (TSS) concentrations originating from the discharge pipeline at various outfall depths for two TSS discharge scenarios:

1) A simulated non-retention rate (approximately 3% non-retention) based on output from three-dimensional numerical model simulations of terminal infilling. This 3% non-retention scenario of suspended fine sediment laden supernatant disposal was simulated using a three-dimensional numerical model of the Strait of Georgia at three outfall depths (-45 m, -60 m, and -75 m CD); and
2) A more conservative 15% non-retention rate. The 15% non-retention rate scenario was simulated using the same three-dimensional numerical model of the Strait of Georgia at a -45 m CD outfall depth only.

The 3% non-retention scenario was considered the best-estimate non-retention scenario based on a quantitative model of settling basin performance for a settling basin with a long residence time, while the 15% non-retention scenario is a conservative upper bound estimate (i.e., worst-case scenario considered for planning purposes). The 3% non-retention scenario, therefore, was simulated for all three outfall depths as a best-estimate case and from these simulations it was clear that, of the three depth cases, the -45 m CD discharge pipe depth resulted in the farthest TSS plume dispersal. Compare, for example, Figure 5.4.10 (-45 m CD), Figure 5.4.24 (-60 m CD), and Figure 5.4.38 (-75 m CD) of EIS Appendix 9.6-C for the discharge of fines from infilling with dredge basin sediment to the east basin.

The -45 m CD site is a more dispersive location for two main reasons: 1) tidal, estuarine, and wind-driven currents in the Strait of Georgia tend to be stronger at shallower depths than at deeper depths; and 2) the shallower -45 m CD site is subject to stronger up-slope flows during flood tides, potentially bringing comparatively more suspended sediment onto Roberts Bank. Since the purpose of the 15% non-retention scenario was to define a worst-case scenario, a 15% non-retention rate was only simulated for the -45 m CD depth case.

IR3-32 Surficial Geology and Marine Sediment – Sediment Dispersion Modeling: Terminal Containment Dyke Permeability

Information Source(s)

EIS Volume 2: Appendix 9.6-C

Context

In Section 2.4 of Appendix 9.6-C of the EIS, the Proponent described the perimeter dyke permeability of the containment cells for the proposed Project. The Proponent indicated that there is a potential for a steep instantaneous hydraulic gradient across the dyke during portions of the tidal cycle, which can drive flow through the perimeter dykes. The Proponent indicated that if this is not managed appropriately, that the flow could result in fugitive losses of water and associated suspended sediments. The Proponent outlined that for the sediment dispersion modeling, it assumed that these fugitive losses would be appropriately managed through engineering design and contractor means and methods.

When determining the settlement of entrained fine sediment following disposal at sea, the Proponent estimated that 85% of dredge basin solids will be retained in the containment cells. This number, which originated from Project planning documents, differed from the settling model results presented in Appendix 9.6-C, which indicated that over 97% of the solids would be retained. The Proponent indicated that this discrepancy is due to differences in assumptions about hydraulic control of the containment cells and the uncertainty associated with the contractor's methods.

Further information is required to determine what engineering design and contractor methods could be used to minimize fugitive losses from the perimeter dykes, and that would influence the amount of dredge basin solids that would be retained in containment cells.

Information Request

Describe the potential engineering design and contractor methods that could be used to manage fugitive losses from the perimeter dyke.

Describe the potential contractor methods that could be used to manage sediment and water within the containment cells, and describe how these methods would affect the retention of dredge basin solids.

VFPA Response

Describe the potential engineering design and contractor methods that could be used to manage fugitive losses from the perimeter dyke

Standard design criteria and methods used to manage fugitive losses from dykes are well understood within the marine engineering community, and are outlined in the US Army Corps

of Engineers Coastal Engineering Manual[1]. Retention, permeability, and internal stability criterion can be specified. Examples of how these criteria can be achieved through design and contractor methods include the following:

- **Dyke core material gradation:** By ensuring the dyke core material is well graded, interstitial spaces can be minimised and transmissivity reduced. The Project conceptual design for perimeter dykes has dyke core material comprised of 4" minus material (as shown in preliminary engineering drawings 60287593-MA-210 to 218 in EIS Appendix 4-B).
- **Dyke core width:** By adjusting the dyke core width, the retention of the water and fines can be modified. For instance, a wider dyke core will result in a lower gradient across the dyke, thereby increasing the retention of water and fines within the perimeter. The Project conceptual design for perimeter dykes has a dyke core width of 15 m at the top, increasing in width to the base (as shown in preliminary engineering drawings 60287593-MA-210 to 218 in EIS Appendix 4-B).
- **Filter layers:** By adding semi-impermeable filter layers of either natural materials (i.e., sand/silt/gravel) or man-made materials (i.e., geotextiles) on the internal side of the dyke, transmissivity will be reduced. The Project conceptual design for perimeter dykes includes 300 mm thick filter layers along various sections, dependent on fill sequencing (as shown in preliminary engineering drawings 60287593-MA-210 to 218 in EIS Appendix 4-B). Final locations for the filter layers will be determined during detailed design by the Infrastructure Developer and additional filter material can be added during construction, if needed.

Describe the potential contractor methods that could be used to manage sediment and water within the containment cells, and describe how these methods would affect the retention of dredge basin solids

A method that could be used by potential contractors to manage sediment and water and retain materials within the containment cell perimeter dykes is to establish a series of retention ponds separated by weirs. The height of the weirs could be adjusted to maintain a minimum water depth above the deposited sediment to promote settling of solids. In the early stages of infilling when retention ponds are empty and have greatest capacity, retention of solids could be maximised, and as the ponds become shallower, the volume and associated retention time will decrease. The effectiveness of this method is proportional to the degree to which flow rates could be reduced and the length of time required to settle finer particles in any given retention pond.

Details pertaining to the management of sediment and water will be addressed during the development of the Dredging and Sediment Discharge Plan prior to the start of construction activities (should the Project be approved), as outlined in EIS Section 33.3.10. The VFPA committed to the development of this plan to mitigate potential Project-related effects on

[1] Engineering Manual 1110-2-5025 Dredging and Dredge Material Management (31 July 2015), specifically Chapter 4 Confined (Diked) Placement and Chapter 4.5 Retention of Solids and Initial Storage Capacity.

water and sediment quality. The plan will describe the management and timing of dredging activities and the discharge of sediment-laden water.

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IR3-33 Surficial Geology and Marine Sediment – Sediment Dispersion Modeling: Instantaneous Plumes

Information Source(s)

EIS Volume 2: Appendix 9.6-C

Context

In Appendix 9.6-C of the EIS, the Proponent modelled the sediment dispersion plumes and total suspended solids (TSS) that would be produced from the combined activities of dredge basin excavation and ITP loading and unloading. Figures 5.2.8 to 5.2.10 showed the predicted fate of TSS plumes originating from the combined dredge basin and ITP operations. However, Figures 5.2.11 and 5.2.12 did not show a plume originating from the ITP, despite the fact that modeling was carried out for dredge basin excavation and ITP loading. The Proponent indicated that the most extensive far-field TSS plume occurred between ITP loading dumps, and so the suspended sediment plume originating from loading the ITP was not present in these figures. A similar explanation was given for why a plume surrounding the ITP is not visible in Figures 5.2.18 and 5.2.19. Given that loads of Fraser river sands would be imported several times daily, modeling the dumping of a load of Fraser river sands to the ITP at the same time as dredge basin excavation would have been a more conservative modeling approach.

Information Request

Update Figures 5.2.11, 5.2.12, 5.2.18 and 5.2.19 of the EIS to display the instantaneous TSS extent originating from the ITP in addition to those plumes already displayed in those figures.

VFPA Response

The intermediate transfer pit (ITP) is no longer proposed for use as a temporary storage site for Fraser River sand, as described in the Preamble at the beginning of this response package. As such, the figures have not been updated to display the instantaneous total suspended solids (TSS) extent originating from the ITP as requested by the Panel; however, clarification is provided below regarding the TSS plumes represented in these figures in the EIS.

The numerical model simulations summarised by Figures 5.2.11 and 5.2.12 of EIS Appendix 9.6-C include simultaneous ITP loading and dredge basin dredging, while Figures 5.2.18 and 5.2.19 of EIS Appendix 9.6-C include simultaneous ITP loading, ITP unloading, and dredge basin dredging. The purpose of these figures was to show the worst-case extent of the TSS plume generated by dredge basin dredging and activities at the ITP during either a flood or ebb tide (i.e., the instant of maximum TSS plume excursion). The worst-case extent shown in these figures did not coincide with activities at the ITP at that instant. This is because, compared to continuous, higher concentration TSS plumes generated by dredge basin dredging, ITP loading occurs in discrete deliveries of clean sand (with

approximately 2% fines content), with each delivery generating relatively short-lived and low concentration TSS plumes spatially confined to the immediate vicinity of the ITP. For ITP unloading, reclamation of sand from the ITP is continuous but is essentially clean sand that does not contribute to the far-field plume. The far-field TSS plume extent and concentration, therefore, is almost entirely determined by the behaviour of sediments arising from dredge basin dredging, rather than ITP loading, and is the reason for not having included the localised sediment plume from the ITP in the figures.

For combined plume statistics for peak TSS levels resulting from ITP loading and dredge basin dredging refer to EIS Appendix 9.6-C: Figures 5.2.9 and 5.2.10 (5 mg/L and 10 mg/L thresholds, respectively), and from ITP loading, ITP unloading, and dredge basin dredging to EIS Appendix 9.6-C: Figures 5.2.16 and 5.2.17 (5 mg/L and 10 mg/L thresholds, respectively).

IR3-34 Surficial Geology and Marine Sediment – Sediment Dispersion Modeling: Simultaneous Activities

Information Source(s)

EIS Volume 2: Section 9.6.8.1, Appendix 9.6-C

Context

In Table 9.6-5 of the EIS, the Proponent reported that the following four modelled scenarios specific to construction activities, including dredging, vibro-densification resulting in vibro-replacement expressed fines (VEF) materials, loading and unloading of the ITP, and DAS, would result in sediment suspension and deposition:

- dredge basin dredging, loading and unloading of ITP;
- DAS discharge of sediment-laden water from dredge basin dredgeate (including VEF) via pipe to the DAS site;
- DAS discharge of sediment-laden water containing ITP stockpile materials via pipe to the DAS site; and
- re-suspension of sediments from tug basin dredging and disposal of dredgeate by surface release to the DAS site.

Figure 1.2 of Appendix 9.6-C of the EIS showed the summary of modelled and scheduled sediment handling activities. According to Figure 1.2, disposal at sea activities will occur at the same time as different dredging activities. Although the Proponent modelled the sediment dispersion plumes and deposition resulting from multiple simultaneous dredging activities, it did not model the plumes that would occur from dredging activities that occur simultaneous to disposal activities.

Further, in Section 9.6.8.1 of the EIS, the Proponent reported that the following activities were not included in the four modelled scenarios:

- construction of dykes and terminal caisson wall;
- rock and rip-rap placement;
- other modifications within the dredge basin; and
- storm water discharge.

Further information is required to quantify the suspended sediment generated by simultaneous dredging and disposal at sea activities, and to determine whether other activities not included in the model could result in measurable changes in suspended sediment and sediment deposition.

Information Request

For all disposal at sea activities that could occur simultaneously to dredging activities, carry out sediment dispersion modeling to:

- quantify the suspended sediment generated by the activities and provide a comparison with applicable guidelines;
- describe the spatial extent of the resultant plume(s), and
- describe the deposition that would occur.

The disposal at sea activities should be modeled at depths of -45, -60 and -75 m CD, with a non-retention rate of 15%.

Generate figures for peak TSS exceeding 1.0 mg/L, 5.0 mg/L, and 10 mg/L, instantaneous TSS extent during ebb and flood tide, total deposition of fine sediment, and D50 of deposited fine sediment for each group of overlapping activities.

Provide a description of the potential changes to suspended sediment and deposition caused by the construction of dykes and terminal caisson wall, rock and rip-rap placement, and other modifications within the dredge basin.

VFPA Response

For all disposal at sea activities that could occur simultaneously to dredging activities, carry out sediment dispersion modeling to: quantify the suspended sediment generated by the activities and provide a comparison with applicable guidelines; describe the spatial extent of the resultant plume(s); and describe the deposition that would occur.

The disposal at sea activities should be modeled at depths of -45, -60 and -75 m CD, with a non-retention rate of 15%.

As background, EIS Appendix 9.6-C included independent simulations of the following activities that are scheduled to occur simultaneously from June 1 to February 28 in year 1 and year 2 of Project construction:

- Dredging of the dredge basin using a cutter-suction dredge;
- Disposal via an outfall pipe at depths of -45 m, -60 m, and -75 m of supernatant water generated during terminal infilling with dredge basin material; and
- Disposal via an outfall pipe at depths of -45 m, -60 m, and -75 m of supernatant water generated during terminal infilling with Fraser River sand.

These activities were not simultaneously simulated previously, as the combined scenario represents neither a worst-case nor best-case scenario. During simultaneous infilling of the terminal containment dykes with dredge basin material and Fraser River sand, the overall discharge of supernatant water will be higher than either individual infilling scenario and the following is expected:

- Compared to the dredge basin dredgeate only infilling scenario (worst-case scenario), the overall concentration of fine sediment in the supernatant water will decrease due to dilution with the water fraction of the Fraser River sand; and
- Compared to the Fraser River sand only infilling scenario (best-case scenario), the overall concentration of fine sediment in the supernatant water will increase due to the presence of dredge basin derived fines.

The size and concentration of the resulting suspended sediment plume with combined simultaneous activities[1], therefore, will be between that of the dredge basin dredgeate only infilling scenario (worst case) and Fraser River sand only infilling scenario (best case). Results for the modelling of these two scenarios are described in EIS Appendix 9.6-C: Sections 5.4.1 and 5.4.2.

As requested by the Panel, the simultaneous total suspended solids (TSS) releases arising from dredge basin dredging and infilling of the terminal containment dykes with dredge basin dredgeate and Fraser River sand have been quantified and are explained below. In alignment with EIS Sections 9.7.4 and 9.7.8, comparisons are made to the Canadian Council of Ministers of the Environment (CCME) Canadian Water Quality Guidelines for the Protection of Aquatic Life – Total Particulate Matter (CCME 2002) for clear flow conditions[2] (i.e., a maximum average TSS increase of 5 mg/L (milligrams per litre) over background conditions).

Updates to Project construction activities, which are described in the Preamble at the beginning of this response package and other information request responses, have been considered in the sediment dispersion modelling conducted in response to this information request, and include the following:

- Loading and unloading activities at the intermediate transfer pit (ITP) have not been included in sediment dispersion modelling. Fraser River sand will be delivered directly into fill areas via a dredge with pump-ashore capability, eliminating the need for underwater stockpiling at the ITP.
- Disposal of tug basin dredgeate to the Project-specific site via direct barge dumping is no longer being considered. Tug basin dredgeate will be re-used for general fill in terminal development or causeway widening.
- The timing of tug basin dredging is not fixed and can be carried out over a period of several days rather than several months. Due to the flexibility of construction timing, the relatively isolated location of dredging activities, and relatively small volume of material to be dredged (compared to dredge basin dredging and discharge activities), tug basin dredging has not been incorporated as a simultaneous activity.
- The outfall of the supernatant discharge pipeline is anticipated to be located at the -45 m chart datum (CD) level (as described in EIS Section 4.4.1.8). As explained in IR3-31, previous modelling activities described in EIS Appendix 9.6-C considered three outfall depths (at 45 m, 60 m, and 75 m CD) because the description of the outfall location had not yet been confirmed prior to the commencement of modelling. Only the -45 m CD level is being considered for the pipeline outfall depth (due to increased operational challenges with the deeper outfall depths), and modelling results for supernatant discharge at -45 m CD are provided in this response. As outlined in IR3-31, the simulation at -45 m represents a worst-case dispersion scenario for two main reasons: 1) tidal, estuarine, and wind-driven currents in the Strait of Georgia

[1] As the fugitive sediment arising from dredging of the dredge basin is relatively minor compared to discharge activities (as shown by comparing EIS Figures 9.7-8 and 9.7-9, respectively), this activity has not been included in the explanation of worst- and best-case scenarios.
[2] For a clear flow period, the guideline states a maximum average increase of 5 mg/L from background levels for longer-term exposures (e.g., inputs lasting between 24 hours and 30 days).

tend to be stronger at shallower depths than at deeper depths; and 2) the shallower -45 m CD site is subject to stronger up-slope flows during flood tides, potentially bringing comparatively more suspended sediment onto Roberts Bank.

The assumptions incorporated into sediment dispersion modelling related to dredging and the infilling and discharge activities included in the simultaneous scenario are described below.

Discharge Outfall Location Model Assumptions

Three outfall locations, all located at -45 m CD as shown on EIS Figure 4-11, is anticipated to be used in series over the four-year fill cycle, as follows:

- Year 1 – supernatant will be discharged from the outfall location near the southernmost end of the terminal footprint;
- Year 2 – supernatant will be discharged from the outfall location near the center of the terminal footprint; and
- Years 3 and 4 – supernatant will be discharged from northernmost outfall location.

Simultaneous infilling with dredge basin material and Fraser River sand is anticipated to occur in fill years 1 and 2; therefore, only the southernmost and central outfall locations have been simulated.

Model Assumptions for Dredge Basin Dredging and Blended Simultaneous Infill Sediment Characteristics

EIS Appendix 9.6-C: Sections 2.2.1, 2.5, 2.6, and 4.2 outline the assumptions incorporated in the modelling for the cutter-suction dredge activities at the dredge basin. As described in EIS Section 4.4.1.8, the dredge basin will be dredged using cutter-suction dredge equipment, with similar specifications to the *Columbia* that is operated by Fraser River Pile & Dredge (FRPD). Dredge basin material will be pumped directly into the terminal footprint as a 10% sediment by volume slurry. The hourly delivery rate of sediment from the dredge basin is summarised in **Table IR3-34-1**.

Fraser River sand will be delivered directly into fill areas via a pump-ashore equipped dredge vessel of similar specifications to the trailing arm suction hopper dredge *FRPD309* operated by FRPD. It is assumed that Fraser River sand will be delivered four times per day and will be pumped as a 20% sediment by volume slurry. The hourly averaged delivery rate of sediment from the Fraser River is summarised in **Table IR3-34-1**.

Table IR3-34-1 Summary of Filling with Simultaneous Dredge Basin and Fraser River Sand Sources

Sediment Source	Assumed Dredge[a]	Solids Production Rate (m^3/h) By Sediment Particle Size						Water Inflow (m^3/h)	Slurry Inflow (m^3/h)[b]
		Total	Coarse	Fine					
			74 – 2000 µm	25.2 - 74.0 µm	8.6 - 25.2 µm	2.9 - 8.6 µm	1.0 - 2.9 µm		
Dredge Basin	*Columbia*	403.7	319.1	41.1	19.8	8.2	15.5	4,037	4,440
Fraser River Sand	*FRPD309*	367.5	360.2	1.8	1.8	1.8	1.8	1,838	2,205
Simultaneous Delivery		**771.2**	**679.3**	**42.9**	**21.6**	**10.0**	**17.3**	**5,874**	**6,645**

Notes: µm = micrometre; m^3/h = cubic metres per hour

a. Activities at the dredge basin are assumed to be conducted by a cutter-suction dredge vessel with similar capabilities to the *Columbia* and Fraser River sand will be delivered directly into fill areas via a pump-ashore equipped dredge vessel of similar specifications to the trailing arm suction hopper dredge *FRPD309*.

b. The slurry inflow rate includes the water inflow rate plus the total solids production rate.

Based on the inflow rates presented in **Table IR3-34-1**, sediment derived from the dredge basin accounts for 52% of the total hourly averaged sediment influx to the terminal containment dykes during simultaneous infilling operations. It is assumed that the simultaneous infilling of the containment dykes with Fraser River sand and dredge basin sediment will be undertaken such that the two inflowing sediment streams are thoroughly mixed, resulting in the combined sediment properties presented in **Table IR3-34-2**. For each midpoint grain size class presented in **Table IR3-34-2** (e.g., 1.7 µm), the fraction of the blended grain size distribution has been calculated from the fraction of that grain size class in each of the dredge basin and Fraser River sediment inflow streams, scaled by the relative inflow rate of each stream. For example, the 1.7 µm fraction represents 3.8% of the dredge basin sediment, but only 0.5% of the Fraser River sand. Since dredge basin sediment represents 52% by volume of the sediment influx into the containment dykes and Fraser River sand represents the remaining 48%, the blended fraction of 1.7 µm sediment is calculated as follows: *(52% x 3.8%) + (48% x 0.5%) = 2.2%.*

Across all grains size fractions, this yields a blended fine sediment content of 11.8%, based on a fine sediment content of 2% in Fraser River sand and approximately 21% in dredge basin sediments (as outlined in EIS Appendix 9.6-C: Sections 2.2.1 and 5.4, and IR3-30).

Table IR3-34-2 Summary of Blended Simultaneous Discharge Particle Size Distribution

Sediment Class	Grain Size Class (µm)			Dredge Basin Fraction (%)	Fraser River Sand Fraction (%)	Blended[b] Fraction (%)[a]
	Midpoint[a]	Lower	Upper			
Fine Sediment	1.7	1.0	2.9	3.8	0.5	2.2
	5.0	2.9	8.6	2.0	0.5	1.3
	14.7	8.6	25.2	4.9	0.5	2.8
	43.2	25.2	74.0	10.2	0.5	5.5
Coarse Sediment	200	74.0	2000.0	79.1	98.0	88.1

Notes: a. The midpoint is calculated as the logarithmic centroid of the particle size bin, rather than the arithmetic mean.

b. The simultaneous discharge fraction equals (52% sediment influx from dredge basin dredgeate slurry x Dredge Basin Fraction) + (48% sediment influx from Fraser River sand slurry x Fraser River Fraction)

To model a non-retention rate of 15% for sediment delivered to the containment dykes, it was assumed that the finest 15% of the blended Fraser River sand and dredge basin fine sediments will be discharged through the outfall pipe. It was also assumed that all coarse sediment from both sources will settle within the containment dykes. If there was insufficient fine sediment to account for a 15% loss rate, then the lower of the fines content and 15% was taken as the non-retention rate (as previously explained in IR3-30).

Based on the blended sediment properties, the overall non-retention rate for simultaneous infilling with dredge basin and Fraser River derived sediment sources is presented in **Table IR3-34-3**. The fines content of the blended material is less than 15%, and assuming a non-retention rate of 100% for fine sediment, the overall non-retention rate of the blended material is 11.8% (**Table IR3-34-3**).

Table IR3-34-3 Summary of Assumed Worst-case Containment Cell Settling Efficiency during Separate and Simultaneous Infilling with Dredge Basin Dredgeate and Fraser River Sand

Sediment Source	Coarse Sediment		Fine Sediment		Overall Non-retention Rate	Fine Sediment Non-retention Rate
	Non-retention Rate	% of Inflow Sediment	Non-retention Rate	% of Inflow Sediment		
Dredge Basin	0.0%	79.1%	71.8%	20.9%	15%[a]	71.8 %
Fraser River Sand	0.0%	98.1%	100.0%	1.9%	1.9%[b]	100%
Simultaneous	**0.0%**	**88.2%**	**100.0%**	**11.8%**	**11.8%[c]**	**100%**

Notes: Calculations to determine the overall non-retention rate are as follows:

a. 15% overall non-retention = (0.0% coarse non-retention x 79.1% coarse content) + (71.8% fines non-retention x 20.9% fines content)

b. 1.9% overall non-retention = (0.0% coarse non-retention x 98.1% coarse content) + (100.0% fines non-retention x 1.9% fines content)

c. 11.8% overall non-retention = (0.0% coarse non-retention x 88.2% coarse content) + (100.0% fines non-retention x 11.8% fines content)

Generate figures for peak TSS exceeding 1.0 mg/L, 5.0 mg/L, and 10 mg/L, instantaneous TSS extent during ebb and flood tide.

This section presents the results of sediment dispersion modelling for the period of when dredge basin dredging and infilling of the containment dykes with dredge basin dredgeate and Fraser River sand occur simultaneously. The probable trajectories of TSS plume dispersion resulting from the simultaneous discharge scenario are illustrated in Figures IR3-34-A1 to IR3-34-A3 in **Appendix IR3-34-A**. These figures show, considering all hours and depth levels during the period of simultaneous dredging and infilling, the percentage of time that the TSS plume will be present at a given location with a maximum water column concentration exceeding 1 mg/L, 5 mg/L, or 10 mg/L, respectively. These figures present results for peak TSS levels that represent a composite of when activities overlap from June 1 to February 28 during fill years 1 and 2 at the southernmost outfall location and the center outfall location, respectively.

In order to quantify the dispersion of sediments during Project construction activities, the TSS content of the sediment plume is tracked as sediments are released over the period of simultaneous dredging and filling activities. At hourly intervals, the maximum TSS concentration in the water column is reported at a 200 m horizontal spatial resolution. This data representation was selected to give a conservative representation of the TSS concentration in the water column, even though the reported maximum TSS would not occur at the same time within the water column or across the spatial extent of the plume. As an example, if the water depth is 40 m, with a near bed (i.e., within 1 m of the seabed) TSS concentration of 100 mg/L and the remainder of the water column has a TSS concentration of 2 mg/L, the maximum TSS concentration would be 100 mg/L, while the water column average (arithmetic mean) TSS would be 4.5 mg/L.

The peak TSS figures, therefore, do not represent the instantaneous TSS plume footprint or a static plume position. Instead, these probability maps represent the likely cumulative percentage of time a given TSS concentration is exceeded at any one location (a block of water 200 m by 200 m in the horizontal and 5 m to 10 m thick in the vertical) over the entire duration of simultaneous dredging and infilling activities. This cumulative percentage is derived as a composite of maximum TSS concentrations in space and time over the full period (i.e., 2 years) and should not be interpreted as a continuous or prevailing condition: the actual size of the plume at any time will fill only a relatively small part of any of the shaded areas.

For example, assume that the maximum TSS concentration will exceed 5 mg/L for 1% of the simultaneous dredging and infilling period at a given location in the Strait of Georgia. This means that the TSS concentration in that specific 200 m by 200 m section of the Strait of Georgia may exceed 5 mg/L for a total of approximately 1 day per year out of the 109 days of simultaneous dredging and infilling per year. Therefore, there is approximately a 1% probability that the TSS concentration would exceeding 5 mg/L in the water column at that location.

At a maximum concentration threshold of 1 mg/L (Figure IR3-34-A1 in **Appendix IR3-34-A**), the plume is transported along the shelf face of Roberts Bank and is occasionally (i.e., less than 10% of the time) drawn onto the tide flat shoreward of the terminal. TSS at a concentration exceeding 5 mg/L from simultaneous activities will not disperse to the tidal flat, as shown in Figure IR3-34-A2 in **Appendix IR3-34-A**, and will not disperse beyond approximately 3,300 m to the northwest of the outfall pipe or 2,500 m to the southeast. More than 50% of the time, TSS concentrations exceeding 5 mg/L will not extend past the terminal face and will be limited to within a 360 m radius of the outfall pipe. The TSS plume exceeds 10 mg/L less than 50% of the time outside of a 200 m radius of the outfall pipe (Figure IR3-34-A3 in **Appendix IR3-34-A**). **Table IR3-34-4** provides the number of days per simultaneous dredge and infill cycle (109 days total) that each of the 1 mg/L, 5 mg/L, and 10 mg/L thresholds are exceeded at various distances from the outfall pipe, to further describe the results illustrated in Figures IR3-34-A1 to IR3-34-A3 in **Appendix IR3-34-A**.

Table IR3-34-4 Summary of Days of Exceedance at Various Distances and TSS Concentrations for 109 Days of Activity

Distance from Outfall Pipe Terminus	Days of Exceedance per Simultaneous Infill Cycle		
	1 mg/L	5 mg/L	10 mg/L
100 m	108.92	108.92	108.63
500 m	77.42	26.44	15.52
1,000 m	62.75	13.02	6.08
5,000 m	19.94	0.29	0.08
Distance to < 1 Day/Cycle Exceedance	9,500 m	3,300 m	1,900 m

Typical maximum dispersion of the TSS plume originating from simultaneous dredge and discharge activities under flood and ebb tidal conditions are plotted on Figures IR3-34-A4 and IR3-34-A5 (**Appendix IR3-34-A**), respectively. The figures present results for instantaneous

TSS levels for the maximum extent of TSS dispersion predicted for the simultaneous scenario within the 2-year period (i.e., the figures illustrate snapshots of the maximum instantaneous extent of the TSS plume during a flood or ebb tide).

During flood tide conditions (Figure IR3-34-A4 in **Appendix IR3-34-A**), the CCME clear flow guideline of 5 mg/L will be exceeded only in subtidal areas northeast from the outfall depth (-45 m CD), dispersing approximately 3 km during flood conditions that result in the maximum extent of dispersion. As **Table IR3-34-4** shows for 5 mg/L, the exceedance of the clear flow guideline value over this maximum 3,300 m distance is expected to occur less than 24 hours over the 109 days of activity. A maximum concentration of 28 mg/L is predicted beyond 100 m from the outfall pipe[3]. A low concentration plume (i.e., TSS concentration of 2 mg/L or less) will be carried during flooding conditions northwards on to the tidal flat less than 10% of the time that simultaneous activities are occurring (as shown in Figure IR3-34-A1 in **Appendix IR3-34-A**, if the dispersion for 1 mg/L concentrations is similar to the dispersion for 2 mg/L concentrations).

During ebb tide conditions (Figure IR3-34-A5 in **Appendix IR3-34-A**), the CCME clear flow guideline of 5 mg/L will be exceeded only in subtidal areas in the immediate vicinity of the outfall. A low concentration plume (i.e., TSS concentration of 3 mg/L or less) will disperse to the southeast. A maximum concentration of 34 mg/L is predicted beyond 100 m from the outfall pipe.

Generate figures for total deposition of fine sediment, and D50 of deposited fine sediment for each group of overlapping activities.

The depositional thickness and median diameter (D50) of deposited fine sediment resulting from the above described simultaneous activity scenario are plotted in Figures IR3-34-A6 and IR3-34-A7 (**Appendix IR3-34-A**), respectively. Deposition is less than 2 mm per year and is relatively uniform along the delta foreslope at Roberts Bank due to the natural reworking of the sediment by tidal currents (refer to IR3-38 for more information). Natural deposition near the Project location from the Fraser River discharge plume is in the range of 8 mm per year (as outlined in EIS Section 9.6.6.1 and Section 2.2.6 of EIS Appendix 9.6-C). As shown in Figure IR3-34-A7 (**Appendix IR3-34-A**), sediment is deposited in specific bands ordered by grain size, with the coarser fraction of fine materials settling closer to the area of activity and a gradual fining of the deposited layer with increasing distance from the area of activity.

Provide a description of the potential changes to suspended sediment and deposition caused by the construction of dykes and terminal caisson wall, rock and rip-rap placement, and other modifications within the dredge basin.

Construction of the dykes, including rock and rip-rap placement, will increase the level of suspended sediment in the water column immediately surrounding material placement activities. The sediment plume, however, is expected to be localised based on past observations at Roberts Bank during similar activities and other land development projects in

[3] The maximum colour scale is 10 mg/L and above to be consistent with information presented in the figures provided in EIS Appendix 9.6-C.

an aqueous environment. TSS concentrations exceeding the 5 mg/L CCME guideline are expected only within the area adjacent to the location of material placement and dispersion of the plume is expected to be immediate due to currents near the Roberts Bank delta foreslope. As the plume will be localised and disperse, and activities will be ongoing within the areas of dyke and wharf construction, deposition of suspended material is not expected to be measurable relative to the deposition that occurs from the Fraser River discharge plume.

Placement of the terminal caissons and associated construction activities, such as placement of mattress rock, rip-rap scour protection rock, and screed layer, within the dredge basin are not expected to measurably increase the level of suspended sediment outside of the immediate area of activity or result in sediment deposition. This is because the area will have been previously dredged (i.e., native soil will have been dredged and placed as fill material in the terminal containment dykes) and materials to be placed in the dredge basin will be relatively clean (i.e., coarse material that is largely absent of fines).

References

Canadian Council of Ministers of the Environment (CCME). 2002. Canadian Water Quality Guidelines for the Protection of Aquatic Life – Total Particulate Matter. Winnipeg, Man.

Appendices

Appendix IR3-34-A Oversize Figures

APPENDIX IR3-34-A
OVERSIZE FIGURES

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Strait of Georgia

Roberts Bank

Boundary Bay

Ladner

Tsawwassen

Point Roberts (U.S.A.)

CANADA

U.S.A.

PERCENT OF TIME CONCENTRATION > 1.0 mg/L

- 0.1%
- 1%
- 5%
- 10%
- 20%
- 30%
- 40%
- 50%
- 60%
- 70%
- 80%
- 90%
- 100%

Legend

- BOUNDARY OF PROJECT AREA
- DEPTH 0 METRES (CHART DATUM)
- BATHYMETRY (10 M CHART DATUM)
- CANADA-U.S.A. BORDER

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ROBERTS BANK TERMINAL 2

PREDICTION FOR TSS LEVELS EXCEEDING 1 mg/L FOR SIMULTANEOUS DREDGE ACTIVITIES AND DISCHARGE ACTIVITIES TO 45 m OUTFALL DEPTH, AT A NON-RETENTION RATE OF 15%

DATE: 06/22/2017

FIG No. IR3-34-A1

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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Strait of Georgia

Roberts Bank

Boundary Bay

Ladner

Tsawwassen

Point Roberts (U.S.A.)

CANADA

U.S.A.

PERCENT OF TIME CONCENTRATION > 5.0 mg/L

- 0.1%
- 1%
- 5%
- 10%
- 20%
- 30%
- 40%
- 50%
- 60%
- 70%
- 80%
- 90%
- 100%

Legend

- BOUNDARY OF PROJECT AREA
- DEPTH 0 METRES (CHART DATUM)
- BATHYMETRY (10 M CHART DATUM)
- CANADA-U.S.A. BORDER

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ROBERTS BANK TERMINAL 2

PREDICTION FOR TSS LEVELS EXCEEDING 5 mg/L FOR SIMULTANEOUS DREDGE ACTIVITIES AND DISCHARGE ACTIVITIES TO 45 m OUTFALL DEPTH, AT A NON-RETENTION RATE OF 15%

DATE:	FIG No.
06/22/2017	IR3-34-A2

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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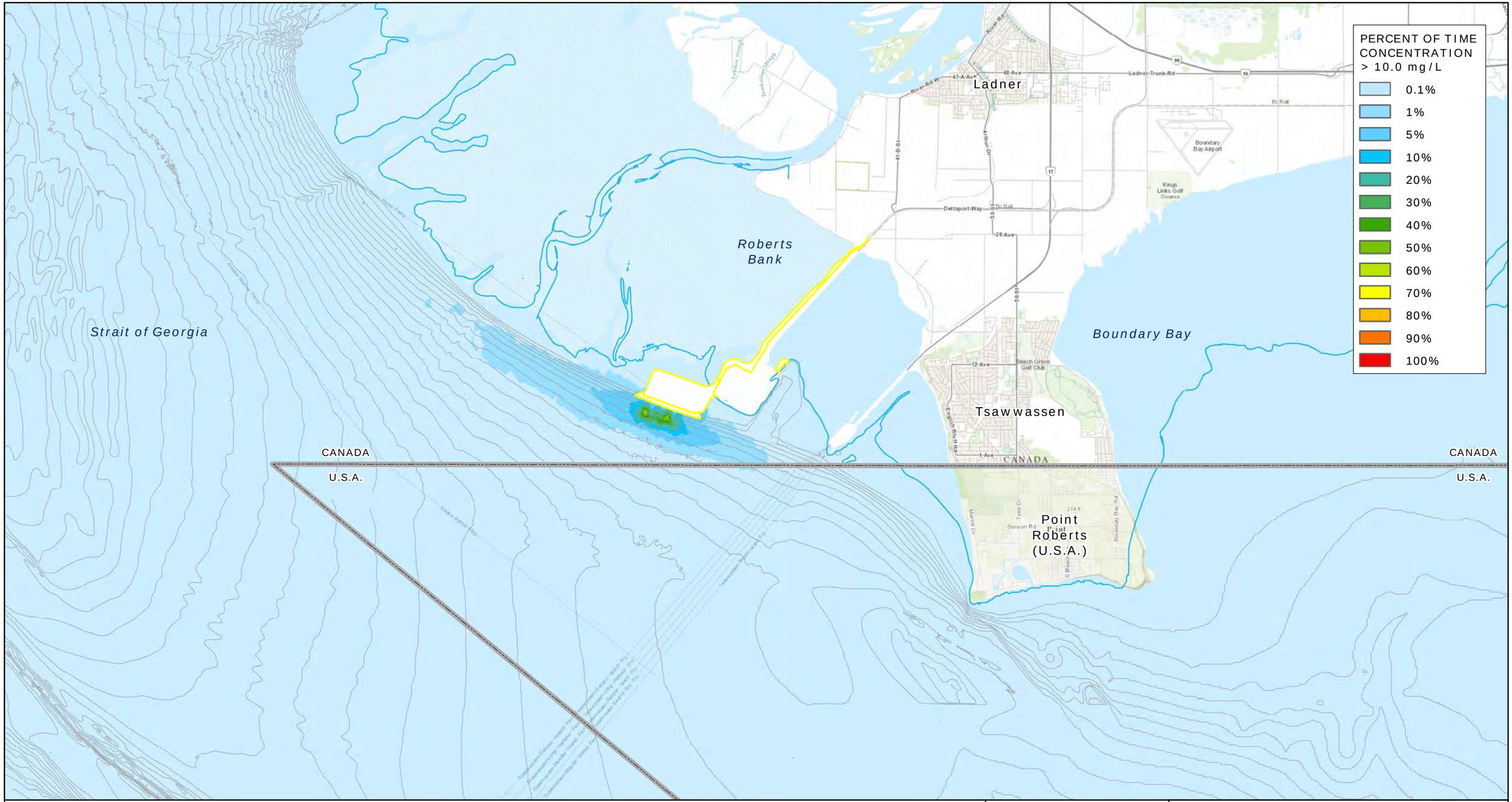

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ROBERTS BANK TERMINAL 2

PREDICTION FOR TSS LEVELS EXCEEDING 10 mg/L FOR SIMULTANEOUS DREDGE ACTIVITIES AND DISCHARGE ACTIVITIES TO 45 m OUTFALL DEPTH, AT A NON-RETENTION RATE OF 15%

DATE:	FIG No.
06/22/2017	IR3-34-A3

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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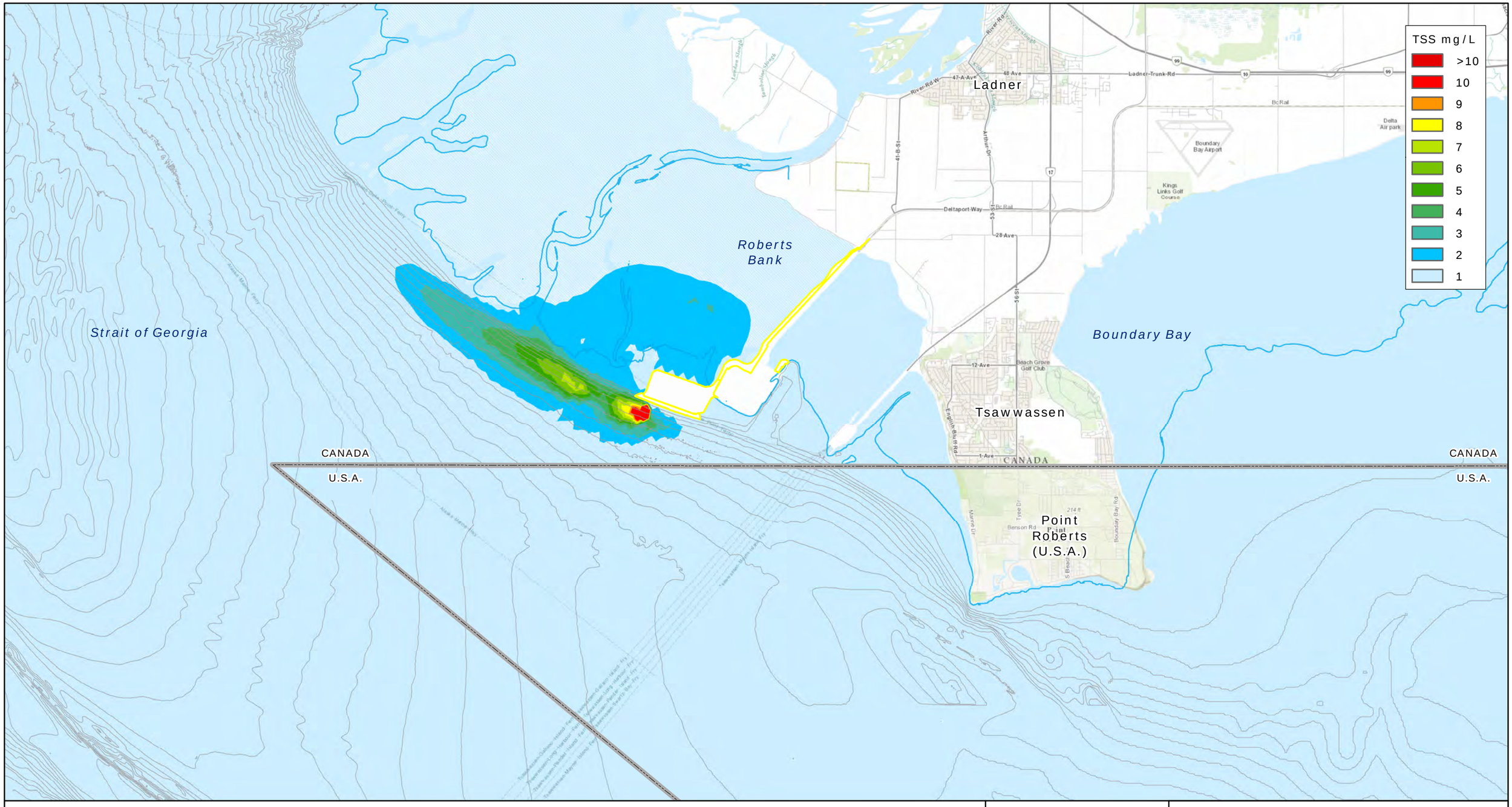

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ROBERTS BANK TERMINAL 2

MAXIMUM INSTANTANEOUS TSS EXTENT FOR SIMULTANEOUS DREDGE ACTIVITIES AND DISCHARGE ACTIVITIES TO 45 m OUTFALL DEPTH, AT A NON-RETENTION RATE OF 15%, FLOOD TIDE

DATE: 06/22/2017

FIG No. IR3-34-A4

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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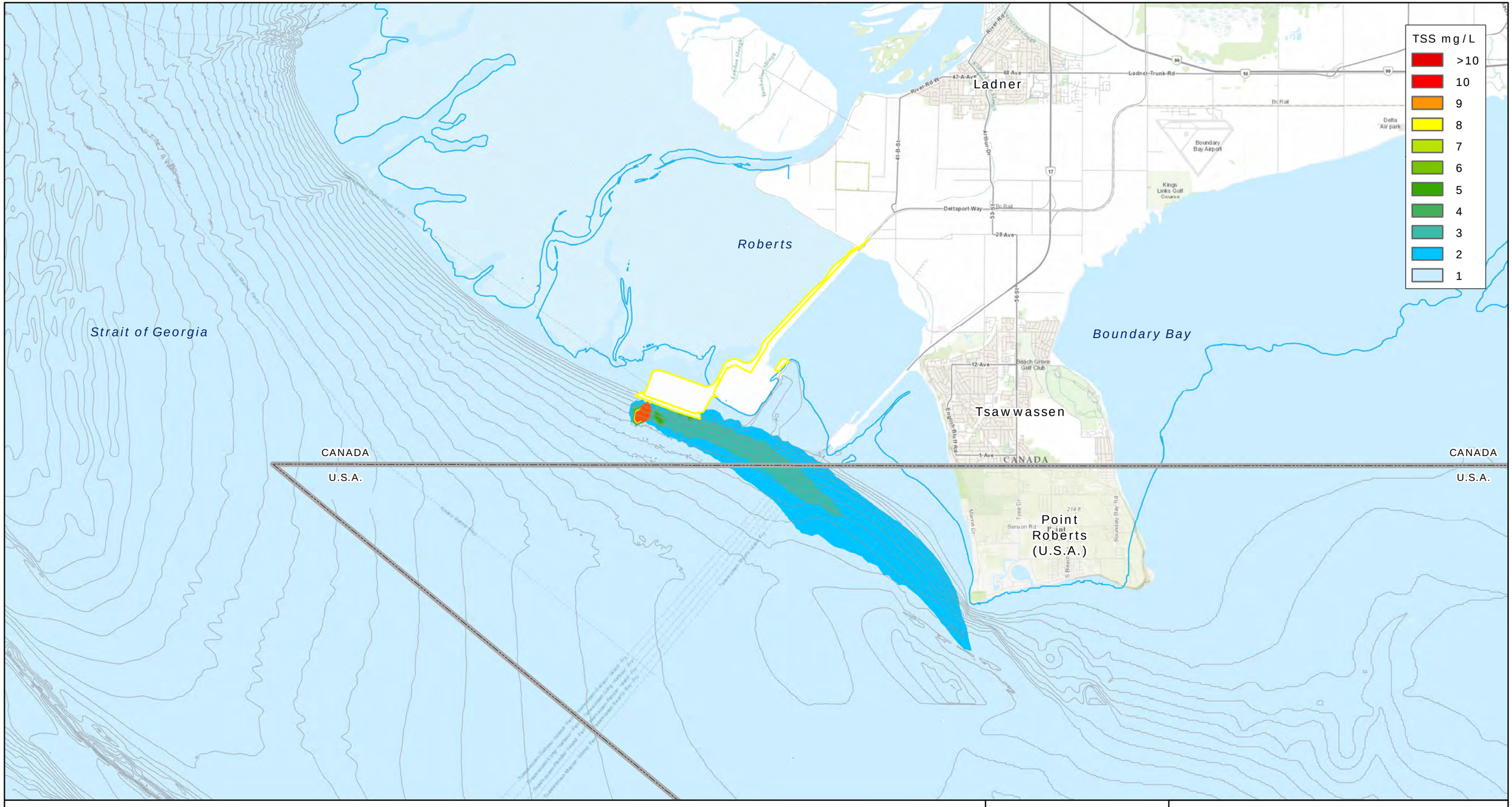

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ROBERTS BANK TERMINAL 2

MAXIMUM INSTANTANEOUS TSS EXTENT FOR SIMULTANEOUS DREDGE ACTIVITIES AND DISCHARGE ACTIVITIES TO 45 m OUTFALL DEPTH, AT A NON-RETENTION RATE OF 15%, EBB TIDE

DATE:	FIG No.
06/22/2017	IR3-34-A5

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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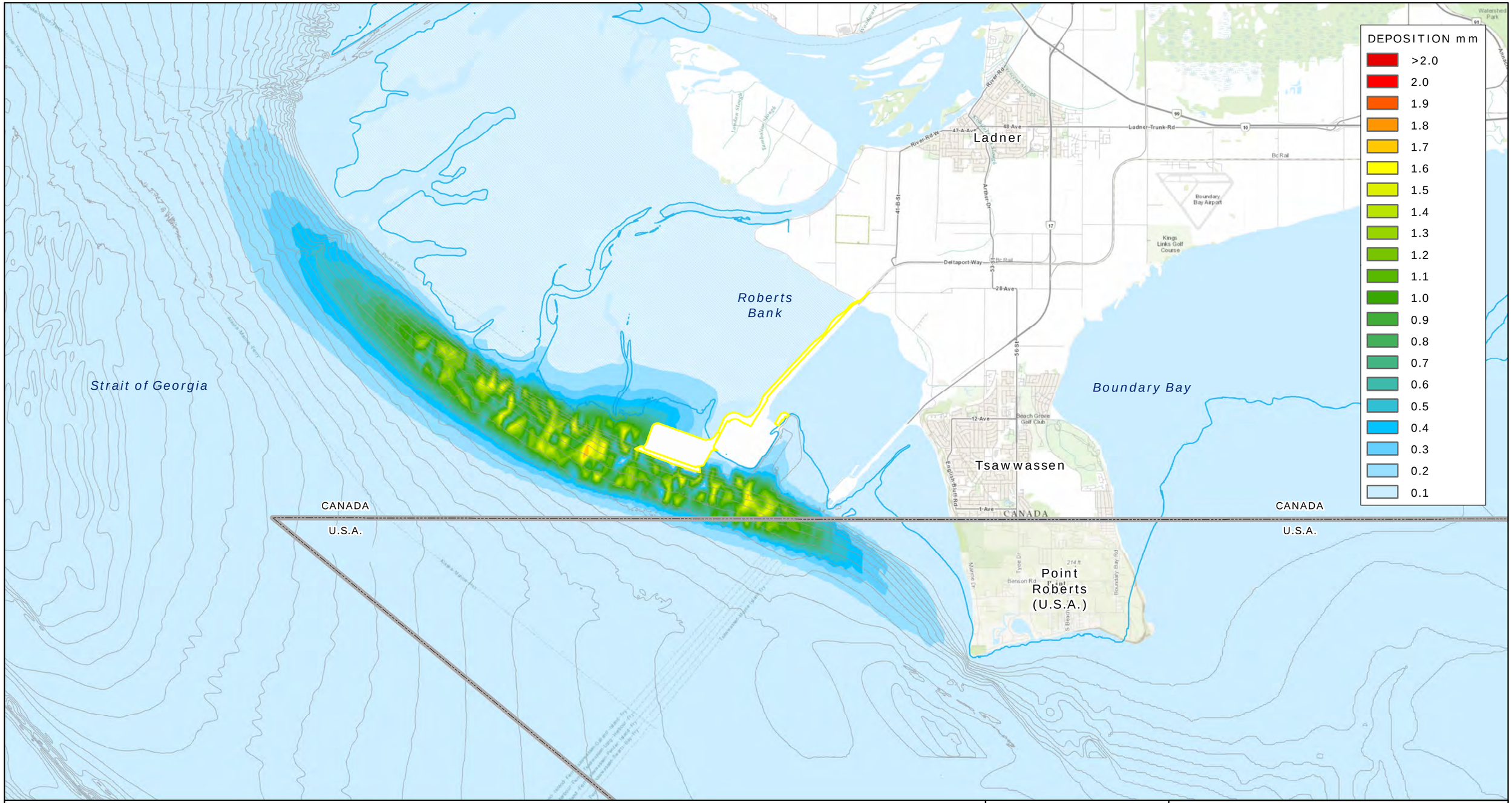

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ROBERTS BANK TERMINAL 2

TOTAL ANNUAL DEPOSITION OF SEDIMENT FOR SIMULTANEOUS DREDGE ACTIVITIES AND DISCHARGE ACTIVITIES TO 45 m OUTFALL DEPTH, AT A NON-RETENTION RATE OF 15 %

DATE: 06/22/2017

FIG No. IR3-34-A6

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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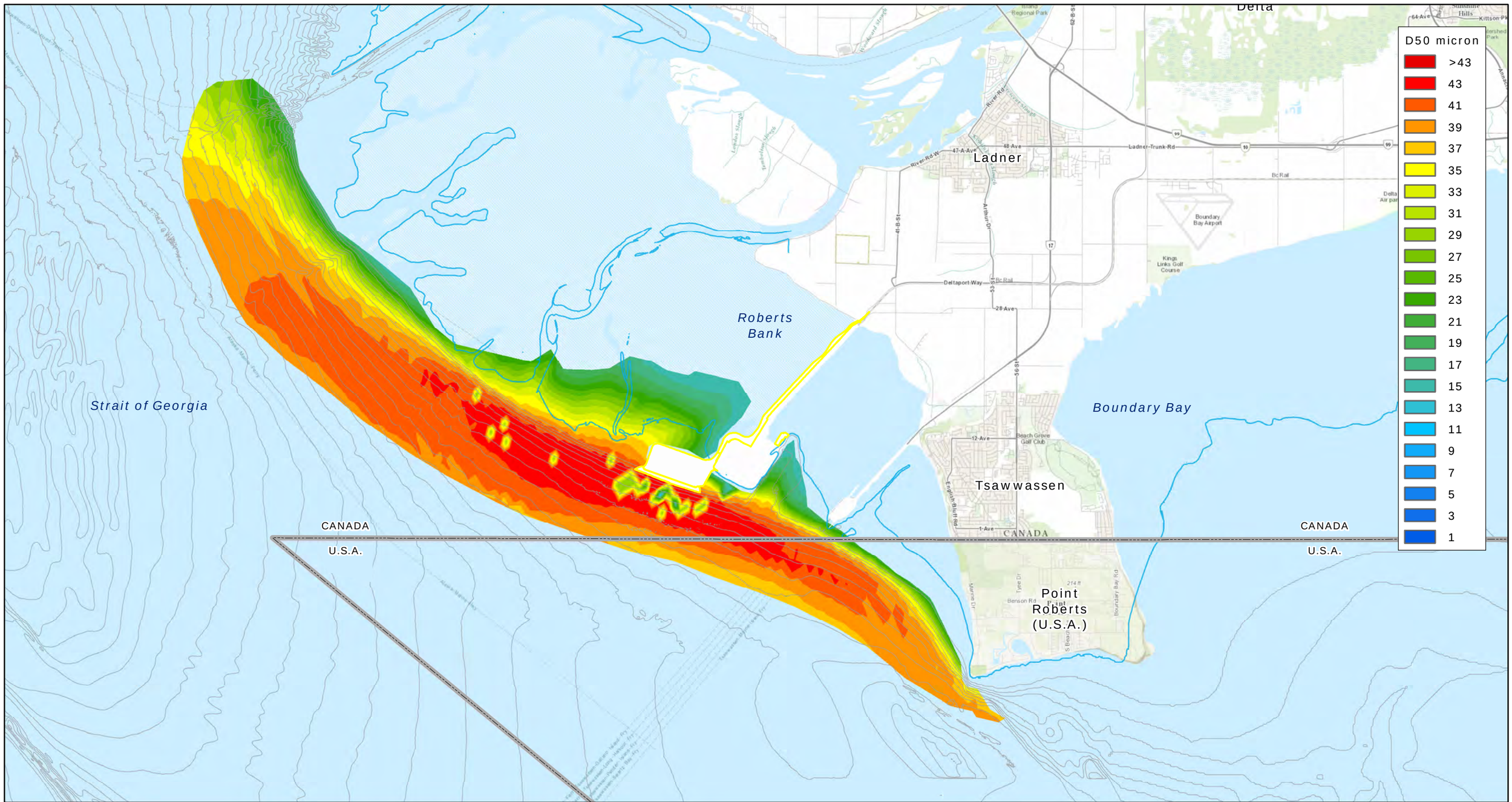

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- CANADA-U.S.A. BORDER

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ROBERTS BANK TERMINAL 2

D50 OF DEPOSITED SEDIMENT
FOR SIMULTANEOUS DREDGE ACTIVITIES AND
DISCHARGE ACTIVITIES TO 45 m OUTFALL
DEPTH, AT A NON-RETENTION RATE OF 15%

DATE: 06/22/2017

FIG No. IR3-34-A7

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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IR3-35 Project Design – Clarification: Post-preload Material

Information Source(s)

EIS Volume 1: Section 4.4, Appendix 4-E

Context

In Section 4.4.1.11 of the EIS, the Proponent indicated that material from the west basin preload and the east causeway preload will be used to complete the wharf apron general fill and eastern wharf apron preload. The western wharf apron area will be preloaded using stockpiled terminal granular base, or reclaimed sand from the ITP.

When describing the causeway widening in Section 4.4.1.15 of the EIS, the Proponent stated that when the last preload for the causeway widening is completed, the remaining preload sand will be used for terminal apron preload, other terminal infrastructure construction purposes, or sold to the local sand market. It is understood from Appendix 4-E of the EIS that preloading of the wharf apron will use preload from the causeway once complete. However, it is unclear how the remaining preload from the wharf apron will be disposed of once preloading is complete.

Information Request

Describe how the excess preload material from the wharf apron, for example, will be dealt with once preloading is complete.

If there is more than one option available for the disposal of this excess preload, carry out an alternative means analysis and clearly specify the criteria used, in addition to feasibility and the potential for environmental effects, in the comparison of the alternatives. Provide a full discussion that supports any determination that an option was rejected due to technical or economic feasibility.

VFPA Response

Disposal of preload will not occur at sea or on land (i.e., disposal as waste material) as part of Project construction. As stated in Section 4.4.1.15 of the EIS, "The preliminary design incorporates an aggregate balance with no surplus remaining". As such, once preloading activities are complete, all preload material is expected to be used as fill or in other onsite applications, or sold to the local construction market, as it is of suitable quality for construction. As an example of an onsite application, a standard approach towards the end of construction with similar projects is to use the preload material as a surfacing layer to bring a project site to final grade once the utilities are installed.

Construction details regarding fill requirements and preload management will be at the discretion of the Infrastructure Developer, and it is in their financial interest to ensure that

there is no surplus aggregate material. Disposal of preload material as waste material will not occur during Project construction.

IR3-36 Project Design – Clarification: Causeway Vibro-replacement

Information Source(s)

EIS Volume 1: Section 4

EIS Volume 2: Section 9.6

Context

In Section 4 of the EIS, the Proponent indicated that it is anticipated that the underwater vibro-replacement technique carried out in the dredge basin will generate a layer of silty soil (termed fallout) on the seabed surface on top of the sacrificial cap layer. The fallout will be collected using a cutter-suction dredge, pumped into the terminal basins, and disposed of at the proposed DAS site. Although vibro-replacement will also occur in the construction of the western portion of the causeway, it is unclear whether this activity will also result in the generation of fallout and any subsequent requirements for disposal at sea.

Information Request

Describe the fallout that would be generated as a result of vibro-replacement in the western causeway perimeter.

Assess the potential environmental effects of this fallout and describe how these effects would be managed.

VFPA Response

The vibro-replacement process for ground improvement for the western causeway perimeter dyke foundations (and terminal perimeter dyke foundations, as stated in EIS Section 4.4.1.12) will occur "in the dry" from the surface of the dyke structure to the native soil beneath the dyke. As a result, fallout will not be generated in the marine environment as any fines that may migrate up to the surface in a slurry will be captured and directed into the terminal or causeway perimeter containment dykes for use as fill.

The volume of fine material to be generated from this process from the causeway and terminal perimeter dykes is anticipated to be relatively small (i.e., estimated at approximately 18,000 cubic metres of material, compared to 12.4 million cubic metres of fill material required for both areas (EIS Table 4-4)). As fines that migrate to the surface of the perimeter dykes will be used as fill and will be fully contained, there will be no environmental effects associated with this material.

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IR3-37 Alternative Means – Disposal at Sea: Sand Heads Alternative

Information Source(s)

Response to IR Package 1 (CEAR Doc #897)

Appendix C of the Applicant's Guide to Applying for a Disposal at Sea Permit (CEAR Doc #924)

Operational Policy Statement: Addressing "Purpose of" and "Alternative Means" under the *Canadian Environmental Assessment Act, 2012*

Context

In Table IR1-06-4 of CEAR #897, the Proponent indicated that disposal at the existing Sand Heads DaS may not be economically feasible due to costs associated with double-handling of material and transportation, but since it is technically feasible, environmental effects were evaluated. The acceptability of construction costs for disposal at Sand Heads was denoted by "Maybe". Table IR1-07-3 of CEAR #897 shows a comparison of the potential environmental effects to key valued components for the Sand Heads DaS location to the potential effects at the Project-specific locations. Comparisons for human health, marine fish, marine mammals, marine vegetation, marine invertebrates, coastal birds, and input from Environment and Climate Change Canada were made. However, the conclusion regarding the preferred option did not elaborate on the differences in the potential environmental effects of the two alternatives.

Further, according to Appendix C of the Applicant's Guide to Applying for a Disposal at Sea Permit produced by Environment and Climate Change Canada, alternate DaS sites at greater distances should be considered when they offer environmental benefits at reasonable increases in costs.

According to the CEAA Operational Policy Statement addressing the "Purpose of" and "Alternative Means", if a preferred alternative mean is selected, the analysis and the rationale for the choice should be explained from the perspective of a proponent, and be documented in the EIS in sufficient detail to provide context for public and technical comment periods during the project EA, and ultimately to allow the decision maker to understand the proponent's choice of a preferred alternative mean.

Sufficient detail has not been provided by the Proponent in the analysis of preferred means for alternatives for the disposal of sediments to allow this understanding. Further information on the economic feasibility and the potential environmental effects of the Sand Heads disposal site versus the Project disposal site is required. For clarity, this assessment of potential environmental effects is required regardless of any additional information that the Proponent may provide regarding its determination of the economic and technical feasibility of these two options.

Information Request

Provide a robust alternative means analysis comparing the use of the Project-specific DaS site with the Sand Head DaS site for all material proposed to be disposed of at sea (tug basin dredgeate, disposal of unsettled fines from the dredge basin and the ITP, and vibro-replacement expressed fines). This analysis should include but is not limited to a comparison of economic feasibility and an assessment of the potential environmental effects of the two alternatives. The effects assessment should be informed by specific criteria, including but not limited to:

- method of discharge;
- proximity to the US border;
- depth of site;
- stability of the sea floor;
- site characteristics or activities that could affect movement of sediments;
- physical, chemical, and biological characteristics of the water column and the seabed;
- dispersion direction and distance of associated plumes;
- erodibility;
- shoaling;
- distribution of TSS after disposal;
- additive effects from repeated or continuous dumping operations or discharges occurring at the same site;
- biological considerations relative to the timing of disposal operations;
- proximity to spawning, feeding, nursery, recruitment, migration, and other important habits; and
- proximity to sensitive resources and timing limitations.

The alternative means analysis effects assessment should be carried out for the following:

- marine sediment, water quality, vegetation, invertebrates, fish and mammals;
- coastal birds; and
- current use of land and resources for traditional purposes by Aboriginal peoples.

VFPA Response

Updated Project activities are described in the Preamble at the beginning of this response package. Sand fill material obtained from the Fraser River as part of the annual maintenance program, and from sediments dredged from the dredge basin and tug basin, will be used in terminal land development and causeway widening. The material will be deposited as a slurry to containment basins to settle, and supernatant containing unsettled fines will be discharged seaward from the terminal via pipelines with outfalls located at -45 m chart datum.

Vibro-replacement expressed fines (also referred to as silty fallout material) will no longer be generated from Project construction, as explained in the Preamble at the beginning of this response package.

Environment and Climate Change Canada (ECCC) identified in letter dated September 30, 2016 (CEAR Document #564[1]) that "the release of the supernatant associated with the use of material for construction purposes may also not require DAS [disposal at sea] permitting" provided it is deemed to be satisfactory for construction purposes and that the work will be carried out in a manner that does not cause marine pollution. The updated construction activities are not expected to require DAS permitting.

In addition, based on recent permits issued for disposal activities at the Sand Heads site pursuant to section 127 of the *Canadian Environmental Protection Act, 1999*, it is a restricted use site because it is located within southern resident killer whale critical habitat. This DAS site can only be used for the deposit of material dredged from the following reaches of the south arm of the Fraser River: Sand Heads, Sand Heads Reach, Steveston Bend, and Steveston Cut. It is therefore no longer considered to be a technically-feasible alternative disposal location to the Project-specific DAS site. As such, a robust alternative means analysis for the Sand Heads site is not provided as part of this response, and the VFPA has updated the assessment of alternative disposal options provided in sub-section M in Table IR1-06-4 of IR1-06 in CEAR Document #897[2] (see **Table IR3-37-1**), even though DAS activities are no longer proposed during Project construction.

[1] CEAR Document #564 From Environment and Climate Change Canada to the Review Panel re: Comments on the information relating to the environmental assessment of the Roberts Bank Terminal 2 Project.
[2] CEAR Document #897 From the Vancouver Fraser Port Authority to the Review Panel re: Responses to Information Request Package 1 (See Reference Document #559).

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Table IR3-37-1 Updated Feasibility Analysis for Construction Alternatives – Disposal at Sea (DAS) of Sediments

Alternatives Considered	Technical Evaluation	Economic Evaluation	Feasibility Assessment Conclusion	Alternative Considered	Technical Evaluation
M. Disposal at Sea (DAS) of Sediments	**Acceptable Concept for Disposal/Settling**	**Acceptable Level of Operational Risk**	**Construction Costs Acceptable**	**Feasible?**	**Rationale for Rejection as a Feasible Alternative**
Creation of settling ponds	Yes	Maybe	No	No	Alternative may not be technically feasible due to uncertainties associated with settling effectiveness during pond operation, and construction costs were not economical. This alternative was excluded from further evaluation.
Disposal at sea (DAS) at existing location (Sand Heads)	No	Not applicable – see rationale	No	No	Alternative not technically feasible due to restricted use of this site, which limits disposal of material to material sourced only from the lower reaches of the Fraser River. Alternative was excluded from further evaluation.
DAS at Project-specific location	Yes	Yes	Yes	Yes	Not applicable, as alternative technically and economically feasible – environmental effects evaluated.

Note: Due to recent construction-related updates to the Project, DAS of sediments is no longer proposed as a Project activity (refer to the Preamble at the beginning of this response package for more information). This information has been provided to update the alternatives comparison provided in Table IR1-06-4 of IR1-06 (CEAR Document #897).

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IR3-38 Alternative Means – Temporary Sand Storage: ITP Use and Schedule

Information Source(s)

Response to IR1-06 and IR1-10 (CEAR Doc #897)

EIS Volume 1: Section 4, Section 5

Context

In Table IR1-06-4 of CEAR Doc #897, the Proponent indicated that the use of in-river storage as an area for temporary sand storage would not be technically feasible because it did not have adequate storage capacity for all of the fill required for the Project (approximately 2.5 to 3.0 million m^3/year). In the response to IR1-10 from CEAR Doc #897, the Proponent ruled out the use of an on-land temporary sand storage alternative because it was found not to be economically feasible. The use of the ITP was indicated to be the preferred alternative for temporary sand storage. The Proponent had identified that if sand is transported via a dredge with pump ashore capability, unloading could also be achieved by rehydrating and pumping to the containment dyke area. Since there are dredges described in the EIS with pump ashore capability, it is unclear why the Proponent did not consider the delivery of a portion of Fraser River sands for immediate use as fill, while the other portion of sand could be stored elsewhere and imported as required.

Further information is required to determine whether a portion of the fill could be delivered directly for use at the Project site as fill, while the other portion could be stored at the ITP or at an on-land or other site.

Information Request

In consideration of technical and economic feasibility and the potential for environmental effects, describe how the temporary storage of material in the ITP could be minimized through the optimization of the timing of material delivery, locations of storage, and volume of sediment deposition.

For example, determine whether it would be technically and economically feasible to deliver a portion of the fill directly to the Project site during the 8-month period when annual maintenance dredging in the Fraser River is carried out, while minimizing the storage of the remaining fill at the ITP or another site.

VFPA Response

The VFPA has revised the Project's construction plan to eliminate temporary storage of Fraser River sand in the intermediate transfer pit (ITP). For more information, refer to the Preamble at the beginning of this response package.

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IR3-39 Disposal at Sea – Characteristics of Receiving Site: Site Morphology

Information Source(s)

EIS Volume 1: Figure 5-7

EIS Volume 2: Section 9.1.3, Appendix 9.5-A

Context

Section 9.1.3 of the EIS described geohazards in the vicinity of the Project including seismic activity, submarine landslides and tsunamis. Failures of the foreslope of the Fraser delta have occurred historically and according to Appendix 9.5-A, retrogressive slope failures and sediment-laden gravity flows have eroded the active deep valley off the mouth of the Main Arm near Sand Heads, and smaller valleys are evident off of Canoe Passage and the North Arm.

Further information is required to determine whether the geohazard risks - in particular those associated with submarine landslides - are similar at the Project-specific DaS locations (as denoted in Figure 5-7 of the EIS) and the Sand Heads DaS location.

Information Request

Describe and compare the Fraser Delta front 3-dimensional morphology and location at Sturgeon and Roberts Banks adjacent to the Sand Heads DaS site and at the Project-specific DaS site.

Describe the site-specific geohazard vulnerabilities at the potential Project-specific DaS locations and Sand Heads, in relation to slope failures and submarine landslides.

VFPA Response

This response expands upon the description provided in the EIS (and IR2-08) regarding geohazard vulnerabilities of the Project area as requested. As background, information about the Fraser River delta foreslope is presented in EIS Section 9.1.3.6 regarding potential erosion of the delta foreslope. In addition, EIS Section 9.5.6.3 describes the historical changes to the delta foreslope as expressed by elevation contours mapped by Stewart and Tassone (1989) and multibeam imagery presented in Hill et al. (2008). A more detailed description of the delta foreslope is presented in EIS Appendix 9.5-A, and includes a discussion of changes to the delta foreslope that are related to ongoing natural processes, and the VFPA's response to IR2-08 presents additional information in response to the information request for an assessment of the foreslope to determine whether it is undergoing active erosion or not.

This information request refers to disposal at sea (DAS) locations that were identified in the EIS (see inset map in EIS Figure 5-7). As outlined in the Preamble at the beginning of this

response package, the VFPA has been working to optimise the design of the Project and update the design and construction activities relevant to DAS requirements. Based on this effort, a DAS permit is no longer required for Project construction to proceed and the following response refers to the area that receives decant water from the containment dykes as the discharge area[1].

Fraser Delta Front 3-dimensional Morphology at Sturgeon and Roberts Banks

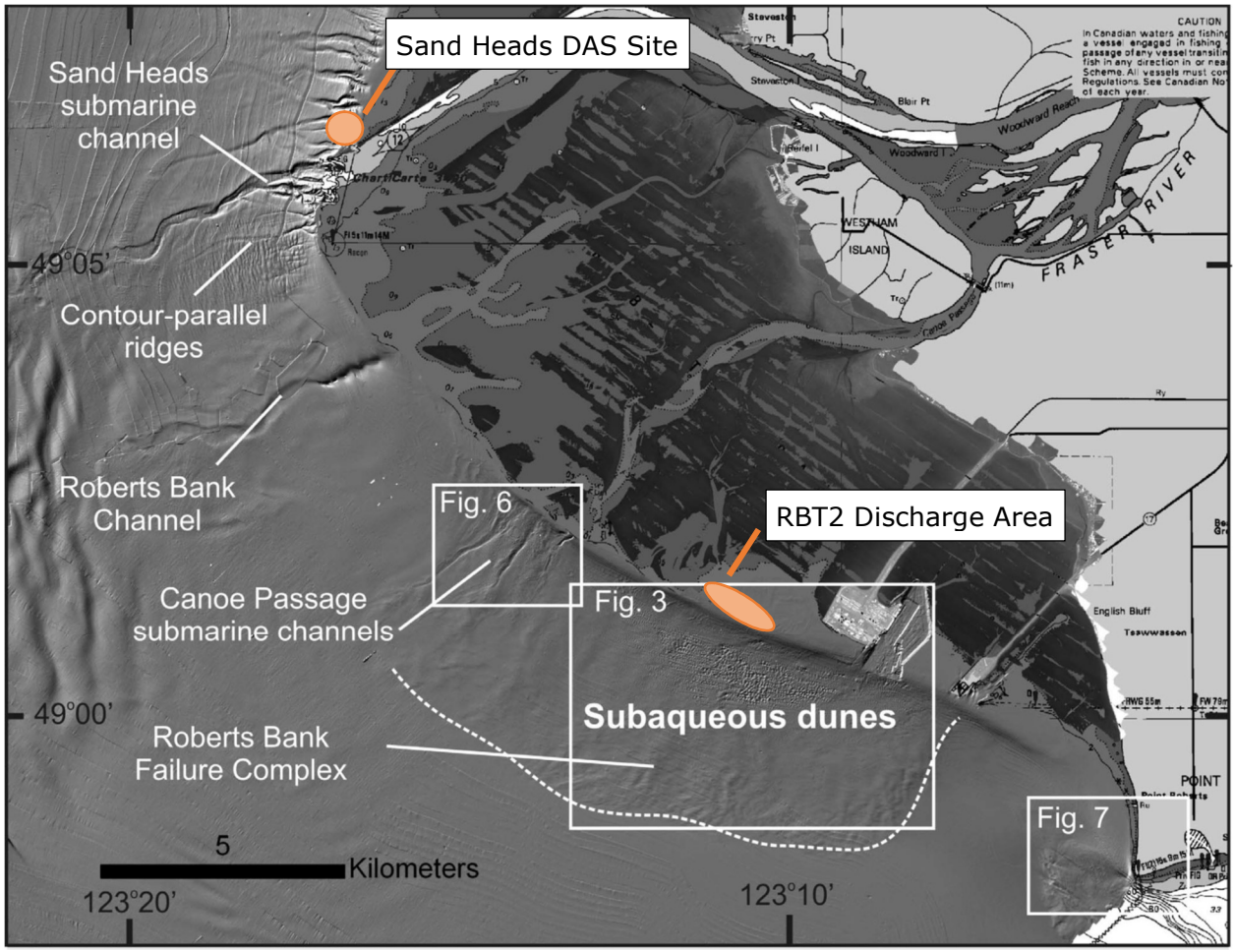
The Sand Heads DAS site, an active Environment and Climate Change Canada ocean disposal site, is located approximately 10 km west of Westham Island and approximately 14 km north-north west of the proposed Project terminal. It is located at 49°06.00'N, 123°19.5'W in approximately 70 m of water (Environment Canada 2006). The Project-specific discharge area is described in EIS Section 5.5.5 and EIS Figure 5-7 as three separate discharge locations at the preferred depth of -45 m CD (chart datum) on the foreslope immediately seaward of the RBT2 terminal (two locations) and slightly to the west of the terminal (one location). For reference, the approximate locations of the Sand Heads DAS site and the RBT2 discharge area are also shown on **Figure IR3-39-1**.

The physical setting at both areas is characterised by the presence of the foreslope, which is the characteristic steepening of the subtidal delta over the transition from the tidal flats into deep water. The sediments consist mainly of mud derived from suspended sediment in the Fraser River plume and coarser sand transported down the delta slope (EIS Appendix 9.5-A, Section 3.4.6). The morphology of the foreslope is dominated by two main processes:

a. Strong asymmetric tidal currents that are directed along the slope towards the north at velocities exceeding 1.2 m/s during flood tides and up to 0.5 m/s during ebb tides (Hill et al. 2008); and
b. Riverine processes that deliver large quantities of sediment to the top of the delta foreslope, resulting in frequent gravity flows and the formation of submarine channels and canyons.

[1] The discharge area for decant water from the containment dykes during infilling is no longer referred to as the Roberts Bank candidate disposal at sea area for the reasons explained in the Preamble provided at the beginning of this response package.

Figure IR3-39-1 Main Morphological Features of Sturgeon Bank and Roberts Bank based on 2001 LiDAR and Multibeam Surveys



Source: Carle and Hill 2009. Notations indicate approximate locations of the Sand Heads DAS site and RBT2 discharge area.

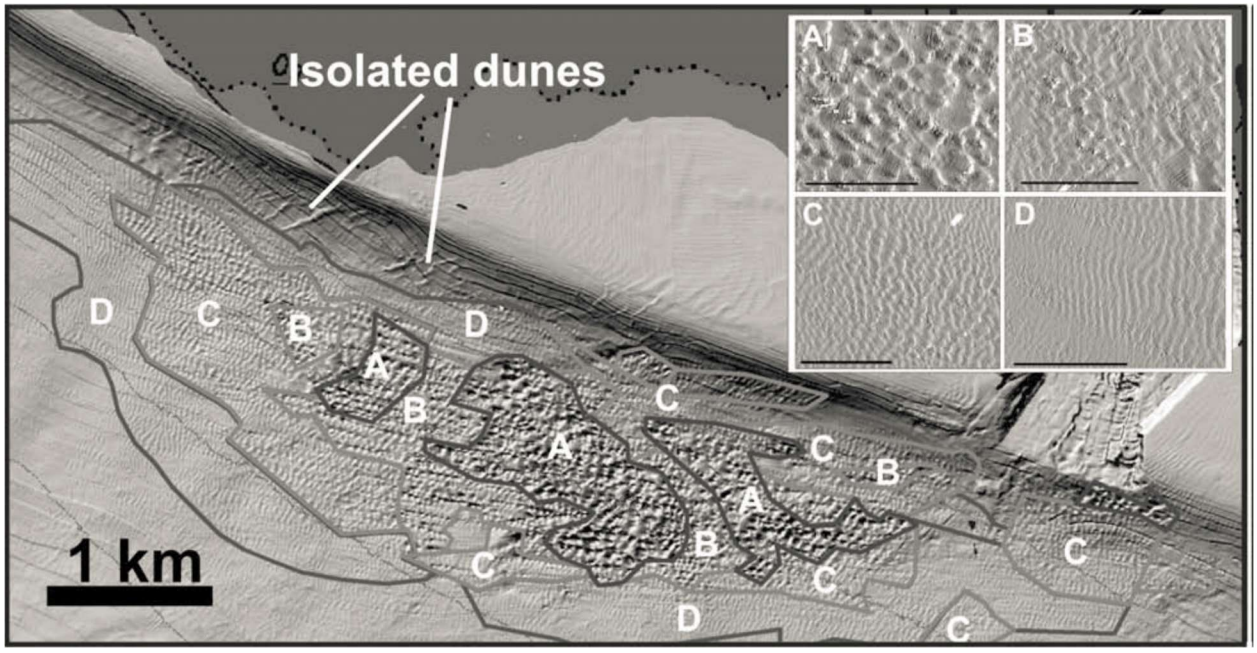
The morphology of the foreslope in the vicinity of the Sand Heads DAS site is dominated by the latter of these two processes (i.e., riverine deposition). As shown in **Figure IR3-39-1**, an extensive system of channels and canyons has formed seaward of the mouth of the Fraser River Main Arm. The Sand Heads Submarine Channel consists of several tributary channels, which converge at mid-slope to form the large, single feature (Hill et al. 2008). Repeated multibeam surveys indicate that repeated and ongoing events in the zone of rapid sediment accumulation result in slope failures or turbidity currents. Some of these currents have carried sediment quite far out into deep water to form a fan-shaped area of coarser sediments at the terminus of the submarine channel. In contrast to the high level of activity in the vicinity of Sand Heads, no bedforms are observed on the delta slope off Sturgeon Bank, and the morphology is relatively smooth, indicating a less energetic environment.

The morphology of the delta foreslope in the vicinity of the RBT2 discharge area is dominated by an extensive system of subaqueous dunes, indicating that tidal currents rather than riverine processes govern at this site. Although submarine channels are present near the

mouth of Canoe Passage, none are present in the vicinity of the discharge area. The area of dunes is indicated in **Figure IR3-39-1** and shown in greater detail in **Figure IR3-39-2**. The dune field is described in detail by Carle and Hill (2009), including classification of the dunes based on size and shape, from which sediment transport is inferred. As summarised in the response to IR2-08, the source of sediments in the dune field is not known with certainty, but likely originates either from past dredging activities (e.g., Hay and Company 1996), erosion of the delta foreslope (e.g., Hart et al. 1995), or a combination of the two.

Underlying a portion of the dune field described above is the Roberts Bank Failure Complex (**Figure IR3-39-1**). This feature was initially described by Currie and Mosher (1996), based on interpretation of multibeam and seismic reflection surveys that show a "hummocky surface and incoherent reflections in the subsurface". The interpretations of the failure complex range from a single massive slope failure event, a series of events, a river mouth failure complex, or simply a change in sediment type unrelated to slope failure (Currie and Mosher 1996). More recent analysis reported by Christian et al. (1997) suggests that multiple failures likely occurred. More recent deposits overlie the failure complex, indicating that the process that resulted in the hummocky surface is not presently active.

Figure IR3-39-2 Subaqueous Dunes on the Delta Slope off Roberts Bank in the Vicinity of the RBT2 Discharge Area



Source: Hill et al. 2008.

Geohazard Vulnerabilities at the Sand Heads DAS Site and RBT2 Discharge Area

As described by numerous researchers (most recently by Hill et al. 2008), slope failures and submarine landslides appear to be confined to the regions immediately seaward of the mouth of the Fraser River distributary channels (e.g., Main Arm and Canoe Passage). For instance, five large-scale mass movement events have occurred at the mouth of the Fraser River Main Arm channel at Sand Heads between 1970 and 1985 (McKenna et al. 1992). These events

have been interpreted as flow slides that resulted from rapid static liquefaction of the native sediments. Essentially, sediment from the Fraser River was rapidly deposited over the Sand Heads area, which loaded the existing sediments and caused an increase in pore pressure that potentially led to the static liquefaction (Christian et al. 1998). More recent research by Hill et al. (2008) that is based on repeated multibeam surveys between 2001 and 2006 has identified a number of small erosional events in the canyon heads of the southern tributaries to the Sand Heads submarine channel. The ongoing natural riverine processes are expected to continue to trigger slope failures and gravity flows in the vicinity of Sand Heads.

There is no evidence to suggest that slope failures or submarine landslides have occurred in the recent past in the vicinity of the RBT2 discharge area. Neither the process that would cause these events (e.g., rapid sediment deposition), nor the characteristic morphology indicating recent past events are present. Rather, as noted above, the area is presently dominated by tidal currents and the resultant formation of an extensive dune field. The sediments that comprise the dune field may originate, at least in part, from erosion of the delta foreslope, as noted in IR2-08. Erosion of the delta front could theoretically result in over-steepening of the foreslope, leading to slope failures; however, the lateral extent of erosion needed to cause slope failure makes this scenario highly unlikely.

As part of an earlier investigation of the dune field, Hay and Company (1996) conducted an assessment of delta slope stability and concluded that erosion on the order of 40 m would be needed to make the delta slope unstable in the vicinity of the existing Roberts Bank terminals. These findings were subsequently presented at an international conference of engineering geologists (Atkins et al. 1998). As noted in the response to IR2-08, construction of the RBT2 terminal will result in armouring of a 1,700 m long section of the foreslope down to -30 m CD, and will effectively halt any erosion of the foreslope in that area that may be occurring at present. The results of previous geotechnical slope stability analyses indicate that the delta foreslope "is in a state of stable equilibrium under existing static loading-induced loads or gravity loads" and that it is highly unlikely that "catastrophic slope failures" (both shallow and deep-seated) under static loading conditions (EIS Section 9.1.3.7) would occur. Static loading conditions comprise all non-seismic scenarios, and therefore include deposition by natural sedimentation.

Project-related sediment deposition along the foreslope is not expected to result in rapid sediment accumulation sufficient to cause slope failures or submarine landslides. Sediment deposition along the foreslope due to RBT2 construction activities will comprise discharge of "sediment-laden water" (i.e., unusable fines remaining in suspension) via submarine pipe to -45 m CD. This discharge is anticipated to take place over a period of several months in multiple years, and disperse over a broader area (see EIS Section 9.6). This is unlike the historical, large-scale Sand Heads flow slides that were the result of rapid deposition in a concentrated area, or the localised dumping of dredged Fraser River Sands at the Sand Heads DAS site.

The deposited sediment at the RBT2 discharge area will predominantly consist of fine-grained soils having a median/50th percentile particle size ranging from 0.010 mm to 0.045 mm. The total thickness of this sediment deposited along the delta foreslope is not anticipated to exceed 1.0 mm based on previous dispersion modelling (EIS Table 9.6-5). The maximum

anticipated total thickness at the end of sediment deposition is less than the estimated natural sedimentation rate for Roberts Bank of 2 mm/year to 20 mm/year (EIS Section 9.6.6.1).

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IR3-40 Disposal at Sea – Characteristics of Disposed Materials: Terminal Vibro-densification

Information Source(s)

EIS Volume 1: Section 4.0

EIS Volume 2: Section 9.6, Appendix 9.6-C

CEAR Doc #564

Context

In Section 4.0 of the EIS, the Proponent proposed the disposal of approximately 128 000 m^3 of material at sea that is expected to result from a vibro-densification process to be used in the construction of the terminal.

According to Environment and Climate Change Canada (CEAR Doc #564), the vibro-densification process would compact (or densify) sediments on the seabed surface so as to support construction of the new terminal structure. The Proponent proposed to suction dredge the silty 'fallout' resulting from the vibro-densification process, pump it into holding basins at the terminal site and then dispose of it at sea via pipes. Based on information presented in the EIS, this activity is recognized by Environment and Climate Change Canada as a Project element that would constitute DaS.

Environment and Climate Change Canada indicated that it is unclear why the Proponent plans to pump silty fallout material (identified as a waste in the EIS) into the same holding basins that would be receiving dredged material intended for construction purposes. The effect of this approach would be to mix a waste with a material that must have physical and chemical characteristics appropriate for construction, and it may not be possible for Environment and Climate Change Canada to consider the material dredged from the berthing dock as suitable for construction. The proposed method of managing the silty fallout waste may be ineligible for DaS permitting and the Proponent has not identified and assessed alternative options for managing this waste.

Information Request

Describe the physical and chemical characteristics of the silty fallout that is proposed for pumping into the holding basins, and describe whether it would be suitable for construction.

If this material is not deemed to be suitable for construction, describe alternative approaches for the management of the silty fallout waste.

VFPA Clarification

The context section for this information request and CEAR Document #564[1] refer to 128,000 m^3 of silty fallout from the vibro-densification process. To clarify, silty fallout only occurs as a by-product of the vibro-replacement process (see EIS Section 4.4.1.9), a technique for in situ subsoil improvement that utilises special depth vibrators and coarse material to replace finer material (e.g., clay and sand) with coarser material. Vibro-densification, a process that uses a depth vibrator to densify in situ material, does not generate silty fallout as it is not a material replacement technique.

VFPA Response

As background, the conceptual wharf structure design described in EIS Section 4.2.1.2 was informed by geotechnical analyses of inferred ground conditions within the Project footprint and the National Building Code of Canada A2475 seismic standard at the time of preliminary design[2]. Based on inferred site conditions and standards, both vibro-densification and vibro-replacement processes were incorporated as soil improvement techniques within the construction sequence, as described in EIS Section 4.4.1.9.

In 2016, in situ ground conditions within the terminal footprint were tested as part of the 2016 RBT2 Geotechnical Program, as outlined in the Preamble at the beginning of this response package. Based on further geotechnical analyses using data obtained from this program, soil material within the terminal footprint has a more favourable seismic response than initially determined based on inferred conditions as described in the EIS. As a result of these analyses and adoption of 2014 seismic performance requirements from the American Society of Civil Engineers (Standards ASCE/COPRI 61-14, Seismic Design of Piers and Wharves), in situ soils below the base of the dredge basin no longer require improvement via the vibro-replacement process. With the elimination of this process, silty fallout will not be generated on the seabed during construction and further characterisation of the fallout and consideration of alternative approaches for the management of the silty fallout waste are not necessary.

[1] CEAR Document #564 From Environment and Climate Change Canada to the Review Panel re: Comments on the information relating to the environmental assessment of the Roberts Bank Terminal 2 Project.

[2] Appendix IR2-22-A of IR2-22 provides the seismic degradation plots for A100, A475, and A2475 earthquake levels that were used to inform the conceptual design.

IR3-41 Marine Water Quality – Baseline: Water Quality Existing Conditions

Information Source(s)

EIS Volume 2: Section 9.7, Appendix 9.6-A

Context

The Proponent conducted field studies and analyses of water for chemical and physical parameters at monthly or by-monthly intervals over a one-year period (July 2012 to June 2013) and obtained *in situ* turbidity measurements in June 2013. According to Section 5.0 of Appendix 9.6-A of the EIS, the freshet of 2012 reflected an abnormally large discharge. Because the discharge from the Fraser River may show significant year-to-year variability in flow and consequent water chemistry, it is necessary to evaluate the influence that using an unusually high flow year may have had on the reporting of baseline water quality parameters.

Information Request

Based on existing information, including available water quality databases, provide a revised set of the water quality parameters identified in Appendix F of Appendix 9.6-A of the EIS which reflects current baseline conditions.

Provide a discussion of how this revised baseline information could influence the Proponent's analysis and conclusions regarding relevant intermediate components and valued components

VFPA Response

The characterisation of existing conditions for marine water quality are described in EIS Section 9.7.6 for a range of parameters, including temperature, salinity, dissolved oxygen and pH, total suspended solids and turbidity, nutrients, and contaminants (including trace elements such as metals and metalloids). The reported water quality values are derived from a variety of information sources that are summarised in EIS Section 9.7.3, including previous studies conducted from the mid-1970s to 2012 and Project-specific field studies conducted during the July 2012 to June 2013 period. Eight sampling campaigns were conducted during the July 2012 to June 2013 period (see Table 24 of EIS Appendix 9.6-A). Fraser River flows were at close to mean flow conditions during the campaigns, with the exception of the sampling conducted in late July 2012. This campaign coincided with higher than mean flow conditions for the Fraser River, as explained further below.

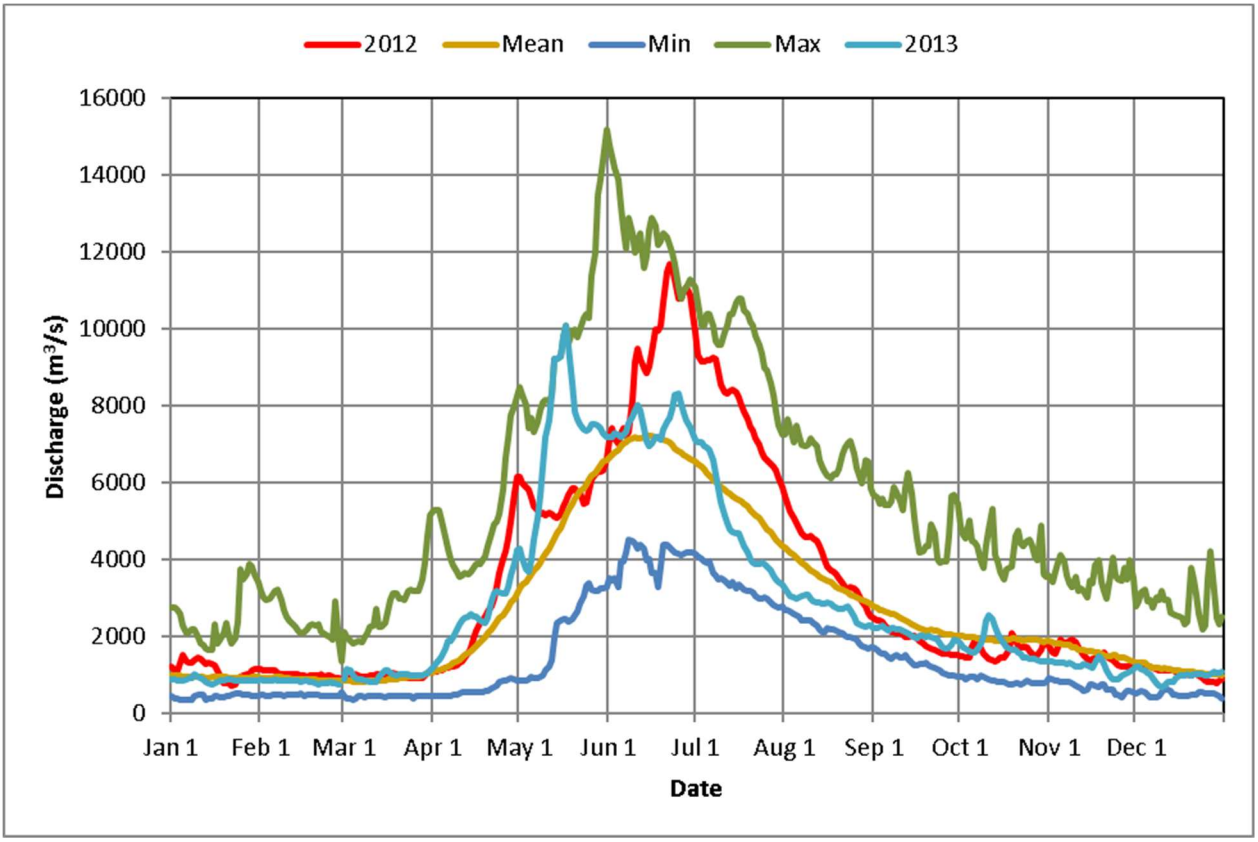
As the information pertaining to water quality parameters described in the EIS has already incorporated the types of information sources mentioned in the information request (e.g., existing information, including available water quality databases), further revision is not possible. The analysis and conclusions regarding relevant intermediate components or valued components, therefore, will not change.

The information that follows provides clarification about the information used to describe water quality parameters and the observed variability, and how Fraser River discharge varied during the 2012 to 2013 sampling period.

Section 5.2 of EIS Appendix 9.6-A states that "The Fraser River freshet that occurred in 2012 reflected an abnormally large spring-time discharge from the Fraser River watershed, so the spatial trends captured over the year-long sampling period adequately reflect higher than average riverine discharge periods through the late summer period." This statement is intended to demonstrate that the field studies captured a representative range of conditions and do not imply that the studies were adversely affected by the large peak freshet observed in June 2012. Furthermore, this description is qualitative, summarising the peak discharge as well as the length of time that discharge exceeded the long-term mean. Water quality parameters in the local study area (LSA) exhibit various degrees of variability, and will depend in part on the discharge of the Fraser River. As such, a description of the annual hydrograph for the Fraser River (Hope Station) is presented in **Figure IR3-41-1**. **Figure IR3-41-1** shows the mean, minimum, and maximum discharges for all years for the period of record (1913-2016) and actual discharge for 2012 and 2013 (with flows within the range of natural variability for the period of record). Quantitative comparisons are provided below.

Water quality field sampling events in 2012 first occurred in late July (23 to 26) and then in late August, late September, and mid-October (see Table 24 in EIS Appendix 9.6-A for specific dates). As shown in **Figure IR3-41-1**, from July 23, Fraser River discharge was around 7,000 m^3/s (cubic metres per second), approximately 2,000 m^3/s higher than the long-term mean and approximately 2,600 m^3/s below the long-term maximum discharge for the period of record, but well within the range of natural variability. By late August, flows had dropped to approximately mean discharge and were then slightly below the long-term mean discharge during sampling events in late September and mid-October. Water quality field sampling events in 2013 occurred in mid-January, mid-February, mid-April, and early June (see Table 24 in EIS Appendix 9.6-A for specific dates). Fraser River flows during the winter months were very close to the long-term mean and then rose slightly above the mean during the April sampling period, reached nearly to historical highs for part of May, and then dropped back to near the mean discharge in early June. In particular, the sampling event of June 5, 2013, the results of which are reported in detail in Appendix F of EIS Appendix 9.6-A, was conducted during the 2013 freshet season when flows were only slightly above the long-term mean (approximately 400 m^3/s above the long-term mean of about 8,000 m^3/s on June 5).

Figure IR3-41-1 Annual Hydrographs of Fraser River at Hope



Note: Min (minimum), Max (maximum), and Mean are calculated from daily flow records for the period 1913 to 2016. Data from Water Survey of Canada 2016.

In addition to the water quality measurements and in situ sampling in the LSA that are reported in EIS Appendix 9.6-A, field sampling and measurements of salinity, turbidity, and temperature are reported in EIS Section 9.5 and EIS Appendix 9.5-A. Specifically:

- Table 5 in Appendix C of EIS Appendix 9.5-A lists CTD[1] measurements that were made at Roberts Bank on eight separate days between June 12 and August 29, 2012. Water samples to describe suspended sediment concentrations were also collected during this period;
- A monitoring station was established on May 8, 2012 in Canoe Passage to continuously measure water velocity, turbidity, and salinity. Appendix C of EIS Appendix 9.5-A provides details of the station, as well as results based on measurements made to December 2013[2];

[1] CTD stands for conductivity, temperature, and depth, and refers to a package of electronic instruments that measure these properties.
[2] The station at Canoe Passage was in operation until the instruments were removed in March 2015. Data collected to December 2013 contributed to the EIS.

- Direct measurements of river discharge and suspended sediment concentration were made at the Canoe Passage station using a boat-mounted ADCP[3] and a LISST-SL[4]. Suspended sediment samples were also collected at the site using a P61[5], which were analysed in a laboratory using a LISST-100[6]. Field measurements were made and samples were collected between May 8 and November 14, 2012 (summarised in Table 2 in Appendix C of EIS Appendix 9.5-A); and
- Based on field measurements and samples, a site-specific relationship between sediment concentration and turbidity was developed for the Canoe Passage station and the samples collected over Roberts Bank (see Figure 14 in Appendix C of EIS Appendix 9.5-A). This relationship captures turbidity conditions ranging from approximately 10 NTU (nephelometric turbidity unit) to almost 200 NTU.

In addition to the measurements undertaken and samples collected as part of the EIS studies, EIS Appendix 9.6-A and EIS Section 9.7.3 present a summary and overview of existing studies for which water (and sediment) properties in the vicinity of the proposed Project were the focus, and in many cases reported on specific results. The characterisation of existing conditions for water quality parameters considered the following studies:

- Water quality assessment in the Fraser River estuary (Levings and Coustalin 1975, Shaw and Tuominen 1999);
- Water quality assessment at Roberts Bank and Sturgeon Bank (Swain et al. 1998);
- Research on the nutrient dynamics in the Fraser River estuary (Harrison et al. 1998);
- Fraser River aquatic ecosystem research conducted under the Fraser River Action Plan (Gray and Tuominen 1998);
- Roberts Bank cumulative environmental effects study for the marine habitat (Triton Environmental Consultants Ltd. 2001);
- Baseline water quality sampling for Deltaport Third Berth (DP3) Project environmental assessment (EVS and Golder 2004);
- Deltaport Third Berth baseline studies of water and sediment quality (Vancouver Port Authority 2005); and
- Quarterly water quality monitoring data and information for the DP3 Adaptive Management Strategy (AMS) from 2007 to 2012 (Hemmera et al. 2008, 2009, 2010, 2011, 2012, 2013).

The above summarised studies span a time period of a decade and a half, and include measurements collected over a broad geographic distribution and across all seasons of the

[3] The standard instrument for measuring discharge and water velocity is the Acoustic Doppler Current Profiler (ADCP), which detects the phase shift returned from particles in the water column to measure the three-dimensional velocity vector at various depths in the water column.
[4] LISST-SL – This instrument pumps a sample of the river water through a test chamber at a flow rate such that the intake velocity matches the stream velocity. A laser beam in the test chamber is sent through the water sample and the refraction of the laser beam is used to determine the particle size and concentration.
[5] P61 – A depth-integrated sampler that collects a sub-surface water sample that is integrated to the flow velocity.
[6] LISST-100 – Similar technology to the LISST-SL described above, this instrument is used to process samples in a lab.

year. The characterisation of existing conditions for water quality, therefore, has been based on a range of conditions.

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IR3-42 Marine Water Quality – Baseline: Seasonal Water Quality

Information Source(s)

EIS Volume 2: Section 9.7.6, Appendix 9.6-A

Context

Environment and Climate Change Canada noted that, in the EIS, some marine water quality parameters (conductivity, temperature) were sampled on a seasonal basis and were collected monthly or bi-monthly over one year (July 2012 to June 2013).

Hardness, TSS, nutrients and trace elements were analysed using a single sampling event in April 2013. This sampling frequency does not capture seasonal trends.

Information Request

Provide seasonal estimates of hardness, TSS, nutrients and trace elements in the marine water quality study area (Figure 9.7-1) based on available data sources.

VFPA Response

Seasonal estimates of hardness, total suspended solids (TSS), nutrients, and trace elements (i.e., anions, metals, metalloids) in the marine water quality local study area (LSA) are provided below. The LSA includes Sturgeon Bank, Roberts Bank, and Boundary Bay, as illustrated in Figure IR3-42-A1 (provided in **Appendix IR3-42-A**). The information provided in this response is aligned with characterisation of existing conditions provided in EIS Sections 9.7.6.4 to 9.7.6.6 and EIS Appendix 9.6-A[1] for TSS, nutrients, and metals and metalloids, respectively.

In response to the Panel's request, the VFPA acquired marine water quality data from recent sampling conducted between 2012 and 2015 in the LSA from the following available sources:

- Samples collected in spring 2013 at Roberts Bank by Hemmera Envirochem Inc. (Hemmera) and reported in the Sediment and Water Quality Characterisation Studies, RBT2 Technical Report (report provided in EIS Appendix 9.6-A);

[1] In addition to the measurements undertaken and samples collected as part of the EIS studies, characterisation of existing conditions for water quality parameters provided in the EIS considered the following studies: Levings and Coustalin (1975), Shaw and Tuominen (1999), Swain et al. (1998), Harrison et al. (1998), Gray and Tuominen (1998), Triton Environmental Consultants Ltd. (2001), EVS and Golder (2004), Vancouver Port Authority (2005), and Hemmera et al. (2008, 2009, 2010, 2011, 2012, and 2013). For more information on the characterisation of existing conditions for water quality parameters, refer to IR3-41.

- Samples collected quarterly in 2014 at Roberts Bank as part of the Deltaport Third Berth Adaptive Management Strategy (DP3 AMS) monitoring program and reported in the 2014 Annual Report prepared by Hemmera et al. (2015);
- Samples collected in spring 2012 by Northwest Hydraulic Consultants (NHC) and reported in the Coastal Geomorphology Study, RBT2 Technical Report (report provided in Appendix C of EIS Appendix 9.5-A); and
- Samples collected in summer and fall 2015 as part of the Metro Vancouver Boundary Bay Assessment and Monitoring Program (BBAMP) and reported in the 2015 Water Column Monitoring Report prepared by Tri-Star Environmental Consulting (Tri-Star; 2017).

Sampling locations within the LSA corresponding to analytical results from these information sources, where some or all of the requested parameters have been analysed, are shown in Figure IR3-42-A1 (**Appendix IR3-42-A**). Information is presented seasonally for Boundary Bay and Roberts Bank (for both the south side of the Roberts Bank causeway in the inter-causeway area and the north side). Information is not presented for Sturgeon Bank as data specific to the requested parameters were not available for this area[2]. A summary of available data for the specific parameters[3] analysed seasonally at each monitoring location is provided in **Table IR3-42-1**.

Table IR3-42-1 Available Data Incorporated in Seasonal Water Quality Estimates in the LSA

Information Source	Hemmera 2013	BBAMP 2015		DP3 AMS 2014				NHC 2012
Season Sampled	Spring	Summer	Fall	Spring	Summer	Fall	Winter	Spring
Physical Tests (mg/L)								
Hardness (as $CaCO_3$)	x	x	x	x	x	x	x	
Total Suspended Solids	x			x	x	x	x	x
Anions and Nutrients (µg/L)								
Ammonia, Total (as N)	x	x	x	x	x	x	x	
Bromide (Br)	x							
Chloride (Cl)	x							
Fluoride (F)	x							
Nitrate (as N)	x	x	x	x	x	x	x	
Nitrite (as N)	x	x	x	x	x	x	x	
Phosphorus (P)	x	x	x	x	x	x	x	
Sulfate (SO_4)	x							
Total Metals (µg/L)								
Aluminum (Al)-Total	x	x	x				x	

[2] The VFPA was unable to acquire marine water quality data from Metro Vancouver monitoring stations located in subtidal waters at the north end of Roberts Bank and near Sturgeon Bank.

[3] The list of parameters presented in this response has been standardised to be consistent with the water chemistry results presented in Appendix F of EIS Appendix 9.6-A. Where relevant, unit concentrations (i.e., milligrams per litre (mg/L) or micrograms per litre (µg/L)) have also be standardised to allow for comparisons between the various studies and the calculation of summary statistics.

Information Source	Hemmera 2013	BBAMP 2015		DP3 AMS 2014				NHC 2012
Season Sampled	Spring	Summer	Fall	Spring	Summer	Fall	Winter	Spring
Antimony (Sb)-Total	x	x	x				x	
Arsenic (As)-Total	x	x	x				x	
Barium (Ba)-Total	x	x	x				x	
Beryllium (Be)-Total	x	x	x				x	
Bismuth (Bi)-Total	x	x	x				x	
Boron (B)-Total	x	x	x				x	
Cadmium (Cd)-Total	x	x	x				x	
Calcium (Ca)-Total	x	x	x				x	
Cesium (Cs)-Total	x						x	
Chromium (Cr)-Total	x	x	x				x	
Cobalt (Co)-Total	x	x	x				x	
Copper (Cu)-Total	x	x	x				x	
Gallium (Ga)-Total	x						x	
Iron (Fe)-Total	x	x	x				x	
Lead (Pb)-Total	x	x	x				x	
Lithium (Li)-Total	x	x	x				x	
Magnesium (Mg)-Total	x	x	x				x	
Manganese (Mn)-Total	x	x	x				x	
Mercury (Hg)-Total	x						x	
Molybdenum (Mo)-Total	x	x	x				x	
Nickel (Ni)-Total	x	x	x				x	
Phosphorus (P)-Total	x	x	x				x	
Potassium (K)-Total	x	x	x				x	
Rhenium (Re)-Total	x						x	
Rubidium (Rb)-Total	x						x	
Selenium (Se)-Total	x	x	x				x	
Silicon (Si)-Total	x	x	x				x	
Silver (Ag)-Total	x	x	x				x	
Sodium (Na)-Total	x	x	x				x	
Strontium (Sr)-Total	x	x	x				x	
Tellurium (Te)-Total	x			x	x	x	x	
Thallium (Tl)-Total	x	x	x	x	x	x	x	
Thorium (Th)-Total	x			x	x	x	x	
Tin (Sn)-Total	x	x	x	x	x	x	x	
Titanium (Ti)-Total	x	x	x	x	x	x	x	
Tungsten (W)-Total	x			x	x	x	x	
Uranium (U)-Total	x	x	x	x	x	x	x	
Vanadium (V)-Total	x	x	x	x	x	x	x	
Yttrium (Y)-Total	x			x	x	x	x	
Zinc (Zn)-Total	x	x	x	x	x	x	x	
Zirconium (Zr)-Total	x			x	x	x	x	

Detailed sampling and laboratory analytical methods (including analytical detection limits), along with comparisons to federal and/or provincial marine water quality guidelines, are provided in the source documents listed above. As outlined in EIS Appendix 9.6-A, some water chemistry parameters of interest were expected to vary only minimally over time. Seasonal

comparisons are provided, where possible, based on available information for samples collected in 2012 to 2015. In addition, seasonal trends documented from sampling in previous years under the BBAMP (2009 to 2014) and DP3 AMS (2007 to 2013) programs and documented in the most recent annual reports for those programs are also summarised, where relevant.

The sub-sections below describe average seasonal estimates for hardness, TSS, anions and nutrients, and total metals for Boundary Bay and Roberts Bank. For nutrients, the discussion focuses on the following parameters:

1) Ammonia, due to potential toxicity to aquatic life (ammonia is the form of nitrogen preferentially taken up by aquatic plants);
2) Nitrates, which can account for the majority of total nitrogen, which is a limiting nutrient in the marine environment; and
3) Total phosphorus, due to its potential to promote algal growth.

For total metals, the discussion generally focuses on parameters that are environmentally important (i.e., most likely to exert biological effects based on either being non-essential or required as essential elements in sparse amounts) and typically present at concentrations greater than the detection limits. The parameters most relevant to human influences that are environmentally important, and that are less of a reflection of natural geological and oceanic major elements (except for iron), include antimony, arsenic, cadmium, chromium, copper, iron, lead, molybdenum, nickel, selenium, uranium, and zinc. Water chemistry analytical results for each sampling location, along with summary statistics for each season (i.e., maximum, minimum, mean, and standard deviation), are provided in **Appendix IR3-42-B**.

Boundary Bay Water Chemistry

The only data available for Boundary Bay was sourced from the BBAMP. Under that program, water quality samples were collected annually in Boundary Bay from 2009 to 2015. The data presented below is from the 2015 sampling campaign, noting that Tri-Star (2017) indicated that annual variation was not observed when comparing to prior years of data.

For the BBAMP 2015 water monitoring program, sampling was conducted in Boundary Bay in both the dry summer (July 22 to August 20, 2015) and wet fall (October 21 to November 12, 2015) seasons, with five sampling events occurring over a 30-day period in each season. Although there are two BBAMP sample sites within the LSA (see Figure IR3-42-A1 in **Appendix IR3-42-A**), water chemistry information is provided in this response for Site 4 Tsawwassen/Delta South only, as Site 8 Blackie Spit Side Channel is heavily influenced by discharge of the Nicomekl River and Serpentine River.

Table IR3-42-2 provides average seasonal estimates (for parameters with concentrations above detection limits) from samples collected one metre below the water surface on a flood tide in Boundary Bay at Site 4, and Table IR3-42-B1 in **Appendix IR3-42-B** provides the complete data set.

Table IR3-42-2 Boundary Bay Water Chemistry in LSA for Summer and Fall 2015, Mean Concentrations

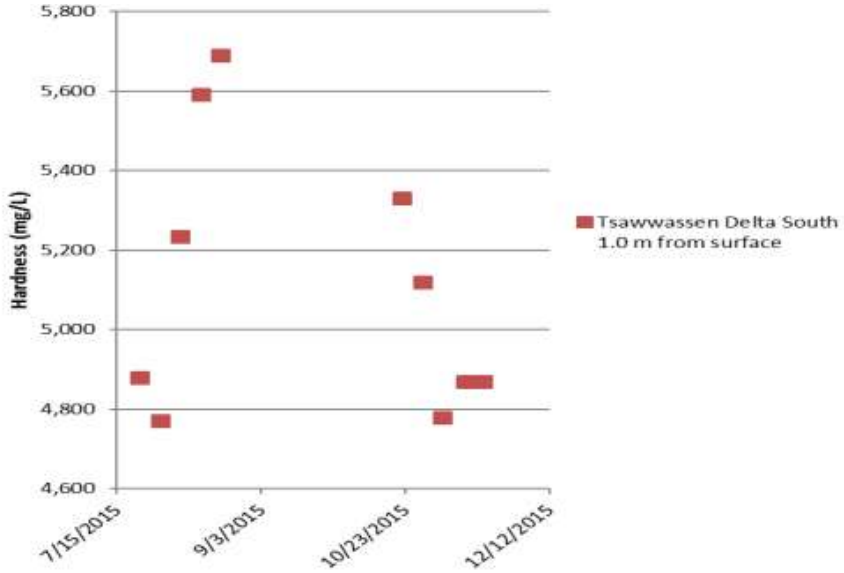
Boundary Bay - BBAMP Site 4 Tsawwassen-Delta South	Summer	Fall
Sample Depth, Below Water Surface (m)	**n=5**	**n=5**
	1.03	1.05
Physical Tests (mg/L)	**n=5**	**n=5**
Hardness (as $CaCO_3$)	5,233	4,994
Anions and Nutrients (µg/L)	**n=5**	**n=5**
Ammonia, Total (as N)	19	68
Nitrate (as N)	< 2.0	194.8
Nitrite (as N)	< 2.0	7.9
Phosphorus (P)-Total	69.6	59.3
Total Metals (µg/L)	**n=5**	**n=5**
Aluminum (Al)-Total	16	77
Arsenic (As)-Total	1.77	1.48
Barium (Ba)-Total	10,500	10,200
Boron (B)-Total	3590	3360
Calcium (Ca)-Total	357,000	330,000
Cobalt (Co)-Total	< 0.10	0.24
Copper (Cu)-Total	< 0.50	1.27
Iron (Fe)-Total	28	115.2
Lithium (Li)-Total	140	146
Magnesium (Mg)-Total	1,055,000	1,012,000
Manganese (Mn)-Total	4.21	7.85
Molybdenum (Mo)-Total	8.6	8.9
Nickel (Ni)-Total	0.39	1.05
Potassium (K)-Total	320,000	309,000
Silicon (Si)-Total	906	1,392
Sodium (Na)-Total	8,500,000	8,312,000
Strontium (Sr)-Total	7255	6,628
Uranium (U)-Total	2.3	2.73

Source: Mean concentrations from Tri-Star (2017).
Note: Only parameters above detection limits are included in this summary table. For a complete list of all parameters and sample concentrations, as well as assumptions pertaining to the inclusion of samples below detection limit in mean concentration calculations, refer to Table IR3-42-B1 in **Appendix IR3-42-B**; 'n' is the number of samples analysed.

Hardness

Hardness concentrations (as $CaCO_3$) did not vary seasonally in Boundary Bay (**Figure IR3-42-1**). The mean concentration was 5,233 mg/L with a standard deviation of 411 mg/L during the summer, and 4,994 mg/L with a standard deviation of 227 mg/L during the fall (Table IR3-42-B1 in **Appendix IR3-42-B**). The within-season variability in hardness is greater than the observed between-season variability, and this is likely a reflection of sampling at different stages of the tidal cycle and the associated tidal shifts in the estuarine salt wedge.

Figure IR3-42-1 Hardness (mg/L) at Boundary Bay (Site 4) within the LSA for Summer and Fall 2015



Source: Tri-Star (2017).

Total Suspended Solids

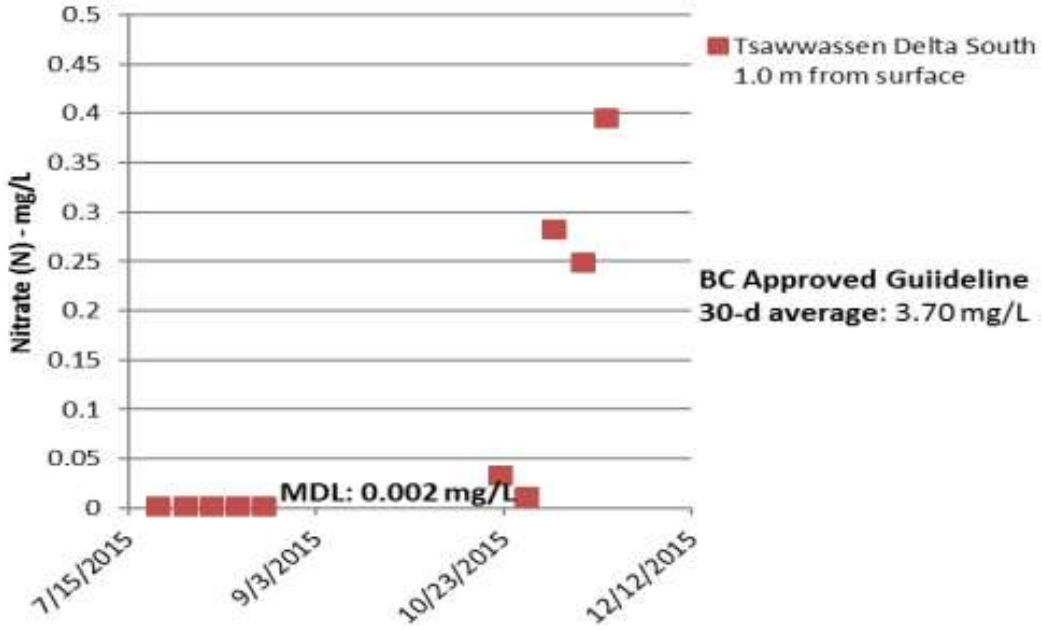
Total suspended solids were not analysed at Tsawwassen-Delta South (Site 4) as part of the BBAMP. However, turbidity at the marine sites was noted by Tri-Star (2017) to be higher during the fall than summer, likely due to the higher volumes of stormwater runoff that enter the Bay during this period from the pump stations as well as the tributaries, but could also originate with storms and higher tides.

Anions and Nutrients

Concentrations for nitrate and nitrite are presented in **Figures IR3-42-2** and **IR3-42-3**, respectively. Concentrations of nitrate and nitrite, and ammonia, were higher during the fall than during the summer, which may be attributed to upwelling of nutrients during fall storms, as noted in Tri-Star (2017) for 2015 and prior sampling periods (2009 to 2014). This further assumes that the samples reflect a predominantly marine influence at their collection point within one meter of the sea surface at this particular location in the Fraser River estuary. An alternative hypothesis is that ammonia and nitrate concentrations are drawn down during the mid-summer period within the photic zone by primary producers, while lesser uptake into primary producers occurs in fall because of decreased light. Total phosphorus levels did not vary seasonally, as shown in **Figure IR3-42-4**[4].

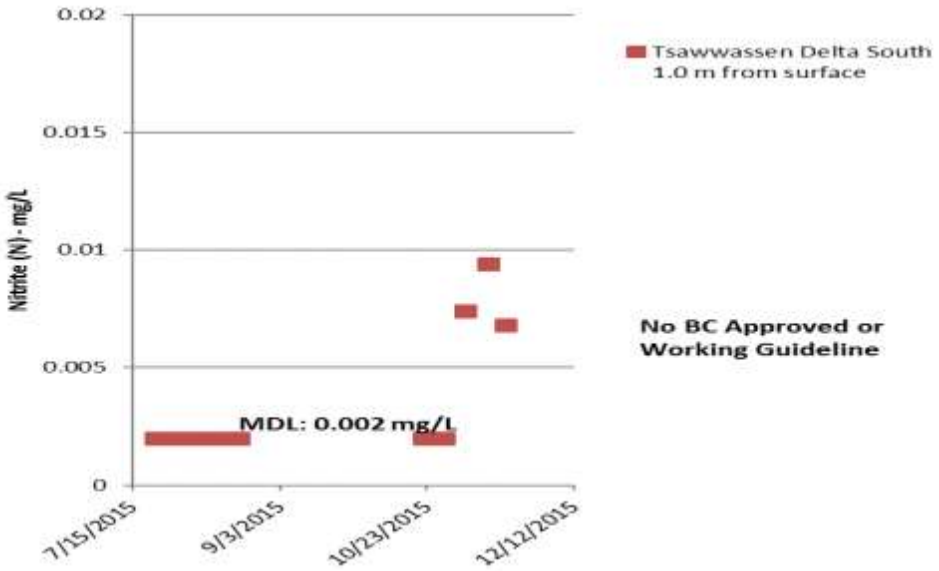
[4] Note that this figure and some subsequent figures sourced from Tri-Star (2017) provide anion and metal (including metalloid) concentrations in milligrams per litre (mg/L); data tables provided in this response list anion and metal concentrations in micrograms per litre (µg/L).

Figure IR3-42-2 Nitrate Concentrations (mg/L) at Boundary Bay (Site 4) within the LSA for Summer and Fall 2015



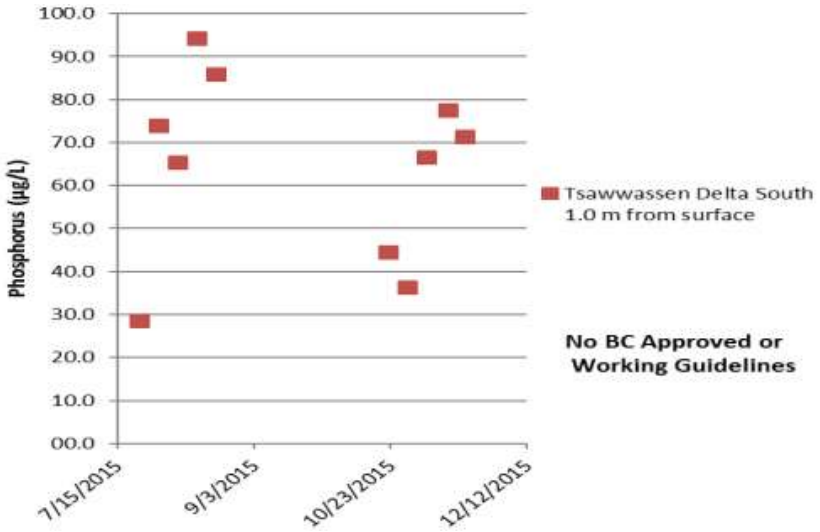
Source: Tri-Star (2017).
Notes: MDL = method detection limit. For information on applicable water quality guidelines for the BBAMP, refer to Tri-Star (2017).

Figure IR3-42-3 Nitrite Concentrations (mg/L) at Boundary Bay within the LSA for Summer and Fall 2015



Source: Tri-Star (2017).
Notes: MDL = method detection limit. For information on applicable water quality guidelines for the BBAMP, refer to Tri-Star (2017).

Figure IR3-42-4 Total Phosphorus Concentrations (µg/L) at Boundary Bay within the LSA for Summer and Fall 2015

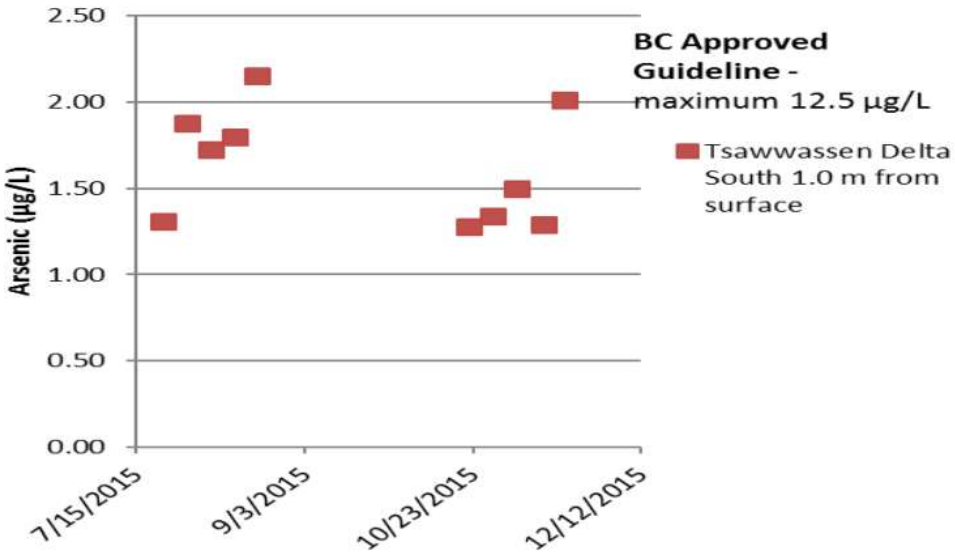


Source: Tri-Star (2017).

Total Metals

Average concentrations of As, Ba, Bo, Ca, Li, Mg, Mo, K, Na, St, and U were generally the same between summer and fall seasons at Site 4 (see **Table IR3-42-2** and Table IR3-42-B1 in **Appendix IR3-42-B**). As examples, **Figures IR3-42-5** and **IR3-42-6** provide As and Bo concentrations, respectively.

Figure IR3-42-5 Total Arsenic Concentrations (µg/L) at Boundary Bay within the LSA for Summer and Fall 2015



Source: Tri-Star (2017).
Notes: For information on applicable water quality guidelines for the BBAMP, refer to Tri-Star (2017).

Figure IR3-42-6 Total Boron Concentrations (mg/L) at Boundary Bay within the LSA for Summer and Fall 2015

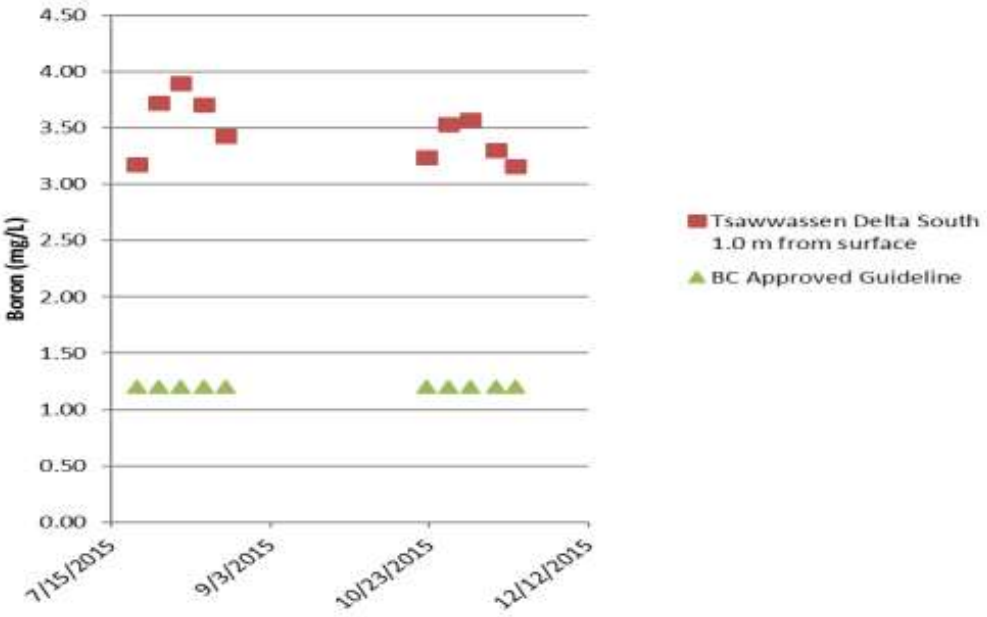
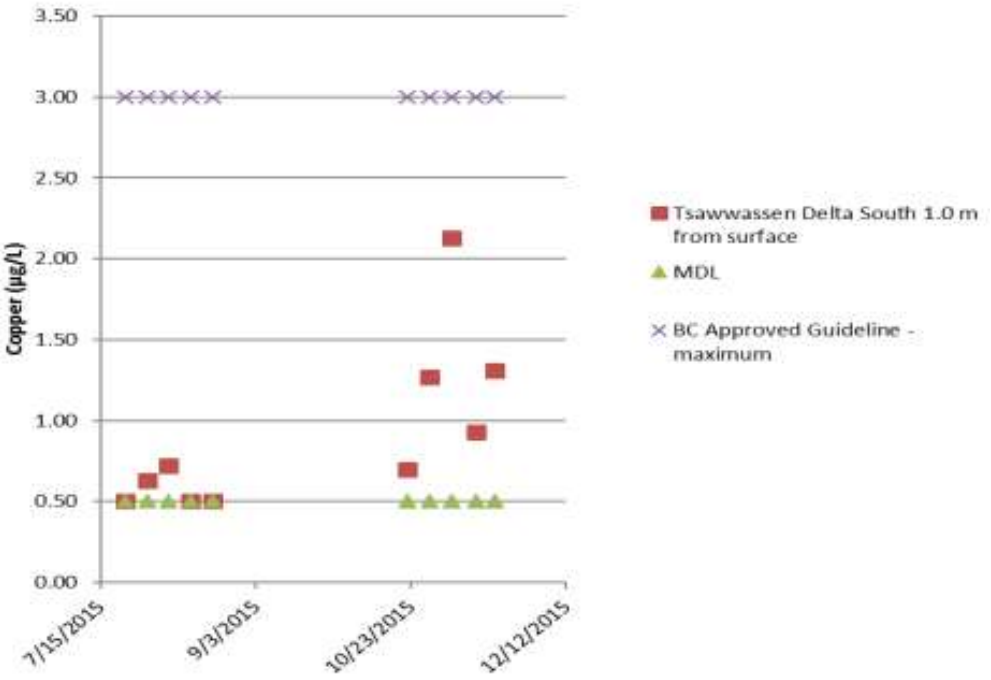


Figure Source: From Tri-Star (2017).
Figure Notes: For information on applicable water quality guidelines for the BBAMP, refer to Tri-Star (2017).

Boron exceeded the BC Approved Guideline for marine waters of 1.2 mg/L (1,200 µg/L) for all samples, as has occurred yearly since 2009 (Tri-Star 2017). Tri-Star (2017) concluded that boron originating from the tributaries was insignificant (usually below method detection limits), and the high concentrations at Site 4 are likely inherent in the marine environment, which can be sourced from sedimentary rocks and clay-rich marine sediments. High concentrations of boron are observed elsewhere in the LSA, as described below. The BC Water Quality Guideline for boron is widely recognised to be lower than ambient marine concentrations (Bright 2017).

Concentrations of Al, Co, Cu, Fe, Mn, Ni, and Si were higher in the fall than the summer, likely resulting from increased turbidity and the known association of some metals with higher fines content (refer to IR3-26 for a discussion of the trend of higher copper concentrations with finer-grained sediments, as an example). **Figure IR3-42-7** provides concentrations for copper, as an example of observed seasonal variability.

Figure IR3-42-7 Total Copper Concentrations (µg/L) at Boundary Bay within the LSA for Summer and Fall 2015



Source: Tri-Star (2017).
Notes: MDL = method detection limit. For information on applicable water quality guidelines for the BBAMP, refer to Tri-Star (2017).

Dissolved metal concentrations were not analysed as part of the BBAMP. Thus, concentrations of trace elements in different samples may reflect variations in total suspended solids, which may contain the major portion of metal/metalloid mass present.

Roberts Bank – Inter-causeway Area Water Chemistry

Extensive sampling has been conducted under the DP3 AMS program in the inter-causeway area at Roberts Bank from 2007 to 2014. In addition to the results presented in EIS Appendix 9.6-C for three sites sampled in April 2013 (RB-10-3, RB-10-1, and RB-7-2), water chemistry results from the 2014 DP3 AMS sampling campaign are presented below (including data from sites DP02, DP03, DP04, DP05, DP08, and DP09, with locations shown in Figure IR3-42-A1 in **Appendix IR3-42-A**). Nutrient concentrations were monitored quarterly at these locations, and metals in early March (late winter season, Q1). Near-surface samples were collected one metre below the surface of the water and at-depth samples were collected two metres above the sediment surface. Although Hemmera et al. (2015) indicated that annual variation was not observed when comparing to prior years of data collected under the DP3 AMS program, comparisons to prior data are provided as relevant to the discussion of seasonal trends.

Table IR3-42-3 provides average seasonal estimates (for parameters with concentrations above detection limits) from samples collected at near-surface (RB-10-3, RB-10-1, RB-7-2,

DP02 to DP04, DP05A, DP08, and DP09) and at-depth (DP5B) in the inter-causeway area. Table IR3-42-B2 in **Appendix IR3-42-B** provides the complete data set.

Table IR3-42-3 Seasonal Water Chemistry (2013 and 2014) at Roberts Bank Inter-causeway Area in LSA, Mean Concentrations

Inter-causeway Water Quality Data	Near-Surface Water Quality Seasonal Average Concentrations				At-Depth Water Quality Seasonal Average Concentrations			
Season	**Spring**	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**	**Fall**	**Winter**
Sample Depth, Below Water Surface (m)	**n=8**	**n=4**	**n=4**	**n=4**	**n=1**	**n=1**	**n=1**	**n=1**
	0.83	0.16	0.5	0.5	15	14	15	13
Physical Tests (mg/L)	**n=3or8**	**n=4**	**n=4**	**n=4**	**n=1**	**n=1**	**n=1**	**n=1**
Hardness (as $CaCO_3$)	4377	-	-	4878	-	-	-	5130
Total Suspended Solids	4.0	0.69	9.6	3.4	2.6	0.74	5	2.3
Anions and Nutrients (µg/L)	**n=4or8**	**n=4**	**n=4**	**n=4**	**n=1**	**n=1**	**n=1**	**n=1**
Ammonia, Total (as N)	20.6	12.8	21.8	12.0	41.8	17.1	<5	6.1
Bromide (Br)	53625	-	-		-	-	-	-
Chloride (Cl)	14400000	-	-		-	-	-	-
Fluoride (F)	1100	-	-		-	-	-	-
Nitrate (as N)	<500	<500	920	<500	<500	570	600	<500
Phosphorus (P)-Total	41.4	39.6	63.5	59.2	48.9	61.8	70.8	73.6
Sulfate (SO_4)	2017500	-	-		-	-	-	-
Total Metals (ug/L)	**n=3or4**	**n=1**	**n=1**	**n=4**	**n=1**	**n=1**	**n=1**	**n=1**
Aluminum (Al)-Total	32.7	-	-	30.9	-	-	-	18.9
Barium (Ba)-Total	12.8	-	-	8.7	-	-	-	8.4
Boron (B)-Total	3586.7	-	-	4010	-	-	-	**4120**
Cadmium (Cd)-Total	0.1	-	-	<0.05	-	-	-	<0.05
Calcium (Ca)-Total	305333.3	-	-	318400	-	-	-	338000
Cobalt (Co)-Total	0.1	-	-	0.077	-	-	-	<0.05
Copper (Cu)-Total	0.66	-	-	0.638	-	-	-	<0.5
Iron (Fe)-Total	65.0	-	-	72.6	-	-	-	41
Lead (Pb)-Total	<0.3	-	-	1.5	-	-	-	0.43
Lithium (Li)-Total	153.7	-	-	157.0	-	-	-	161
Magnesium (Mg)-Total	961000	-	-	990200	-	-	-	1040000
Manganese (Mn)-Total	8.16	-	-	5.31	-	-	-	3.02
Molybdenum (Mo)-Total	9.1	-	-	9.84	-	-	-	10.2
Nickel (Ni)-Total	0.51	-	-	0.632	-	-	-	0.53
Phosphorus (P)-Total	48.6	66.25	77.25	68.46	58.5	90	71	76.7
Potassium (K)-Total	290333.3	-	-	290600	-	-	-	309000

Inter-causeway Water Quality Data	Near-Surface Water Quality Seasonal Average Concentrations				At-Depth Water Quality Seasonal Average Concentrations			
Season	**Spring**	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**	**Fall**	**Winter**
Rubidium (Rb)-Total	93.1	-	-	104.54	-	-	-	108
Silicon (Si)-Total	1060.0	-	-	1296	-	-	-	1410
Sodium (Na)-Total	8256667	-	-	8418000	-	-	-	8980000
Strontium (Sr)-Total	5570.0	-	-	5832	-	-	-	6230
Uranium (U)-Total	2.5	-	-	2.65	-	-	-	2.73
Vanadium (V)-Total	1.4	-	-	1.39	-	-	-	1.43

Note: Only parameters above detection limits are included in this summary table. For a complete list of all parameters and sample concentrations, as well as assumptions pertaining to the inclusion of samples below detection limit in mean concentration calculations, refer to Table IR3-42-B2 in **Appendix IR3-42-B**; 'n' is the number of samples analysed.

Hardness

Hardness for near-surface samples did not vary seasonally in the inter-causeway area. The mean concentration was 4,377 mg/L (standard deviation of 384 mg/L) during the spring, and 4,878 mg/L (standard deviation of 155 mg/L) during the winter (see Table IR3-42-B2 in **Appendix IR3-42-B**). As only one at-depth sample was analysed in the winter season, a seasonal comparison for hardness in deeper waters is not possible.

Total Suspended Solids

Average TSS concentrations were lowest in the summer (less than 1 mg/L) and highest in the fall for both near-surface and at-depth samples collected in the inter-causeway area (see **Table IR3-42-3**).

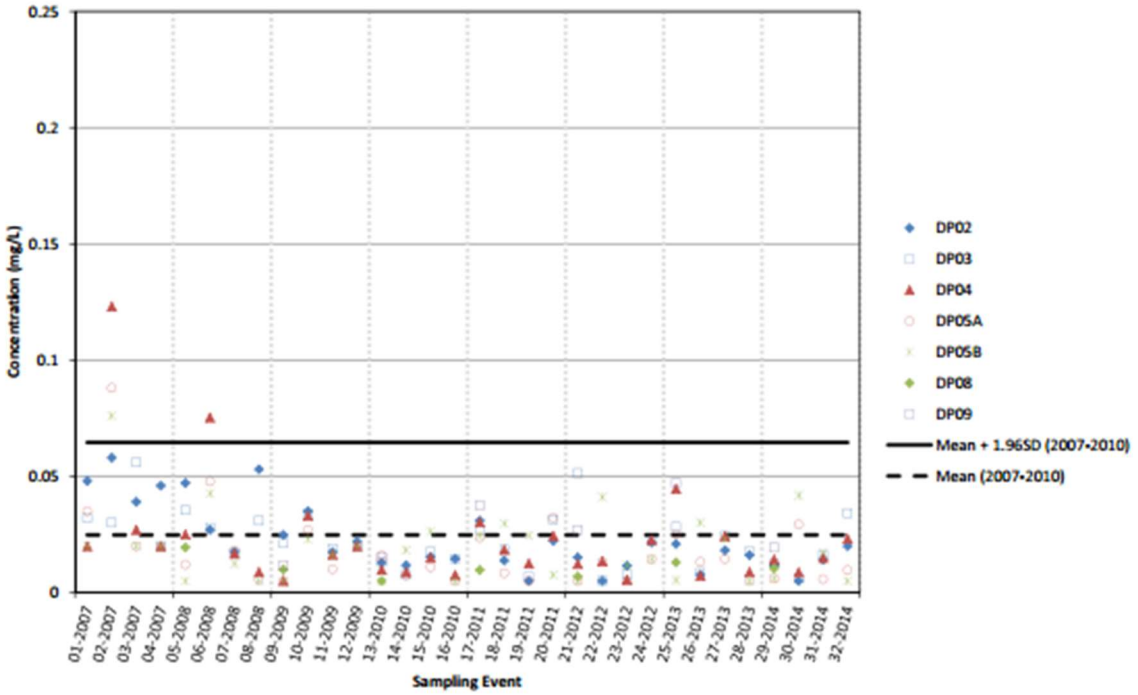
Anions and Nutrients

Ammonia, nitrate, and total phosphorus average seasonal concentrations in 2014 in near-surface samples were highest in the fall. In 2014, all nitrite concentrations and some nitrate concentrations were less than detection limits, which is comparable to concentrations noted since 2009 by Hemmera et al. (2015). Based on a single at-depth sample (DP05B), total phosphorus concentrations in deeper waters (for samples taken 13 m to 15 m below the water surface) were higher compared to near-surface average concentrations in all seasons.

Trend graphs from 2007 to 2014 for inter-causeway DP3 AMS stations (DP02 to DP05, DP08, and DP09) are provided in **Figures IR3-42-8** to **IR3-42-9** for ammonia and total phosphorus, respectively[5]. For each year, the concentrations are provided in the order of Q1 to Q4, or roughly winter, spring, summer, and fall.

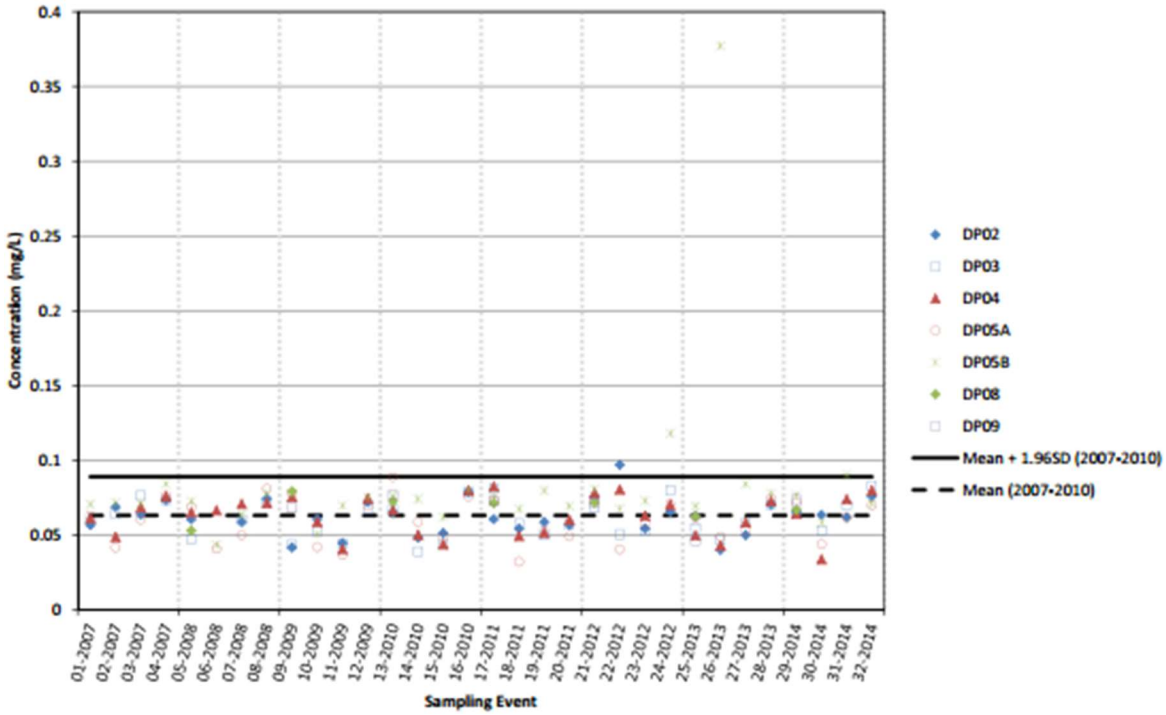
[5] Note that these figures and some subsequent figures sourced from Hemmera et al. (2015) provide nutrient concentrations in mg/L; data tables provided in this response list nutrient concentrations in µg/L.

Figure IR3-42-8 Ammonia Concentrations (mg/L) for DP3 AMS Inter-causeway Stations 2007-2014



Source: Hemmera et al. (2015).

Figure IR3-42-9 Total Phosphorus Concentrations (mg/L) for DP3 AMS Inter-causeway Stations 2007-2014



Source: Hemmera et al. (2015).

There was no inter-annual trend in total phosphorus concentrations over the 2007 to 2014 period, but a general seasonal trend of lower concentrations in Q2 (May or June spring samples) and higher concentrations (as shown by the peaks on the trend graph) in Q4 (November or December fall samples) have been observed.

Total Metals

Seasonal comparisons of metal concentrations from recent available data (2012 to 2014) are limited to spring and winter comparisons for near-surface waters, as sampling at-depth was only conducted in winter (Q1).

Average winter concentrations of total boron in the inter-causeway area were higher, ranging from 3,980 µg/L to 4,210 µg/L, compared to average spring concentrations, which ranged from 3,320 µg/L to 3,780 µg/L. The spring concentrations are comparable with summer and fall boron concentrations observed in Boundary Bay (described above). Boron concentrations in coastal marine water in Canada typically range from 3,700 to 4,300 µg/L (Moss and Nagpal 2003).

Detectable metals that had lower concentrations in the spring compared to the winter include Ba, B, Fe, Pb, Ni, K, Ru, and Si (**Table IR3-42-3**). Concentrations of Ca, Cu, Li, Mg, Mo, K, Na, U, and V were similar between seasons, while Al, Cd, Co, and Mn concentrations were higher in the spring (**Table IR3-42-3**). The average concentrations of all elements for the spring and winter sampling period were generally within 20% of each other, except for Ba.

Metal concentrations in surface waters in the inter-causeway area did not show a significant temporal trend in the eight years (2007 to 2014) of DP3 AMS monitoring and did not show clear increasing or decreasing temporal trends between quarters or consistent seasonal patterns (Hemmera et al. 2015).

Roberts Bank – North of Causeway Water Chemistry

In addition to the results presented in EIS Appendix 9.6-C for two sites sampled in April 2013 (RB-6-1 and RB-11-1), water chemistry results from the 2014 DP3 AMS sampling campaign (DP06 and DP07) and TSS levels sampled in surface waters in June 2012 by NHC (T1 to T22) are provided below (see Figure IR3-42-A1 in **Appendix IR3-42-A**).

As for the inter-causeway area, DP3 AMS samples were collected quarterly for nutrients and in early March (late winter, Q1) for metals. **Tables IR3-42-4** and **IR3-42-5** provide average seasonal estimates (for parameters with concentrations above detection limits) for near-surface and at-depth samples collected at Roberts Bank north of the causeway, respectively. Tables IR3-42-B3 and IR3-42-B4 in **Appendix IR3-42-B** provide the complete data set for near-surface and at-depth samples collected at Roberts Bank, respectively.

Table IR3-42-4 Seasonal Water Chemistry for Near-Surface Samples Collected at Roberts Bank (2012 to 2014), Mean Concentrations

Roberts Bank Water Quality Data - Seasonal Mean Concentrations for Near-Surface Water Samples				
Season	**Spring**	**Summer**	**Fall**	**Winter**
Sample Depth, Below Water Surface (m)	**n=5; n=27 for TSS**	**n=2**	**n=2**	**n=2**
	0.6	**0.5**	**0.5**	**0.5**
Physical Tests (mg/L)	**n=1 or 27**	**n=2**	**n=2**	**n=2**
Hardness (as $CaCO_3$)	4710	-	-	4350
Total Suspended Solids	52.2	4.2	18.6	2.8
Anions and Nutrients (µg/L)	**n=3 or 5**	**n=2**	**n=2**	**n=2**
Ammonia, Total (as N)	26.02	30.9	21.2	26.2
Bromide (Br)	51700	-	-	-
Chloride (Cl)	13566666	-	-	-
Fluoride (F)	1073	-	-	-
Nitrate (as N)	471.2	530	525	<500
Phosphate Phosphorus (P)	39.0	26.3	46.1	63.4
Sulfate (SO_4)	1903333	-	-	-
Total Metals (ug/L)	**n=1 or 2**	**n=2**	**n=2**	**n=2**
Aluminum (Al)-Total	71.3	-	-	25.3
Barium (Ba)-Total	11	-	-	10.5
Boron (B)-Total	3700	-	-	3525
Cadmium (Cd)-Total	0.1	-	-	<0.05
Calcium (Ca)-Total	303000	-	-	286500
Cobalt (Co)-Total	0.1	-	-	0.055
Copper (Cu)-Total	0.8	-	-	0.67
Iron (Fe)-Total	170	-	-	54
Lead (Pb)-Total	<0.3	-	-	1.49
Lithium (Li)-Total	159.0	-	-	135.5
Magnesium (Mg)-Total	980000	-	-	882500
Manganese (Mn)-Total	11	-	-	7.32
Molybdenum (Mo)-Total	9	-	-	8.65
Nickel (Ni)-Total	1	-	-	0.635
Phosphorus (P)-Total	87	58	74.5	69.3
Potassium (K)-Total	292000	-	-	262000
Rubidium (Rb)-Total	96.1	-	-	91.7
Silicon (Si)-Total	1450	-	-	1675
Sodium (Na)-Total	8220000	-	-	7600000
Strontium (Sr)-Total	5560	-	-	5300
Uranium (U)-Total	2.53	-	-	2.36
Vanadium (V)-Total	1.53	-	-	1.23
Zinc (Zn)-Total	<3	-	-	3.1

Note: Only parameters above detection limits are included in this summary table. For a complete list of all parameters and sample concentrations, as well as assumptions pertaining to the inclusion of samples below detection limit in mean concentration calculations, refer to Table IR3-42-B3 in **Appendix IR3-42-B**; 'n' is the number of samples analysed.

Table IR3-42-5 Seasonal Water Chemistry for At-depth Samples Collected at Roberts Bank (2013 to 2014), Mean Concentrations

Roberts Bank Water Quality Data - Seasonal Mean Concentrations for At-depth Water Samples				
Season	**Spring**	**Summer**	**Fall**	**Winter**
Sample Depth, Below Water Surface (m)	**n=2**	**n=1**	**n=1**	**n=1**
	14.1	**19**	**19**	**23**
Physical Tests (mg/L)	**n=1 or 2**	**n=1**	**n=1**	**n=1**
Hardness (as $CaCO_3$)	5140	-	-	5170
Total Suspended Solids	4.3	1.64	4	2.8
Anions and Nutrients (µg/L)	**n=1 or 2**	**n=1**	**n=1**	**n=1**
Ammonia, Total (as N)	27.9	11.8	6.9	6
Bromide (Br)	57600	-	-	-
Chloride (Cl)	15600000	-	-	-
Fluoride (F)	1220	-	-	-
Nitrate (as N)	<500	570	630	570
Nitrite (as N)	<500	110	<100	<100
Phosphate Phosphorus (P)	56.2	66.6	67.9	72
Sulfate (SO_4)	2210000	-	-	-
Total Metals (ug/L)	**n=1**	**n=1**	**n=1**	**n=1**
Aluminum (Al)-Total	22.1	-	-	21.5
Barium (Ba)-Total	10.5	-	-	8.8
Boron (B)-Total	4260	-	-	4010
Cadmium (Cd)-Total	0.072	-	-	<0.05
Calcium (Ca)-Total	328000	-	-	335000
Cobalt (Co)-Total	0.061	-	-	<0.05
Copper (Cu)-Total	0.55	-	-	<0.5
Iron (Fe)-Total	41	-	-	43
Lithium (Li)-Total	180	-	-	157
Magnesium (Mg)-Total	1050000	-	-	1050000
Manganese (Mn)-Total	3.98	-	-	3.29
Molybdenum (Mo)-Total	10.5	-	-	10.1
Nickel (Ni)-Total	0.51	-	-	1.05
Phosphorus (P)-Total	65.3	97	79	75.9
Potassium (K)-Total	313000	-	-	310000
Rubidium (Rb)-Total	107	-	-	107
Silicon (Si)-Total	1250	-	-	1550
Sodium (Na)-Total	8830000	-	-	8870000
Strontium (Sr)-Total	5950	-	-	6150
Uranium (U)-Total	2.84	-	-	2.69
Vanadium (V)-Total	1.57	-	-	1.43

Note: Only parameters above detection limits are included in this summary table. For a complete list of all parameters and sample concentrations, as well as assumptions pertaining to the inclusion of samples below detection limit in mean concentration calculations, refer to Table IR3-42-B4 in **Appendix IR3-42-B**; 'n' is the number of samples analysed.

Near-surface samples and station locations closer to the Fraser River (e.g., DP06) are expected to display different physical and chemical characteristics compared to at-depth sample concentrations and inter-causeway area and Boundary Bay samples, due to temporal patterns associated with seasonal variability in Fraser River discharge (i.e., a lower marine influence). The sample concentrations for both near-surface and at-depth concentrations are collectively representative of the range of natural variability of the estuarine system and were useful in examining seasonal trends.

Hardness

Hardness at the one location sampled in the spring and the two locations sampled in the fall ranged from ranged from 4,200 mg/L to 4,710 mg/L, consistent with levels presented above for the inter-causeway area and Boundary Bay.

Total Suspended Solids

Levels of TSS for spring were sourced from the 2014 DP3 AMS annual program (Hemmera et al. 2015), the Coastal Geomorphology Study Technical Data Report by NHC (2012 data provided in graphical format in Figure 14 of Appendix C in EIS Appendix 9.5-A), and the Sediment and Water Quality Characterisation Studies Technical Data Report by Hemmera (2013 data provided in Appendix F of EIS Appendix 9.6-A). The summer, fall, and winter TSS levels were from sites DP06 and DP07, sampled during the 2014 DP3 AMS program.

Sampling intensity was greater in spring to capture maximum particulate levels during the period of peak Fraser River discharge. TSS for samples collected in 2012 to 2014 in the spring ranged from 6.2 mg/L to 89.1 mg/L and averaged 52.2 mg/L. This seasonal average was higher than the average summer, fall, and winter concentrations, as shown in **Table IR3-42-6**. This seasonal trend is consistent with quarterly observations noted over the eight-year duration of the DP3 AMS program (Hemmera et al. 2015).

Table IR3-42-6 Near-Surface Total Suspended Solids Concentrations (mg/L) at Roberts Bank (2012 to 2014)

Roberts Bank - Near-Surface Sample TSS Concentrations and Summary Statistics for Spring			
Location ID	**Date Sampled**	**Sample Depth, Below Water Surface (m)**	**Total Suspended Solids (mg/L)**
RB-11-1	12/04/2013	0.5	6.2
RB-6-1	12/04/2013	1	6.8
RB-6-1	12/04/2013	0.5	8.8
DP06	04/06/2014	0.5	88.4
DP07A	04/06/2014	0.5	63.3
T1 (n=5)	14/06/2012	1	81.3
T2	12/06/2012	1	82.3
T3	12/06/2012	1	36.8
T4	12/06/2012	1	36.5
T5 (n=5)	14/06/2012	1	12.8
T6	12/06/2012	1	17.4
T7	12/06/2012	1	44.3
T8	12/06/2012	1	51.1
T9	12/06/2012	1	66.2

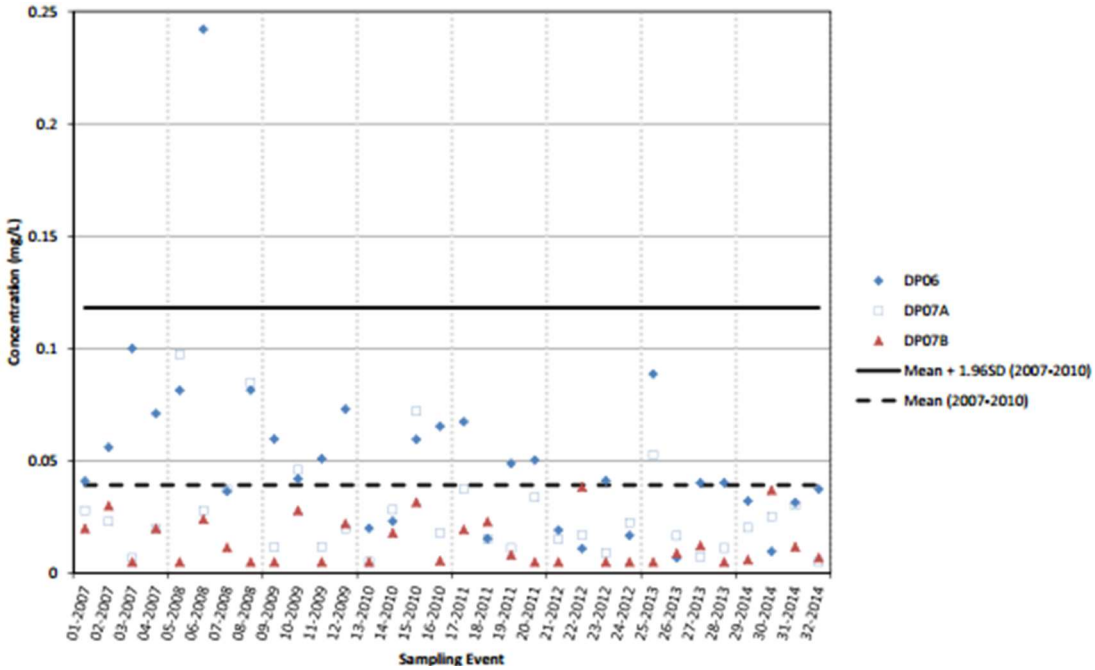
Roberts Bank - Near-Surface Sample TSS Concentrations and Summary Statistics for Spring			
Location ID	**Date Sampled**	**Sample Depth, Below Water Surface (m)**	**Total Suspended Solids (mg/L)**
T10 (n=6)	14/06/2012	1	74.2
T11	12/06/2012	1	89.0
T12	12/06/2012	1	55.1
T13	12/06/2012	1	57.9
T14	12/06/2012	1	55.1
T15	12/06/2012	1	81.2
T16 (n=5)	12/06/2012	1	53.8
T17	12/06/2012	1	36.5
T18	12/06/2012	1	31.1
T19	12/06/2012	1	34.6
T20	12/06/2012	1	74.4
T21	12/06/2012	1	89.1
T22	12/06/2012	1	76.1
Near-Surface TSS Concentration Statistics (n=27)	Maximum	1	89.1
	Minimum	0.5	6.2
	Mean	**0.93**	**52.2**
	Std Dev	0.18	26.5

Note: One sample (n=1) was collected from each monitoring station, unless otherwise noted ('n' is the number of samples analysed).

Anions and Nutrients

Average seasonal ammonia concentrations at Roberts Bank were highest in near-surface waters (30.85 µg/L) during the summer and fluctuated between seasons (**Table IR3-42-4**). Average seasonal ammonia concentrations were highest in at-depth waters in the spring (27.9 µg/L), and decreased as time progressed (**Table IR3-42-5**). These seasonally averaged results indicate a difference in the timing of peak concentrations, as shown in **Figure IR3-42-10** for near-surface samples (DP06 and DP07A) and at-depth samples (DP07B) from DP3 AMS data collected 2007 to 2014.

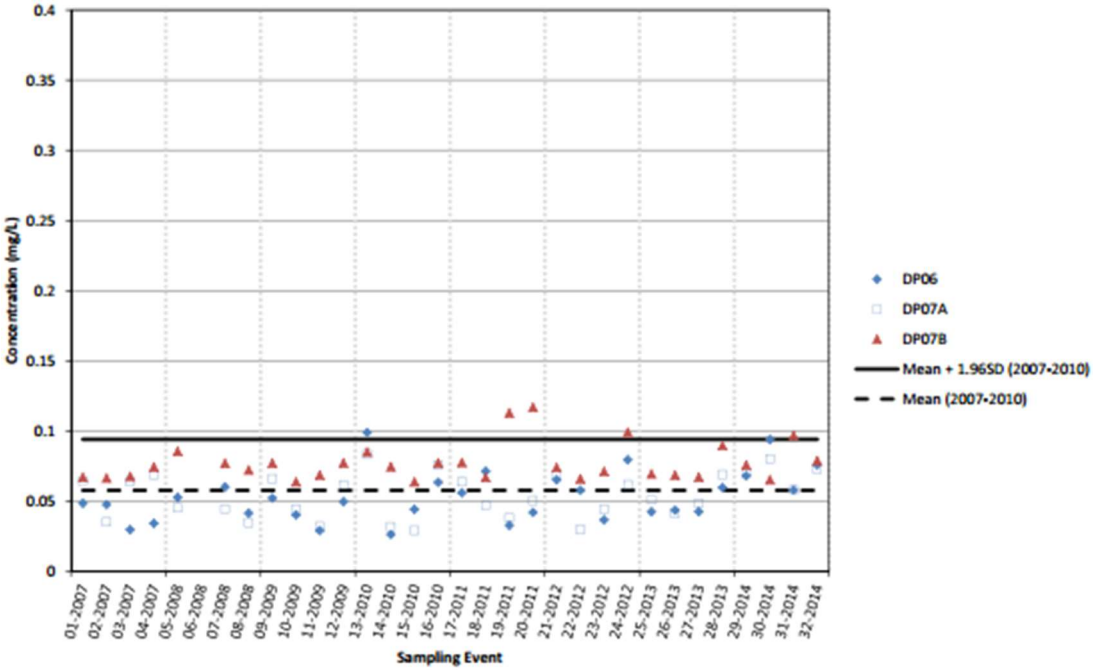
Figure IR3-42-10 Ammonia Concentrations (mg/L) for DP3 AMS Roberts Bank Stations 2007-2014



Source: Hemmera et al. (2015).

Total phosphorus concentrations ranged from 4.4 µg/L to 69 µg/L for near-surface samples and 48.8 µg/L to 72 µg/L for at-depth samples (see Tables IR3-42-B3 and IR3-42-B4 in **Appendix IR3-42-B**, respectively). For both depths, concentrations were highest during the winter (as shown in Tables **IR3-42-4** and **IR3-42-5**). The trend of increased concentration with greater water depth (DP07B) and increased concentrations in fall-winter (Q3-Q4) has been observed during some of the DP3 AMS monitoring campaigns, as shown in **Figure IR3-42-11**.

Figure IR3-42-11 Total Phosphorus Concentrations (mg/L) for DP3 AMS Roberts Bank Stations 2007-2014



Source: Hemmera et al. (2015).

Total Metals

Seasonal comparisons of metal concentrations from recent available data (2013 and 2014) are presented in **Table IR3-42-4** for near surface samples and in **Table IR3-42-5** for at-depth samples.

For near-surface samples, the average concentrations of Al, Fe, Mn and Ni were lower in winter than spring, with a much lower TSS concentration in winter than spring (average of 2.8 mg/L and 52 mg/L, respectively). These elements are major constituents of silt and clay particles, and total water-borne concentrations are expected to parallel concentrations of suspended particulates. The average Pb concentration in near-surface samples was higher in the winter (1.49 µg/L) than spring (<0.3 µg /L); however, the winter average is the mean of two values (2.5 µg /L and 0.48 µg /L) while the tabulated spring-time concentration of <0.3 mg/L is based on a single sample result. The concentration range of all three samples is in the same range as observed Pb concentrations from the inter-causeway area samples discussed above (<0.3 µg /L to 2.4 µg /L). Other than Al, Fe, Mn and Ni, concentrations of elements observed in spring were within 20% of those observed in winter.

Total boron average winter concentrations at Roberts Bank averaged 3,525 µg/L, compared to a spring concentration of 3,700 µg/L, which are similar to the high levels measured elsewhere in the LSA.

Summary

The evaluation of seasonal trends in water quality, as presented herein, further supports the conceptual model for the LSA and Fraser River estuary in general. The major controlling influences of variations in TSS, nutrients, and trace element concentrations over both time and space are tidal exchange and dynamics of the estuarine salt wedge, further modified by the Fraser River discharge stage. Thus, instantaneous data on salinity (or electrical conductivity) and temperature provide a good proxy for the status of all other parameters of interest in the LSA. When observing trace element concentrations as total concentrations, there is also a strong co-variation between the observed concentrations of TSS and most of the trace elements. Given the association of TSS within estuarine circulation of Fraser River discharge, an understanding of physical oceanographic conditions in the estuary (based on salinity and temperature distributions) provides the relative degree of local influence of Fraser River brackish outflows and Pacific-origin marine waters, and in turn an understanding of the expected water chemistry conditions for the broader range of substances of interest.

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Appendices

Appendix IR3-42-A Oversize Figure IR3-42-A1

Appendix IR3-42-B Water Chemistry Data Tables

APPENDIX IR3-42-A
OVERSIZE FIGURE IR3-42-A1

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Strait of Georgia

Sturgeon Bank

SEA ISLAND

LULU ISLAND

Richmond

Delta

Ladner

Westham Island

Roberts Bank

Tsawwassen

Point Roberts

Mud Bay

Boundary Bay

Strait of Georgia

UNITED STATES

CANADA

Fraser River / Fleuve Fraser

Canadian Pacific Railway

Richmond-Fwy

Annacis Hwy

Cougar Canyon Creek

Crescent Slough

Cohilekhan Slough

Serpentine River

Nicomekl River

Pacific Highway

Westminster

Middlegate

Glenbrooke North

Kelvin

Queen's Park

Connaught Heights

West End

Queensborough

North Delta

Annacis

Townsend

Sunbury

Sunshine Hills

Newton

Cloverdale

Surrey

South Surrey

White Rock

West Side

Oxford Hills

East Side

West Beach

Victoria Hill

Columbia

East Beach

Blaine

Loomis Trail Golf Club

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T14

T15

T16

T17

T18

T19

T20

T21

T22

RB-11-1

RB-6-1

RB-10-1

RB-10-3

RB-7-2

DP02

DP03

DP04

DP05

DP08

DP09

Site 8
Blackie Spit Side channel

Site 4
Tsawwassen / Delta - South

PROJECT LOCATION

Whistler

LILLOOET RANGES

Garibaldi Provincial Park

Jervis Inlet

Malaspina Strait

Parksville

Strait of Georgia

North Vancouver

Vancouver

Port Alberni

Nanaimo

Richmond

Surrey

Langley

White Rock

Abbotsford

Duncan

Bellingham

SKAGIT

Legend

- BBAMP 2015 - SUMMER AND FALL SAMPLING
- DP3 AMS 2014 - QUARTERLY SAMPLING
- HEMMERA 2013 - SPRING SAMPLING
- NHC 2012 - SPRING SAMPLING
- STUDY AREA
- BOUNDARY OF PROJECT AREA
- U.S.A. - CANADA BORDER

0 2.5 5
Kilometres
1:140,000
NAD 1983 UTM Zone 10N

N

PORT of vancouver

ROBERTS BANK TERMINAL 2

SEASONAL MARINE WATER QUALITY SAMPLING LOCATIONS WITHIN LOCAL STUDY AREA

DATE: 06/26/2017

IR3-42-A1

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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APPENDIX IR3-42-B
WATER CHEMISTRY DATA TABLES

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Table IR3-42-B1 Boundary Bay 2015 Seasonal Water Chemistry Dataset

Boundary Bay - BBAMP Site 4 Tsawwassen-Delta South	Summer									Fall								
Parameters	7/23/2015	7/30/2015	08/06/2015	8/13/2015	8/20/2015	**Maximum**	**Minimum**	**Mean**	**Std Dev**	10/22/2015	10/29/2015	11/05/2015	11/13/2015	11/19/2015	**Maximum**	**Minimum**	**Mean**	**Std Dev**
Sample Depth, Below Water Surface (m)								**n=5**									**n=5**	
	1.01	1.09	0.89	0.94	1.23	1.23	0.89	**1.03**	0.13	0.98	1.06	1.09	1.08	1.02	1.09	0.98	**1.05**	0.05
Physical Tests (mg/L)								**n=5**									**n=5**	
Hardness (as $CaCO_3$)	4,880	4,770	5,235	5,590	5,690	5,690	4,770	**5,233**	411	5,330	5,120	4,780	4,870	4,870	5,330	4,780	**4,994**	227
Total Suspended Solids	-	-	-	-	-	-	-	**-**	-	-	-	-	-	-	-	-	**-**	-
Anions and Nutrients (µg/L)								**n=5**									**n=5**	
Ammonia, Total (as N)	< 5.0	15.5	29.8	11.8	< 5.0	30	< 5.0	**19**	10	17.2	44	87.6	94.3	97.1	97	17.2	**68**	36
Bromide (Br)	-	-	-	-	-	-	-	**-**	-	-	-	-	-	-	-	-	**-**	-
Chloride (Cl)	-	-	-	-	-	-	-	**-**	-	-	-	-	-	-	-	-	**-**	-
Fluoride (F)	-	-	-	-	-	-	-	**-**	-	-	-	-	-	-	-	-	**-**	-
Nitrate (as N)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	**< 2.0**	< 2.0	33.5	12.3	283	249	396	396	12.3	**194.8**	166.2
Nitrite (as N)	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	**< 2.0**	< 2.0	< 2.0	< 2.0	7.4	9.4	6.8	9.4	< 2.0	**7.9**	1.4
Phosphorus (P)-Total	28.6	74	65.4	94.3	86	94.3	28.6	**69.6**	25.5	44.6	36.4	66.5	77.6	71.4	77.6	36.4	**59.3**	17.8
Sulfate (SO_4)	-	-	-	-	-	-	-	**-**	-	-	-	-	-	-	-	-	**-**	-
Total Metals (µg/L)								**n=5**									**n=5**	
Aluminum (Al)-Total	<10	11	20	12	23	23	<10	**16**	6	16	16	41	262	51	262	16	**77**	104
Antimony (Sb)-Total	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	**< 0.50**	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	**< 0.50**	< 0.50
Arsenic (As)-Total	1.31	1.88	1.73	1.8	2.15	2.15	1.31	**1.77**	0.3	1.28	1.34	1.5	1.29	2.01	2.01	1.28	**1.48**	0.31
Barium (Ba)-Total	8,300	10,600	11,500	11,900	10,200	11,900	8,300	**10,500**	1,400	11,200	10,500	10,200	9,800	9,300	11,200	9,300	**10,200**	700
Beryllium (Be)-Total	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	**< 1.0**	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	**< 1.0**	< 1.0
Bismuth (Bi)-Total	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	**< 1.0**	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	**< 1.0**	< 1.0
Boron (B)-Total	3180	3720	3900	3710	3430	3900	3180	**3590**	280	3240	3530	3570	3300	3160	3570	3160	**3360**	180
Cadmium (Cd)-Total	< 0.050	< 0.050	0.059	< 0.050	0.065	0.065	< 0.050	**< 0.050**	< 0.050	< 0.050	< 0.050	< 0.050	0.052	0.066	0.066	< 0.050	**< 0.050**	< 0.050
Calcium (Ca)-Total	303,000	316,000	345,000	435,000	384,000	435,000	303,000	**357,000**	54,000	347,000	341,000	330,000	310,000	321,000	347,000	310,000	**330,000**	15,000
Cesium (Cs)-Total	-	-	-	-	-	-	-	**-**	-	-	-	-	-	-	-	-	**-**	-
Chromium (Cr)-Total	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	**< 0.50**	< 0.50	< 0.50	< 0.50	< 0.50	0.53	< 0.50	0.53	< 0.50	**< 0.50**	< 0.50
Cobalt (Co)-Total	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	**< 0.10**	< 0.10	< 0.10	< 0.10	0.21	0.29	0.23	0.29	< 0.10	**0.24**	0.04
Copper (Cu)-Total	< 0.50	0.63	0.72	< 0.50	< 0.50	0.72	< 0.50	**< 0.50**	< 0.50	0.7	1.27	2.13	0.93	1.31	2.13	0.7	**1.27**	0.54
Gallium (Ga)-Total	-	-	-	-	-	-	-	**-**	-	-	-	-	-	-	-	-	**-**	-
Iron (Fe)-Total	10.7	22	40.1	46.6	20.5	46.6	10.7	**28**	14.9	18.6	22.6	50	419	65.7	419	18.6	**115.2**	171
Lead (Pb)-Total	< 0.10	< 0.10	0.13	0.16	0.11	0.16	< 0.10	**< 0.10**	< 0.10	< 0.10	< 0.10	< 0.10	0.23	< 0.10	0.23	< 0.10	**< 0.10**	< 0.10
Lithium (Li)-Total	129	131	136	153	149	153	129	**140**	11	157	149	153	135	135	157	135	**146**	10

Boundary Bay - BBAMP Site 4 Tsawwassen-Delta South	Summer									Fall								
Parameters	7/23/2015	7/30/2015	8/06/2015	8/13/2015	8/20/2015	**Maximum**	**Minimum**	**Mean**	**Std Dev**	10/22/2015	10/29/2015	11/05/2015	11/13/2015	11/19/2015	**Maximum**	**Minimum**	**Mean**	**Std Dev**
Sample Depth, Below Water Surface (m)	**n=5**																**n=5**	
	1.01	1.09	0.89	0.94	1.23	1.23	0.89	**1.03**	0.13	0.98	1.06	1.09	1.08	1.02	1.09	0.98	**1.05**	0.05
Total Metals (µg/L)	**n=5**																**n=5**	
Magnesium (Mg)-Total	1,000,000	968,000	1,065,000	1,090,000	1,150,000	1,150,000	968,000	**1,055,000**	72,000	1,080,000	1,040,000	960,000	995,000	987,000	1,080,000	960,000	**1,012,000**	48,000
Manganese (Mn)-Total	2.78	5.6	3.83	5.48	3.36	5.6	2.78	**4.21**	1.27	4.93	4.22	11.4	9.42	9.27	11.4	4.22	**7.85**	3.11
Mercury (Hg)-Total	-	-	-	-	-	-	-	**-**	-	-	-	-	-	-	-	-	**-**	-
Molybdenum (Mo)-Total	7.8	8.1	8.8	8.8	9.6	9.6	7.8	**8.6**	0.7	9.3	8.7	9.3	8.9	8.5	9.3	8.5	**8.9**	0.4
Nickel (Ni)-Total	0.3	0.34	0.42	0.44	0.47	0.47	0.3	**0.39**	0.07	< 0.20	0.4	0.88	1.87	1.03	1.87	0.4	**1.05**	0.61
Potassium (K)-Total	296,000	291,000	325,000	334,000	356,000	356,000	291,000	**320,000**	27,000	334,000	304,000	302,000	301,000	304,000	334,000	301,000	**309,000**	14,000
Rhenium (Re)-Total	-	-	-	-	-	-	-	**-**	-	-	-	-	-	-	-	-	**-**	-
Rubidium (Rb)-Total	-	-	-	-	-	-	-	**-**	-	-	-	-	-	-	-	-	**-**	-
Selenium (Se)-Total	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	**< 0.50**	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	0.64	< 0.50	< 0.50	**< 0.50**	< 0.50
Silicon (Si)-Total	141	1,000	980	1,380	1,030	1380	141	**906**	458	928	744	1,160	2,130	2,000	2,130	744	**1,392**	633
Silver (Ag)-Total	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	**< 0.050**	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	**< 0.050**	< 0.050
Sodium (Na)-Total	8,100,000	7,960,000	8,610,000	8,680,000	9,150,000	9,150,000	7,960,000	**8,500,000**	479,000	8,650,000	8,440,000	8,210,000	8,160,000	8,100,000	8,650,000	8,100,000	**8,312,000**	229,000
Strontium (Sr)-Total	6,370	6,530	7,445	7,840	8,090	8090	6370	**7255**	772	6,560	6,840	6,610	6,380	6,750	6,840	6,380	**6,628**	178
Tellurium (Te)-Total	-	-	-	-	-	-	-	**-**	-	-	-	-	-	-	-	-	**-**	-
Thallium (Tl)-Total	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	**< 0.10**	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	**< 0.10**	< 0.10
Thorium (Th)-Total	-	-	-	-	-	-	-	**-**	-	-	-	-	-	-	-	-	**-**	-
Tin (Sn)-Total	< 1.0	< 1.0	< 1.0	< 1.0	1.1	1.1	< 1.0	**< 1.0**	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	**< 1.0**	< 1.0
Titanium (total)	< 10	< 10	< 10	< 10	< 10	< 10	< 10	**< 10**	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	**< 10**	< 10
Tungsten (W)-Total	-	-	-	-	-	-	-	**-**	-	-	-	-	-	-	-	-	**-**	-
Uranium (U)-Total	2.07	2.11	2.42	2.14	2.78	2.78	2.07	**2.3**	0.3	2.88	2.93	2.69	2.64	2.5	2.93	2.5	**2.73**	0.18
Vanadium (V)-Total	< 10	< 10	< 10	< 10	< 10	< 10	< 10	**< 10**	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	**< 10**	< 10
Yttrium (Y)-Total	-	-	-	-	-	-	-	**-**	-	-	-	-	-	-	-	-	**-**	-
Zinc (Zn)-Total	< 1.0	< 1.0	3.5	< 1.0	2.1	3.5	< 1.0	**< 1.0**	< 1.0	< 1.0	< 1.0	< 1.0	1.9	1.2	1.9	< 1.0	**< 1.0**	< 1.0
Zirconium (Zr)-Total	-	-	-	-	-	-	-	**-**	-	-	-	-	-	-	-	-	**-**	-

Notes: Data sourced from Tri-Star (2017).

1. Concentrations that are <D.L. (less than detection limit) are used in summary statistics at a value equating to the absolute value of the D.L.
2. When more than two values are <D.L., the mean and standard deviation values are equated to the detection limit.
3. Duplicate/replicate values for certain sampling dates were designated as such when sampling took place. The values have not been included in this data set.

Table IR3-42-B2 Roberts Bank Inter-causeway Area 2013 to 2014 Seasonal Water Chemistry Dataset

Inter-causeway Water Quality Data	SPRING													SUMMER								
Location ID:	**RB-10-3**	**RB-10-1**	**RB-7-2**		**DP02**	**DP03**	**DP04**	**DP05A**	**Near-Surface Sample Statistics**				**DP05B**	**DP02**	**DP03**	**DP04**	**DP05A**	**Near-Surface Sample Statistics**				**DP05B**
Date Sampled:	12/04/2013		12/04/2013		04/06/2014				Maximum	Minimum	**Mean**	Std Dev	04/06/2014	12/09/2014				Maximum	Minimum	**Mean**	Std Dev	12/09/2014
Sample Depth, Below Water Surface (m)											**n=8**									**n=4**		
	1	1.6	1.5	0.5	0.5	0.5	0.5	0.5	1.6	0.5	**0.83**	0.45	15	0.05	0.05	0.05	0.5	0.5	0.05	**0.1625**	0.19	14
Physical Tests (mg/L)	**n=3or8**																			**n=4**		
Hardness (as $CaCO_3$)	4110	4100	4920	-	-	-	-	-	4920	4100	**4377**	384	-	-	-	-	-	-	-	**-**	-	-
Total Suspended Solids	2.2	3.4	6.2	2.4	5.4	6.4	4.2	2.1	6.4	2.1	**4.0**	1.7	2.6	0.61	0.68	0.81	0.64	0.81	0.61	**0.69**	0.08	0.74
Anions and Nutrients (µg/L)	**n=4or8**																			**n=4**		
Ammonia, Total (as N)	26.7	32	15.2	26.2	<5	6.2	8.7	29.3	32	6.2	**20.6**	9.7	41.8	14.2	16.1	14.9	5.8	16.1	5.8	**12.75**	4.07	17.1
Bromide (Br)	57400	48900	57700	50500	-	-	-	-	57700	48900	**53625**	3967	-	-	-	-	-	-	-	**-**	-	-
Chloride (Cl)	15800000	13100000	15400000	13300000	-	-	-	-	15800000	13100000	**14400000**	1210372	-	-	-	-	-	-	-	**-**	-	-
Fluoride (F)	1080	950	1240	1130	-	-	-	-	1240	950	**1100**	104	-	-	-	-	-	-	-	**-**	-	-
Nitrate (as N)	<500	<500	<500	<500	<500	<500	<500	<500	<500	<500	**<500**	0	<500	<500	<500	<500	<500	<500	<500	**<500**	0	570
Nitrite (as N)	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	**<100**	0	<100	150	110	180	<100	<100	<100	**<100**	0	<100
Phosphorus (P)-Total	54.5	55	53.4	51.2	35.9	27.9	17.3	35.8	55	17.3	**41.4**	13.3	48.9	39.4	41.5	42.6	34.9	42.6	34.9	**39.6**	2.95	61.8
Sulfate (SO_4)	2180000	1850000	2160000	1880000	-	-	-	-	2180000	1850000	**2017500**	153032	-	-	-	-	-	-	-	**-**	-	-
Total Metals (ug/L)	**n=3or4**													**n=1**								
Aluminum (Al)-Total	23.2	52.7	22.1	-	-	-	-	-	52.7	22.1	**32.7**	14.2	-	-	-	-	-	-	-	**-**	-	-
Antimony (Sb)-Total	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	-	-	-	**-**	-	-
Arsenic (As)-Total	<2	<2	<2	-	-	-	-	-	<2	<2	**<2**	0	-	-	-	-	-	-	-	**-**	-	-
Barium (Ba)-Total	9.5	19.3	9.6	-	-	-	-	-	19.3	9.5	**12.8**	4.6	-	-	-	-	-	-	-	**-**	-	-
Beryllium (Be)-Total	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	-	-	-	**-**	-	-
Bismuth (Bi)-Total	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	-	-	-	**-**	-	-
Boron (B)-Total	3660	3320	3780	-	-	-	-	-	3780	3320	**3586.7**	194.8	-	-	-	-	-	-	-	**-**	-	-
Cadmium (Cd)-Total	0.09	0.054	0.058	-	-	-	-	-	0.09	0.054	**0.1**	0.02	-	-	-	-	-	-	-	**-**	-	-
Calcium (Ca)-Total	324000	267000	325000	-	-	-	-	-	325000	267000	**305333**	27109	-	-	-	-	-	-	-	**-**	-	-
Cesium (Cs)-Total	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	-	-	-	**-**	-	-
Chromium (Cr)-Total	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	-	-	-	**-**	-	-
Cobalt (Co)-Total	0.132	0.089	0.082	-	-	-	-	-	0.132	0.082	**0.1**	0.02	-	-	-	-	-	-	-	**-**	-	-
Copper (Cu)-Total	0.7	0.78	<0.5	-	-	-	-	-	0.78	0.5	**0.66**	0.12	-	-	-	-	-	-	-	**-**	-	-
Gallium (Ga)-Total	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	-	-	-	**-**	-	-
Iron (Fe)-Total	63	85	47	-	-	-	-	-	85	47	**65.0**	15.6	-	-	-	-	-	-	-	**-**	-	-
Lead (Pb)-Total	<0.3	<0.3	<0.3	-	-	-	-	-	<0.3	<0.3	**<0.3**	0	-	-	-	-	-	-	-	**-**	-	-
Lithium (Li)-Total	159	140	162	-	-	-	-	-	162	140	**153.7**	9.7	-	-	-	-	-	-	-	**-**	-	-
Magnesium (Mg)-Total	997000	866000	1020000	-	-	-	-	-	1020000	866000	**961000**	67828	-	-	-	-	-	-	-	**-**	-	-
Manganese (Mn)-Total	10.8	7.34	6.35	-	-	-	-	-	10.8	6.35	**8.16**	1.91	-	-	-	-	-	-	-	**-**	-	-
Mercury (Hg)-Total	<0.01	<0.01	<0.01	-	-	-	-	-	<0.01	<0.01	**<0.01**	0	-	-	-	-	-	-	-	**-**	-	-
Molybdenum (Mo)-Total	9.5	8.3	9.6	-	-	-	-	-	9.6	8.3	**9.1**	0.6	-	-	-	-	-	-	-	**-**	-	-

Inter-causeway Water Quality Data	SPRING													SUMMER								
Location ID:	**RB-10-3**	**RB-10-1**	**RB-7-2**		**DP02**	**DP03**	**DP04**	**DP05A**	**Near-Surface Sample Statistics**				**DP05B**	**DP02**	**DP03**	**DP04**	**DP05A**	**Near-Surface Sample Statistics**				**DP05B**
Date Sampled:	12/04/2013		12/04/2013		04/06/2014				Maximum	Minimum	**Mean**	Std Dev	04/06/2014	12/09/2014				Maximum	Minimum	**Mean**	Std Dev	12/09/2014
Sample Depth, Below Water Surface (m)											**n=8**									**n=4**		
	1	1.6	1.5	0.5	0.5	0.5	0.5	0.5	1.6	0.5	**0.83**	0.45	15	0.05	0.05	0.05	0.5	0.5	0.05	**0.1625**	0.19	14
Total Metals (ug/L)	**n=3or4**													**n=1**								
Nickel (Ni)-Total	0.53	<0.5	<0.5	-	-	-	-	-	0.53	<0.5	**0.51**	0.014	-	-	-	-	-	-	-	**-**	-	-
Phosphorus (P)-Total	<1000*	<1000*	<1000*	-	63.5	53.1	33.8	44	63.5	33.8	48.6	12.13	58.5	62	70	71	62	71	62	**66.25**	4.26	90
Potassium (K)-Total	304000	257000	310000	-	-	-	-	-	310000	257000	**290333.3**	23697.2	-	-	-	-	-	-	-	**-**	-	-
Rhenium (Re)-Total	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	-	-	-	**-**	-	-
Rubidium (Rb)-Total	96.9	84.3	98	-	-	-	-	-	98	84.3	**93.1**	6.2	-	-	-	-	-	-	-	**-**	-	-
Selenium (Se)-Total	<2	<2	<2	-	-	-	-	-	<2	<2	**<2**	0	-	-	-	-	-	-	-	**-**	-	-
Silicon (Si)-Total	780	1530	870	-	-	-	-	-	1530	780	**1060.0**	334.4	-	-	-	-	-	-	-	**-**	-	-
Silver (Ag)-Total	<0.1	<0.1	<0.1	-	-	-	-	-	<0.1	<0.1	**<0.1**	0	-	-	-	-	-	-	-	**-**	-	-
Sodium (Na)-Total	8600000	7350000	8820000	-	-	-	-	-	8820000	7350000	**8256667**	647371	-	-	-	-	-	-	-	**-**	-	-
Strontium (Sr)-Total	5780	4970	5960	-	-	-	-	-	5960	4970	**5570.0**	430.6	-	-	-	-	-	-	-	**-**	-	-
Tellurium (Te)-Total	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	-	-	-	**-**	-	-
Thallium (Tl)-Total	<0.05	<0.05	<0.05	-	-	-	-	-	<0.05	<0.05	**<0.05**	0	-	-	-	-	-	-	-	**-**	-	-
Thorium (Th)-Total	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	-	-	-	**-**	-	-
Tin (Sn)-Total	<1	<1	<1	-	-	-	-	-	<1	<1	**<1**	0	-	-	-	-	-	-	-	**-**	-	-
Titanium (Ti)-Total	<5	<5	<5	-	-	-	-	-	<5	<5	**<5**	0	-	-	-	-	-	-	-	**-**	-	-
Tungsten (W)-Total	<1	<1	<1	-	-	-	-	-	<1	<1	**<1**	0	-	-	-	-	-	-	-	**-**	-	-
Uranium (U)-Total	2.64	2.29	2.66	-	-	-	-	-	2.66	2.29	**2.5**	0.2	-	-	-	-	-	-	-	**-**	-	-
Vanadium (V)-Total	1.43	1.28	1.36	-	-	-	-	-	1.43	1.28	**1.4**	0.1	-	-	-	-	-	-	-	**-**	-	-
Yttrium (Y)-Total	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	-	-	-	**-**	-	-
Zinc (Zn)-Total	<3	<3	<3	-	-	-	-	-	<3	<3	**<3**	0	-	-	-	-	-	-	-	**-**	-	-
Zirconium (Zr)-Total	<0.5	<0.5	<0.5	-	-	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	-	-	-	**-**	-	-

Notes: Samples and concentrations shown in blue text are at-depth samples, and have not been included in the summary statistics calculated for near-surface samples.

1. Concentrations that are <D.L. (less than detection limit) are used in summary statistics at a value equating to the absolute value of the D.L., unless all samples are <D.L. or otherwise noted.

2. if all concentrations are <D.L. the means is shown as <D.L. and the standard deviation as zero (0).

* As detection limit is higher than concentration in other samples for this parameter, the <D.L. value has not been used in summary statistics.

Inter-causeway Water Quality Data	FALL									WINTER									
Location ID:	**DP02**	**DP03**	**DP04**	**DP05A**	**Sub-Surface Sample Statistics**				**DP05B**	**DP02**	**DP03**	**DP05A**	**DP08**	**DP09**	**Sub-Surface Sample Statistics**				**DP05B**
Date Sampled:	12/12/2014	12/12/2014	12/12/2014	12/12/2014	Maximum	Minimum	**Mean**	Std Dev	12/12/2014	06/03/2014	06/03/2014	06/03/2014	06/03/2014	06/03/2014	Maximum	Minimum	**Mean**	Std Dev	06/03/2014
Sample Depth, Below Water Surface (m)							**n=4**										**n=4**		
	0.5	0.5	0.5	0.5	0.5	0.5	**0.5**	0.00	15	0.5	0.5	0.5	0.5	0.5	0.5	0.5	**0.5**	0	13
Physical Tests (mg/L)							**n=4**										**n=4**		
Hardness (as $CaCO_3$)	-	-	-	-	-	-	-	-	-	4880	4830	4980	5080	4620	5080	4620	**4878**	155	5130
Total Suspended Solids	8.9	15.7	9.8	3.9	15.7	3.9	**9.6**	4.19	5	3.2	3.2	2.1	<2.000	6.7	6.7	2	**3.4**	1.7	2.3
Anions and Nutrients (µg/L)							**n=4**										**n=4**		
Ammonia, Total (as N)	20	34.2	23.2	9.7	34.2	9.7	**21.775**	8.74	<5	11.8	12.4	6	10.4	19.3	19.3	6	**12.0**	4.3	6.1
Bromide (Br)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chloride (Cl)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride (F)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitrate (as N)	810	780	1010	1080	1080	780	**920**	127.87	600	<500	<500	<500	<500	<500	<500	<500	**<500**	0	<500
Nitrite (as N)	<100	<100	<100	<100	<100	<100	<100	0	<100	<100	<100	<100	<100	<100	<100	<100	**<100**	0	<100
Phosphorus (P)-Total	64.2	59	64.4	66.5	66.5	59	**63.525**	2.76	70.8	59.3	59.5	65.5	63	48.7	65.5	48.7	**59.2**	5.7	73.6
Sulfate (SO_4)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Metals (ug/L)							**n=1**										**n=4**		
Aluminum (Al)-Total	-	-	-	-	-	-	-	-	-	17.7	25	24	12.9	75	75	12.9	**30.9**	22.5	18.9
Antimony (Sb)-Total	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	**<0.5**	0	<0.5
Arsenic (As)-Total	-	-	-	-	-	-	-	-	-	<2	<2	<2	<2	<2	<2	<2	**<2**	0	<2
Barium (Ba)-Total	-	-	-	-	-	-	-	-	-	8.5	8.8	8.7	8.4	9.1	9.1	8.4	**8.7**	0.2	8.4
Beryllium (Be)-Total	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	**<0.5**	0	<0.5
Bismuth (Bi)-Total	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	**<0.5**	0	<0.5
Boron (B)-Total	-	-	-	-	-	-	-	-	-	4040	3980	4210	4070	3750	4210	3750	**4010**	150	**4120**
Cadmium (Cd)-Total	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	**<0.05**	0	<0.05
Calcium (Ca)-Total	-	-	-	-	-	-	-	-	-	318000	320000	324000	329000	301000	329000	301000	**318400**	9478	338000
Cesium (Cs)-Total	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	**<0.5**	0	<0.5
Chromium (Cr)-Total	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	**<0.5**	0	<0.5
Cobalt (Co)-Total	-	-	-	-	-	-	-	-	-	0.053	0.066	<0.05	<0.05	0.165	0.165	0.05	0.077	0.044	<0.05
Copper (Cu)-Total	-	-	-	-	-	-	-	-	-	0.58	<0.5	<0.5	<0.5	1.11	1.11	<0.5	0.638	0.2380	<0.5
Gallium (Ga)-Total	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	**<0.5**	0.0	<0.5
Iron (Fe)-Total	-	-	-	-	-	-	-	-	-	44	65	48	38	168	168	38	**72.6**	48.5	41
Lead (Pb)-Total	-	-	-	-	-	-	-	-	-	2.4	3.35	0.67	<0.3	0.75	3.35	<0.3	**1.5**	1.2	0.43
Lithium (Li)-Total	-	-	-	-	-	-	-	-	-	162	157	164	159	143	164	143	**157.0**	7.4	161
Magnesium (Mg)-Total	-	-	-	-	-	-	-	-	-	993000	979000	1010000	1030000	939000	1030000	939000	**990200**	30760	1040000
Manganese (Mn)-Total	-	-	-	-	-	-	-	-	-	4.19	4.99	2.79	3.67	10.9	10.9	2.79	**5.31**	2.89	3.02
Mercury (Hg)-Total	-	-	-	-	-	-	-	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	**<0.01**	0	<0.01
Molybdenum (Mo)-Total	-	-	-	-	-	-	-	-	-	9.9	9.8	10.3	9.9	9.3	10.3	9.3	**9.84**	0.32	10.2

Inter-causeway Water Quality Data	FALL									WINTER									
Location ID:	**DP02**	**DP03**	**DP04**	**DP05A**	**Near-Surface Sample Statistics**				**DP05B**	**DP02**	**DP03**	**DP05A**	**DP08**	**DP09**	**Near-Surface Sample Statistics**				**DP05B**
Date Sampled:	12/12/2014	12/12/2014	12/12/2014	12/12/2014	Maximum	Minimum	**Mean**	Std Dev	12/12/2014	06/03/2014	06/03/2014	06/03/2014	06/03/2014	06/03/2014	Maximum	Minimum	**Mean**	Std Dev	06/03/2014
Sample Depth, Below Water Surface (m)							**n=4**										**n=4**		
	0.5	0.5	0.5	0.5	0.5	0.5	**0.5**	0.00	15	0.5	0.5	0.5	0.5	0.5	0.5	0.5	**0.5**	0	13
Total Metals (ug/L)							**n=1**										**n=4**		
Nickel (Ni)-Total	-	-	-	-	-	-	-	-	-	0.52	0.56	<0.5	<0.5	1.08	1.08	<0.5	**0.632**	0.225	0.53
Phosphorus (P)-Total	76	83	80	70	83	70	**77.25**	4.87	71	65.3	65.3	71.3	66.8	73.6	73.6	65.3	**68.46**	3.38	76.7
Potassium (K)-Total	-	-	-	-	-	-	-	-	-	286000	289000	298000	305000	275000	305000	275000	**290600**	10288	309000
Rhenium (Re)-Total	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	**<0.5**	0	<0.5
Rubidium (Rb)-Total	-	-	-	-	-	-	-	-	-	106	104	109	107	96.7	109	96.7	**104.54**	4.24	108
Selenium (Se)-Total	-	-	-	-	-	-	-	-	-	<2	<2	<2	<2	<2	<2	<2	**<2**	0	<2
Silicon (Si)-Total	-	-	-	-	-	-	-	-	-	1230	1210	1460	1300	1280	1460	1210	**1296**	88	1410
Silver (Ag)-Total	-	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	**<0.1**	0	<0.1
Sodium (Na)-Total	-	-	-	-	-	-	-	-	-	8380000	8460000	8670000	8740000	7840000	8740000	7840000	**8418000**	317641	8980000
Strontium (Sr)-Total	-	-	-	-	-	-	-	-	-	5810	5840	5990	6080	5440	6080	5440	**5832**	219	6230
Tellurium (Te)-Total	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	**<0.5**	0	<0.5
Thallium (Tl)-Total	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	**<0.05**	0	<0.05
Thorium (Th)-Total	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	**<0.5**	0	<0.5
Tin (Sn)-Total	-	-	-	-	-	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	**<1**	0	<1
Titanium (Ti)-Total	-	-	-	-	-	-	-	-	-	<5	<5	<5	<5	<5	<5	<5	**<5**	0	<5
Tungsten (W)-Total	-	-	-	-	-	-	-	-	-	<1	<1	<1	<1	<1	<1	<1	**<1**	0	<1
Uranium (U)-Total	-	-	-	-	-	-	-	-	-	2.69	2.64	2.72	2.69	2.49	2.72	2.49	**2.65**	0.08	2.73
Vanadium (V)-Total	-	-	-	-	-	-	-	-	-	1.27	1.36	1.46	1.39	1.47	1.47	1.27	**1.39**	0.07	1.43
Yttrium (Y)-Total	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	**<0.5**	0	<0.5
Zinc (Zn)-Total	-	-	-	-	-	-	-	-	-	<3	<3	<3	<3	<3	<3	<3	**<3**	0	<3
Zirconium (Zr)-Total	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	**<0.5**	0	<0.5

Notes: Samples and concentrations shown in blue text are at-depth samples, and have not been included in the summary statistics calculated for near-surface samples.

1. Concentrations that are <D.L. (less than detection limit) are used in summary statistics at a value equating to the absolute value of the D.L., unless all samples are <D.L. or otherwise noted.

2. if all concentrations are <D.L. the means is shown as <D.L. and the standard deviation as zero (0).

* As detection limit is higher than concentration in other samples for this parameter, the <D.L. value has not been used in summary statistics.

Table IR3-42-B3 Roberts Bank North of Causeway 2012 to 2014 Seasonal Water Chemistry Dataset for Near-Surface Samples

Roberts Bank Water Quality Data	SPRING - Near-Surface Samples									SUMMER - Near-Surface Samples					
Location ID:	**RB-11-1**	**RB-6-1**	**RB-6-1**	**DP06**	**DP07A**	**Summary Statistics**				**DP06**	**DP07A**	**Summary Statistics**			
Date Sampled:	12/04/2013	12/04/2013	12/04/2013	04/06/2014	04/06/2014	Maximum	Minimum	**Mean**	Std Dev	12/09/2014	12/09/2014	Maximum	Minimum	**Mean**	Std Dev
Sample Depth, Below Water Surface (m)								**n=5**						**n=2**	
	0.5	1	0.5	0.5	0.5	1	0.5	**0.6**	0.2	0.5	0.5	0.5	0.5	**0.5**	0
Physical Tests (mg/L)								**n=1 or 27**						**n=2**	
Hardness (as $CaCO_3$)	-	4710	-	-	-	4710	4710	**4710**	0	-	-	-	-	**-**	-
Total Suspended Solids	see TSS Table for Spring sample data (n=27)							**52.2**	26.5	4.35	3.97	4.35	3.97	**4.16**	0.19
Anions and Nutrients (µg/L)								**n=3or5**						**n=2**	
Ammonia, Total (as N)	33.1	32.1	29.9	9.7	25.3	33.1	9.7	**26.02**	8.6	31.4	30.3	31.4	30.3	**30.85**	0.55
Bromide (Br)	41800	57000	56300	-	-	57000	41800	**51700**	7006	-	-	-	-	**-**	-
Chloride (Cl)	10600000	15200000	14900000	-	-	15200000	10600000	**13566666.67**	2101322	-	-	-	-	**-**	-
Fluoride (F)	960	1140	1120	-	-	1140	960	**1073**	80.6	-	-	-	-	**-**	-
Nitrate (as N)	<500	1000	<500	106	250	1000	106	**471.2**	304.5	<500	560	560	<500	**530**	30
Nitrite (as N)	<100	<100	<100	<100	<100	<100	<100	**<100**	0	<100	<100	<100	<100	**<100**	0
Phosphate Phosphorus (P)	51.6	65.4	64.1	4.4	9.4	65.4	4.4	**39.0**	26.7	29	23.5	29	23.5	**26.25**	2.75
Sulfate (SO_4)	1450000	2150000	2110000	-	-	2150000	1450000	**1903333.333**	320970.7	-	-	-	-	**-**	-
Total Metals (ug/L)								**n=1 or 2**						**n=2**	
Aluminum (Al)-Total	-	71.3	-	-	-	71.3	71.3	**71.3**	0	-	-	-	-	**-**	-
Antimony (Sb)-Total	-	<0.5	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	**-**	-
Arsenic (As)-Total	-	<2	-	-	-	<2	<2	**<2**	0	-	-	-	-	**-**	-
Barium (Ba)-Total	-	11	-	-	-	11	11	**11**	0	-	-	-	-	**-**	-
Beryllium (Be)-Total	-	<0.5	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	**-**	-
Bismuth (Bi)-Total	-	<0.5	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	**-**	-
Boron (B)-Total	-	3700	-	-	-	3700	3700	**3700**	0	-	-	-	-	**-**	-
Cadmium (Cd)-Total	-	0.066	-	-	-	0.066	0.066	**0.1**	0	-	-	-	-	**-**	-
Calcium (Ca)-Total	-	303000	-	-	-	303000	303000	**303000**	0	-	-	-	-	**-**	-
Cesium (Cs)-Total	-	<0.5	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	**-**	-
Chromium (Cr)-Total	-	<0.5	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	**-**	-
Cobalt (Co)-Total	-	0.106	-	-	-	0.106	0.106	**0.1**	0	-	-	-	-	**-**	-
Copper (Cu)-Total	-	0.79	-	-	-	0.79	0.79	**0.8**	0	-	-	-	-	**-**	-
Gallium (Ga)-Total	-	<0.5	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	**-**	-
Iron (Fe)-Total	-	170	-	-	-	170	170	**170**	0	-	-	-	-	**-**	-
Lead (Pb)-Total	-	<0.3	-	-	-	<0.3	<0.3	**<0.3**	0	-	-	-	-	**-**	-
Lithium (Li)-Total	-	159	-	-	-	159	159	**159.0**	0	-	-	-	-	**-**	-
Magnesium (Mg)-Total	-	980000	-	-	-	980000	980000	**980000.0**	0	-	-	-	-	**-**	-
Manganese (Mn)-Total	-	11	-	-	-	11	11	**11**	0	-	-	-	-	**-**	-
Mercury (Hg)-Total	-	<0.01	-	-	-	<0.01	<0.01	**<0.01**	0	-	-	-	-	**-**	-
Molybdenum (Mo)-Total	-	9.2	-	-	-	9.2	9.2	**9**	0	-	-	-	-	**-**	-

Roberts Bank Water Quality Data	SPRING - Near-Surface Samples									SUMMER - Near-Surface Samples					
Location ID:	**RB-11-1**	**RB-6-1**	**RB-6-1**	**DP06**	**DP07A**	**Summary Statistics**				**DP06**	**DP07A**	**Summary Statistics**			
Date Sampled:	12/04/2013	12/04/2013	12/04/2013	04/06/2014	04/06/2014	Maximum	Minimum	**Mean**	Std Dev	12/09/2014	12/09/2014	Maximum	Minimum	**Mean**	Std Dev
Sample Depth, Below Water Surface (m)								**n=5**						**n=2**	
	0.5	1	0.5	0.5	0.5	1	0.5	**0.6**	0.2	0.5	0.5	0.5	0.5	**0.5**	0
Total Metals (ug/L)								**n=1 or 2**						**n=2**	
Nickel (Ni)-Total	-	0.73	-	-	-	0.73	0.73	**1**	0	-	-	-	-	**-**	-
Phosphorus (P)-Total	-	<1000*	-	94	80.3	94	80.3	**87**	7	58	58	58	58	**58**	0
Potassium (K)-Total	-	292000	-	-	-	292000	292000	**292000**	0	-	-	-	-	**-**	-
Rhenium (Re)-Total	-	<0.5	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	**-**	-
Rubidium (Rb)-Total	-	96.1	-	-	-	96.1	96.1	**96.1**	0	-	-	-	-	**-**	-
Selenium (Se)-Total	-	<2	-	-	-	<2	<2	**<2**	0	-	-	-	-	**-**	-
Silicon (Si)-Total	-	1450	-	-	-	1450	1450	**1450**	0	-	-	-	-	**-**	-
Silver (Ag)-Total	-	<0.1	-	-	-	<0.1	<0.1	**<0.1**	0	-	-	-	-	**-**	-
Sodium (Na)-Total	-	8220000	-	-	-	8220000	8220000	**8220000**	0	-	-	-	-	**-**	-
Strontium (Sr)-Total	-	5560	-	-	-	5560	5560	**5560**	0	-	-	-	-	**-**	-
Tellurium (Te)-Total	-	<0.5	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	**-**	-
Thallium (Tl)-Total	-	<0.05	-	-	-	<0.05	<0.05	**<0.05**	0	-	-	-	-	**-**	-
Thorium (Th)-Total	-	<0.5	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	**-**	-
Tin (Sn)-Total	-	<1	-	-	-	<1	<1	**<1**	0	-	-	-	-	**-**	-
Titanium (Ti)-Total	-	<5	-	-	-	<5	<5	**<5**	0	-	-	-	-	**-**	-
Tungsten (W)-Total	-	<1	-	-	-	<1	<1	**<1**	0	-	-	-	-	**-**	-
Uranium (U)-Total	-	2.53	-	-	-	2.53	2.53	**2.53**	0	-	-	-	-	**-**	-
Vanadium (V)-Total	-	1.53	-	-	-	1.53	1.53	**1.53**	0	-	-	-	-	**-**	-
Yttrium (Y)-Total	-	<0.5	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	**-**	-
Zinc (Zn)-Total	-	<3	-	-	-	<3	<3	**<3**	0	-	-	-	-	**-**	-
Zirconium (Zr)-Total	-	<0.5	-	-	-	<0.5	<0.5	**<0.5**	0	-	-	-	-	**-**	-

Notes:

1. Concentrations that are <D.L. (less than detection limit) are used in summary statistics at a value equating to the absolute value of the D.L., unless all samples are <D.L. or otherwise noted.

2. if all concentrations are <D.L. the means is shown as <D.L. and the standard deviation as zero (0).

* As detection limit is higher than concentration in other samples for this parameter, the <D.L. value has not been used in summary statistics.

Roberts Bank Water Quality Data	FALL - Near-Surface Samples						Winter - Near-Surface Samples					
Location ID:	**DP06**	**DP07A**	**Summary Statistics**				**DP07A**	**DP06**	**Summary Statistics**			
Date Sampled:	12/12/2014	12/12/2014	Maximum	Minimum	**Mean**	Std Dev	06/03/2014	06/03/2014	Maximum	Minimum	**Mean**	Std Dev
Sample Depth, Below Water Surface (m)					**n=2**						**n=2**	
	0.5	0.5	0.5	0.5	**0.5**	0	0.5	0.5	0.5	0.5	**0.5**	0
Physical Tests (mg/L)					**n=2**						**n=2**	
Hardness (as $CaCO_3$)	-	-	-	-	**-**	-	4490	4210	4490	4210	**4350**	140
Total Suspended Solids	35.1	<2.0	35.1	<2.0	**18.55**	16.55	<2	3.6	3.6	<2	**2.8**	0.8
Anions and Nutrients (µg/L)					**n=2**						**n=2**	
Ammonia, Total (as N)	37.4	<5	37.4	<5	**21.2**	16.2	20.2	32.1	32.1	20.2	**26.15**	5.95
Bromide (Br)	-	-	-	-	**-**	-	-	-	-	-	**-**	-
Chloride (Cl)	-	-	-	-	**-**	-	-	-	-	-	**-**	-
Fluoride (F)	-	-	-	-	**-**	-	-	-	-	-	**-**	-
Nitrate (as N)	420	630	630	420	**525**	105	<500	<500	<500	<500	**<500**	0
Nitrite (as N)	<100	<100	<100	<100	**<100**	0	100	<100	100	<100	**100**	0
Phosphate Phosphorus (P)	23.1	69	69	23.1	**46.1**	23.0	65.5	61.3	65.5	61.3	**63.4**	2.1
Sulfate (SO_4)	-	-	-	-	**-**	-	-	-	-	-	**-**	-
Total Metals (ug/L)					**n=2**						**n=2**	
Aluminum (Al)-Total	-	-	-	-	**-**	-	11.4	39.1	39.1	11.4	**25.25**	13.85
Antimony (Sb)-Total	-	-	-	-	**-**	-	<0.5	<0.5	<0.5	<0.5	**<0.5**	0
Arsenic (As)-Total	-	-	-	-	**-**	-	<2	<2	<2	<2	**<2**	0
Barium (Ba)-Total	-	-	-	-	**-**	-	10	10.9	10.9	10	**10.45**	0.45
Beryllium (Be)-Total	-	-	-	-	**-**	-	<0.5	<0.5	<0.5	<0.5	**<0.5**	0
Bismuth (Bi)-Total	-	-	-	-	**-**	-	<0.5	<0.5	<0.5	<0.5	**<0.5**	0
Boron (B)-Total	-	-	-	-	**-**	-	3600	3450	3600	3450	**3525**	75
Cadmium (Cd)-Total	-	-	-	-	**-**	-	<0.05	<0.05	<0.05	<0.05	**<0.05**	0
Calcium (Ca)-Total	-	-	-	-	**-**	-	292000	281000	292000	281000	**286500**	5500
Cesium (Cs)-Total	-	-	-	-	**-**	-	<0.5	<0.5	<0.5	<0.5	**<0.5**	0
Chromium (Cr)-Total	-	-	-	-	**-**	-	<0.5	<0.5	<0.5	<0.5	**<0.5**	0
Cobalt (Co)-Total	-	-	-	-	**-**	-	<0.05	0.06	0.06	<0.05	**0.055**	0.005
Copper (Cu)-Total	-	-	-	-	**-**	-	<0.5	0.84	0.84	<0.5	**0.67**	0.17
Gallium (Ga)-Total	-	-	-	-	**-**	-	<0.5	<0.5	<0.5	<0.5	**<0.5**	0
Iron (Fe)-Total	-	-	-	-	**-**	-	28	80	80	28	**54**	26
Lead (Pb)-Total	-	-	-	-	**-**	-	2.5	0.48	2.5	0.48	**1.49**	1.01
Lithium (Li)-Total	-	-	-	-	**-**	-	140	131	140	131	**135.5**	4.5
Magnesium (Mg)-Total	-	-	-	-	**-**	-	913000	852000	913000	852000	**882500**	30500
Manganese (Mn)-Total	-	-	-	-	**-**	-	5.37	9.27	9.27	5.37	**7.32**	1.95
Mercury (Hg)-Total	-	-	-	-	**-**	-	<0.01	<0.01	<0.01	<0.01	**<0.01**	0
Molybdenum (Mo)-Total	-	-	-	-	**-**	-	8.9	8.4	8.9	8.4	**8.65**	0.25

Roberts Bank Water Quality Data	FALL - Near-Surface Samples						Winter - Near-Surface Samples					
Location ID:	**DP06**	**DP07A**	**Summary Statistics**				**DP07A**	**DP06**	**Summary Statistics**			
Date Sampled:	12/12/2014	12/12/2014	Maximum	Minimum	**Mean**	Std Dev	06/03/2014	06/03/2014	Maximum	Minimum	**Mean**	Std Dev
Sample Depth, Below Water Surface (m)					**n=2**						**n=2**	
	0.5	0.5	0.5	0.5	**0.5**	0	0.5	0.5	0.5	0.5	**0.5**	0
Total Metals (ug/L)					**n=2**						**n=2**	
Nickel (Ni)-Total	-	-	-	-	**-**	-	0.55	0.72	0.72	0.55	**0.635**	0.085
Phosphorus (P)-Total	76	73	76	73	**74.5**	1.5	70.5	68.1	70.5	68.1	**69.3**	1.2
Potassium (K)-Total	-	-	-	-	**-**	-	268000	256000	268000	256000	**262000**	6000
Rhenium (Re)-Total	-	-	-	-	**-**	-	<0.5	<0.5	<0.5	<0.5	**<0.5**	0
Rubidium (Rb)-Total	-	-	-	-	**-**	-	94.4	89	94.4	89	**91.7**	2.7
Selenium (Se)-Total	-	-	-	-	**-**	-	<2	<2	<2	<2	**<2**	0
Silicon (Si)-Total	-	-	-	-	**-**	-	1610	1740	1740	1610	**1675**	65
Silver (Ag)-Total	-	-	-	-	**-**	-	<0.1	<0.1	<0.1	<0.1	**<0.1**	0
Sodium (Na)-Total	-	-	-	-	**-**	-	7770000	7430000	7770000	7430000	**7600000**	170000
Strontium (Sr)-Total	-	-	-	-	**-**	-	5420	5180	5420	5180	**5300**	120
Tellurium (Te)-Total	-	-	-	-	**-**	-	<0.5	<0.5	<0.5	<0.5	**<0.5**	0
Thallium (Tl)-Total	-	-	-	-	**-**	-	<0.05	<0.05	<0.05	<0.05	**<0.05**	0
Thorium (Th)-Total	-	-	-	-	**-**	-	<0.5	<0.5	<0.5	<0.5	**<0.5**	0
Tin (Sn)-Total	-	-	-	-	**-**	-	<1	<1	<1	<1	**<1**	0
Titanium (Ti)-Total	-	-	-	-	**-**	-	<5	<5	<5	<5	**<5**	0
Tungsten (W)-Total	-	-	-	-	**-**	-	<1	<1	<1	<1	**<1**	0
Uranium (U)-Total	-	-	-	-	**-**	-	2.41	2.31	2.41	2.31	**2.36**	0.05
Vanadium (V)-Total	-	-	-	-	**-**	-	1.24	1.22	1.24	1.22	**1.23**	0.01
Yttrium (Y)-Total	-	-	-	-	**-**	-	<0.5	<0.5	<0.5	<0.5	**<0.5**	0
Zinc (Zn)-Total	-	-	-	-	**-**	-	<3	3.2	3.2	<3	**3.1**	0.1
Zirconium (Zr)-Total	-	-	-	-	**-**	-	<0.5	<0.5	<0.5	<0.5	**<0.5**	0

Notes:

1. Concentrations that are <D.L. (less than detection limit) are used in summary statistics at a value equating to the absolute value of the D.L., unless all samples are <D.L. or otherwise noted.
2. if all concentrations are <D.L. the means is shown as <D.L. and the standard deviation as zero (0).

Table IR3-42-B4 Roberts Bank North of Causeway 2013 to 2014 Seasonal Water Chemistry Dataset for At-depth Samples

Roberts Bank Water Quality Data	**All Seasons – At-Depth Water Samples**								
Location ID:	**DP07B**	**RB-11-1**	**Summary Statistics**				**DP07B**	**DP07B**	**DP07B**
Date Sampled:	04/06/2014	12/04/2013	Maximum	Minimum	**Mean**	Std Dev	12/09/2014	12/12/2014	06/03/2014
Season	**Spring**						**Summer**	**Fall**	**Winter**
Sample Depth, Below Water Surface (m)	21	7.1	21	7.1	**14.05**	6.95	**19**	**19**	**23**
Physical Tests (mg/L)					**n=1 or 2**		**n=1**	**n=1**	**n=1**
Hardness (as $CaCO_3$)	-	5140	5140	5140	**5140**	0	**-**	**-**	**5170**
Total Suspended Solids	4.2	4.4	4.4	4.2	**4.3**	0.1	**1.64**	**4**	**2.8**
Anions and Nutrients (µg/L)					**n=1 or 2**		**n=1**	**n=1**	**n=1**
Ammonia, Total (as N)	37	18.8	37	18.8	**27.9**	9.1	**11.8**	**6.9**	**6**
Bromide (Br)	-	57600	57600	57600	**57600**	0	**-**	**-**	**-**
Chloride (Cl)	-	15600000	15600000	15600000	**15600000**	0	**-**	**-**	**-**
Fluoride (F)	-	1220	1220	1220	**1220**	0	**-**	**-**	**-**
Nitrate (as N)	<500	<500	<500	<500	**<500**	0	**570**	**630**	**570**
Nitrite (as N)	<100	<100	<500	<500	**<500**	0	**110**	**<100**	**<100**
Phosphate Phosphorus (P)	48.8	63.6	63.6	48.8	**56.2**	7.4	**66.6**	**67.9**	**72**
Sulfate (SO_4)	-	2210000	2210000	2210000	**2210000**	0	**-**	**-**	**-**
Total Metals (ug/L)					**n=1**		**n=1**	**n=1**	**n=1**
Aluminum (Al)-Total	-	22.1	22.1	22.1	**22.1**	0	**-**	**-**	**21.5**
Antimony (Sb)-Total	-	<0.5	<0.5	<0.5	**<0.5**	0	**-**	**-**	**<0.5**
Arsenic (As)-Total	-	<2	<2	<2	**<2**	0	**-**	**-**	**<2**
Barium (Ba)-Total	-	10.5	10.5	10.5	**10.5**	0	**-**	**-**	**8.8**
Beryllium (Be)-Total	-	<0.5	<0.5	<0.5	**<0.5**	0	**-**	**-**	**<0.5**
Bismuth (Bi)-Total	-	<0.5	<0.5	<0.5	**<0.5**	0	**-**	**-**	**<0.5**
Boron (B)-Total	-	4260	4260	4260	**4260**	0	**-**	**-**	**4010**
Cadmium (Cd)-Total	-	0.072	0.072	0.072	**0.072**	0	**-**	**-**	**<0.05**
Calcium (Ca)-Total	-	328000	328000	328000	**328000**	0	**-**	**-**	**335000**
Cesium (Cs)-Total	-	<0.5	<0.5	<0.5	**<0.5**	0	**-**	**-**	**<0.5**
Chromium (Cr)-Total	-	<0.5	<0.5	<0.5	**<0.5**	0	**-**	**-**	**<0.5**
Cobalt (Co)-Total	-	0.061	0.061	0.061	**0.061**	0	**-**	**-**	**<0.05**
Copper (Cu)-Total	-	0.55	0.55	0.55	**0.55**	0	**-**	**-**	**<0.5**
Gallium (Ga)-Total	-	<0.5	<0.5	<0.5	**<0.5**	0	**-**	**-**	**<0.5**
Iron (Fe)-Total	-	41	41	41	**41**	0	**-**	**-**	**43**
Lead (Pb)-Total	-	<0.3	<0.3	<0.3	**<0.3**	0	**-**	**-**	**0.51**
Lithium (Li)-Total	-	180	180	180	**180**	0	**-**	**-**	**157**
Magnesium (Mg)-Total	-	1050000	1050000	1050000	**1050000**	0	**-**	**-**	**1050000**
Manganese (Mn)-Total	-	3.98	3.98	3.98	**3.98**	0	**-**	**-**	**3.29**
Mercury (Hg)-Total	-	<0.01	<0.01	<0.01	**<0.01**	0	**-**	**-**	**<0.01**
Molybdenum (Mo)-Total	-	10.5	10.5	10.5	**10.5**	0	**-**	**-**	**10.1**

Roberts Bank Water Quality Data	All Seasons - At-Depth Water Samples								
Location ID:	**DP07B**	**RB-11-1**	**Spring Deep Water Sample Statistics**				**DP07B**	**DP07B**	**DP07B**
Date Sampled:	04/06/2014	12/04/2013	Maximum	Minimum	**Mean**	Std Dev	12/09/2014	12/12/2014	06/03/2014
Season	**Spring**						**Summer**	**Fall**	**Winter**
Sample Depth, Below Water Surface (m)	21	7.1	21	7.1	**14.05**	6.95	**19**	**19**	**23**
Total Metals (ug/L)					**n=1**		**n=1**	**n=1**	**n=1**
Nickel (Ni)-Total	-	0.51	0.51	0.51	**0.51**	0	**-**	**-**	**1.05**
Phosphorus (P)-Total	65.3	<1000*	65.3	65.3	**65.3**	0	**97**	**79**	**75.9**
Potassium (K)-Total	-	313000	313000	313000	**313000**	0	**-**	**-**	**310000**
Rhenium (Re)-Total	-	<0.5	<0.5	<0.5	**<0.5**	0	**-**	**-**	**<0.5**
Rubidium (Rb)-Total	-	107	107	107	**107**	0	**-**	**-**	**107**
Selenium (Se)-Total	-	<2	<2	<2	**<2**	0	**-**	**-**	**<2**
Silicon (Si)-Total	-	1250	1250	1250	**1250**	0	**-**	**-**	**1550**
Silver (Ag)-Total	-	<0.1	<0.1	<0.1	**<0.1**	0	**-**	**-**	**<0.1**
Sodium (Na)-Total	-	8830000	8830000	8830000	**8830000**	0	**-**	**-**	**8870000**
Strontium (Sr)-Total	-	5950	5950	5950	**5950**	0	**-**	**-**	**6150**
Tellurium (Te)-Total	-	<0.5	<0.5	<0.5	**<0.5**	0	**-**	**-**	**<0.5**
Thallium (Tl)-Total	-	<0.05	<0.05	<0.05	**<0.05**	0	**-**	**-**	**<0.05**
Thorium (Th)-Total	-	<0.5	<0.5	<0.5	**<0.5**	0	**-**	**-**	**<0.5**
Tin (Sn)-Total	-	<1	<1	<1	**<1**	0	**-**	**-**	**<1**
Titanium (Ti)-Total	-	<5	<5	<5	**<5**	0	**-**	**-**	**<5**
Tungsten (W)-Total	-	<1	<1	<1	**<1**	0	**-**	**-**	**<1**
Uranium (U)-Total	-	2.84	2.84	2.84	**2.84**	0	**-**	**-**	**2.69**
Vanadium (V)-Total	-	1.57	1.57	1.57	**1.57**	0	**-**	**-**	**1.43**
Yttrium (Y)-Total	-	<0.5	<0.5	<0.5	**<0.5**	0	**-**	**-**	**<0.5**
Zinc (Zn)-Total	-	<3	<3	<3	**<3**	0	**-**	**-**	**<3**
Zirconium (Zr)-Total	-	<0.5	<0.5	<0.5	**<0.5**	0	**-**	**-**	**<0.5**

Notes:

1. Concentrations that are <D.L. (less than detection limit) are used in summary statistics at a value equating to the absolute value of the D.L., unless all samples are <D.L. or otherwise noted.
2. If all concentrations are <D.L., the mean is shown as <D.L. and the standard deviation as zero (0).

* As detection limit is higher than concentration in other samples for this parameter, the <D.L. value has not been used in summary statistics.

IR3-43 Marine Water Quality – Baseline: Ambient Contamination Levels in Water

Information Source(s)

Marine Shipping Addendum: Section 7.3.2.2

Context

In Section 7.3.2.2 of the Marine Shipping Addendum, the Proponent indicated that there are no available studies documenting ambient contaminant levels in water in the area of the marine shipping lanes, and identified this as a constraint to its study.

The Proponent is to consult with relevant provincial and federal entities in an attempt to obtain appropriate information that could be used to present a baseline characterization of ambient contaminant levels in water within the study area boundaries.

Information Request

Provide a description of the ambient contaminant levels in water in the marine shipping area.

VFPA Response

The VFPA attempted to solicit information regarding ambient contaminant levels in water in the marine shipping area from the following regulatory entities:

- Federal – Environment and Climate Change Canada (ECCC) and Fisheries and Oceans Canada (DFO);
- Provincial – Ministry of Environment (MOE), and Ministry of Forests, Lands and Natural Resource Operations (MFLNRO); and
- Regional – Metro Vancouver.

The following information was provided by the regulatory entities:

1. ECCC indicated that water quality monitoring is conducted in support of the Canadian Shellfish Sanitation Program at several sites within the Project study area[1];

[1] Canadian Shellfish Sanitation Program – website provided by ECCC: https://www.ec.gc.ca/marine/default.asp?lang=En&n=F2648EE6-1.

2. MOE and MFLNRO provided internet links to two documents: 1) *Ambient Water Quality Objectives for Boundary Bay and its Tributaries, Fraser-Delta Area - Overview Report*[2], and 2) *Metro Vancouver 2013 Wastewater Quality Control Annual Report*[3]; and
3. MOE also provided a document entitled *Status of Water Quality Conditions in the Little Campbell, Serpentine, and Nicomekl Rivers from 1971 to 2009*, which is provided in **Appendix IR3-43-A**.

The information provided by the regulatory entities either did not pertain to contaminants relevant to marine shipping or was not specific to the area of the marine shipping lanes. Since the VFPA was unable to obtain appropriate information that could be used to characterise ambient contaminant levels in water in the area of the marine shipping lanes, further characterisation of ambient contaminant levels was not conducted.

The constraint to the assessment of water quality pertaining to a lack of information on contaminant levels previously outlined in Section 7.3.2.2 of the Marine Shipping Addendum is aligned with recent information provided in the *Trans Mountain Pipeline Expansion Project: An Application Pursuant to Section 52 of the National Energy Board Act,* which stated "there are no available studies documenting ambient contaminant levels over the marine shipping lanes" (TMX 2013: Page 8A–108).

Transport Canada has indicated[4] that with respect to chronic oiling, the use of anti-fouling agents, and discharges of ballast water, bilge water, and sewage, that marine water quality in the marine shipping area is not expected to change because these potential contributors are regulated by the *Canada Shipping Act, 2001,* and in particular the *Vessel Pollution and Dangerous Chemicals Regulations* (VPDCR) under this act. Furthermore, Transport Canada states that "In relation to the Project, the technical requirements of the VPDCR apply to all vessels over 400 gross tonnage. As such, all container ships and most tugs serving container ships that would call at the proposed RBT2 would be subject to these requirements".

References

Trans Mountain Pipeline ULC (TMX). 2013. Trans Mountain Pipeline Expansion Project: An Application Pursuant to Section 52 of the National Energy Board Act. Volume 8A: Marine Transportation. December 2013. 882 p.

[2] Ambient Water Quality Objectives for Boundary Bay and its Tributaries Fraser-Delta Area, Overview Report (February 2, 1988) – website provided by MOE: http://www.env.gov.bc.ca/wat/wq/objectives/boundarybay/boundarybay.html.

[3] The Greater Vancouver Sewerage and Drainage District Environmental Management and Quality Control Annual Report 2013 – website provided by MOE: http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/2013_Wastewater_Quality_Control_Annual_Report.pdf.

[4] In CEAR Document #982, specifically responses to TCIR-02 to TCIR-06, from Transport Canada to the Review Panel Re: Response to Information Requests issued by the Review Panel on May 10, 2017 (CEAR Document #962).

Appendices

Appendix IR3-43-A Information Received from Regulatory Entities

APPENDIX IR3-43-A

INFORMATION RECEIVED FROM REGULATORY ENTITIES

BRITISH COLUMBIA

Ministry of Environment

LOWER MAINLAND REGION

ENVIRONMENTAL QUALITY

Status of Water Quality Conditions in the Little Campbell, Serpentine, and Nicomekl Rivers from 1971 to 2009

Status of Water Quality Conditions in the Little Campbell, Serpentine, and Nicomekl Rivers from 1971 to 2009

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Preface

This report is one in a series of water, groundwater, and air quality reports that are being issued by the Lower Mainland Regional Office in fiscal year 2010/11. It is the intention of the Regional Office to publish air and water quality reports on our website (http://www.env.gov.bc.ca/epd/regions/lower_mainland/water_quality/reports/index.htm - 8) in order to provide the information to industry and local government, other stakeholders and the public at large. By providing such information in a readily understood format, and on an ongoing basis, it is hoped that local environmental quality conditions can be better understood, and better decisions regarding air and water quality management can be made.

Water Quality Objectives and Attainment Monitoring

Water quality objectives are established in British Columbia for water bodies on a site-specific basis and are set to protect the most sensitive designated water uses at a specific location. Objectives are prepared for those water bodies and water quality measurements that may be affected by human activity currently, or in the future.

Attainment monitoring and reporting is conducted to check whether the objectives are being met, and is important for preparing waste management plans, issuing of permits, licenses and orders, as well as for regulating water uses. Monitoring usually takes place at a critical time, during a five-week period, when water quality objectives may not be met. This will generally represent the 'worst case scenario' for the water uses in question, which will ensure that they will be protected at other times when the threat to water quality is lower. In the case of streams and river systems, monitoring will ideally take place before and after a first flush event. In the Lower Mainland this generally occurs in August, prior to the first flush event, and in October and/or November depending on significant precipitation onset.

This Boundary Bay tributaries report is part of a larger collaboration on monitoring within the Boundary Bay area. The Boundary Bay Monitoring and Assessment Program (BBAMP) has come together as part of Metro Vancouver's Liquid Waste Management Plan for environmental monitoring of relevant waterbodies. BBAMP is a partnership involving a number of environmental monitoring efforts of local governments, senior governments, First Nations and non-governmental organizations.

Water Quality Index

A water quality index was developed by the Canadian Council of Ministers of the Environment (CCME) in 1999 to reflect the overall and ongoing condition of water bodies. The index is based on a formula developed by the BC Ministry of Environment (MOELP, 1995), with a few modifications. The index can be used to assess water quality relative to its desirable state (as defined by the water quality objectives) and to provide insight into the degree to which water quality is affected by human activity. The index is also useful for ranking the suitability of water for use by humans and aquatic life.

The index is founded on three factors involving the measurement of the attainment of water quality objectives. The factors measure the number of objectives not met (scope), the frequency with which objectives are not met (frequency), and the maximum amount by which objectives are not met (amplitude). The index then ranks water quality into one of five categories: excellent, good, fair, marginal and poor.

Acknowledgements

Ministry staff completed the fieldwork. Microbiological tests were performed by CANTEST Ltd. (Burnaby, B.C.) and analytical chemistry tests for water quality parameters were performed by Maxxam Analytics Inc. (Burnaby, B.C.). Precipitation data for August-November 2009 was obtained from Environment Canada. The author would also like to thank Liz Freyman (Ministry of the Environment) for feedback provided on the report.

SUMMARY

The Little Campbell, Nicomekl, and Serpentine Rivers, which flow into Boundary Bay, are at risk of contamination from diffuse agricultural sources and stormwater runoff due to intensive agricultural and urban use of the area. This report presents the results of monitoring undertaken in 2009 to check attainment of Boundary Bay tributary water quality objectives set in 1988. Objectives have not been formally monitored since 2002. The CCME Water Quality Index was also determined for each tributary using 2009 results. The river systems of concern are the Little Campbell River, the Nicomekl River and its tributaries (Murray and Anderson Creeks), and Serpentine River and its tributaries (Latimer, Mahood and Hyland Creeks). The current results were also compared with data obtained over the past 40 years to determine the overall state of water quality in the three river systems.

Chemical and bacteriological indicators were monitored five times during a 30-day period in both August (dry period) and November 2009 (wet period). Bacteriological indicators included fecal coliforms, *Escherichia coli* (*E. coli)* and enterococci. Water quality indicators included dissolved oxygen, pH, suspended solids, turbidity, ammonia, nitrite, and lead. Data collected in 2008 for polychlorinated biphenyls (PCBs) in water, sediment and tissue are also included for Serpentine River and Mahood Creek.

The Little Campbell River

Historically, the Little Campbell River has not consistently met objectives for dissolved oxygen at the upstream location (at 216th St.), and for fecal coliforms and suspended solids at the downstream location (at 176th St.). In 2009, objectives for fecal coliforms, pH, ammonia, and nitrite were generally met at all three sites sampled, although there were seasonal differences. **Objectives for dissolved oxygen (DO) were not met at any site in either season, while suspended solids and turbidity objectives were not met at downstream sites in the fall**. These results are similar to those found in 2002, although DO values were lower at the upstream site in 2009.

While fecal coliform and suspended solids conditions at the downstream site have improved since 1990, DO conditions, which have always been poor at the upstream site, appear to be deteriorating further. The **Water Quality Index rating** was **Fair** in 2009, mainly due to very low DO conditions at the upstream site, as well as elevated suspended solids and turbidity levels at downstream sites. This is an improvement over the Marginal rating calculated in 2002.

The Nicomekl River and its tributaries

The Nicomekl River main stem has failed to meet fecal coliform, suspended solid, dissolved oxygen, and pH objectives in previous attainment monitoring, while Murray Creek has failed to meet fecal coliform and suspended solid objectives. In 2009, objectives for fecal coliforms, ammonia, nitrite, suspended solids, pH and lead were generally met in the Nicomekl River and its tributaries, with a few exceptions. **Minimum DO objectives were not met in summer on several occasions in the Nicomekl main stem and tributaries, and were not met at any time during fall sampling.** The turbidity objective was also not met on several occasions in the Nicomekl main stem

during fall sampling, although the exceedences were not large. These results are similar to those found in 2002, although DO values were lower at all sites in the fall of 2009.

In general, water quality indicators in the Nicomekl main stem and tributaries are stable or have improved since 1972. However, fecal coliform levels were found to be higher in 2009 in the tributaries and midstream Nicomekl site than in 2002. Additionally, DO levels were significantly lower in the tributaries and at both Nicomekl sites in 2009 compared to previous years. This is of particular concern for salmonids, which require high DO levels in the fall when spawning. The **Water Quality Index ratings** for the **Nicomekl River, Murray Creek, and Anderson Creek** were **Fair in the fall of 2009**, which was a decline from Good ratings calculated in 2002. Thus, water use for aquatic life may not be adequately protected at times in the Nicomekl River and tributaries, due mainly to low DO conditions. Other uses, including irrigation and livestock watering, appear to be protected at this time.

The Serpentine River

The Serpentine River main stem and its tributaries have not consistently met objectives for fecal coliforms, suspended solids, DO, and pH in the past. Objectives for fecal coliforms, ammonia, nitrite, suspended solids, and pH were generally met in 2009 at sites in the Serpentine River and its tributaries, with some exceptions. The provincial *E. coli* criterion and **long-term fecal coliform objectives were not met** at both Serpentine sites in the fall, while suspended solids and turbidity objectives were not met at the downstream site on several occasions. **Minimum DO objectives were not met in summer or fall on several occasions in the Serpentine main stem and tributaries.** DO values were particularly low in the main stem during fall sampling, which is a degradation of conditions since 2002. PCB sampling in Mahood Creek and the Serpentine main stem in 2008 showed levels generally below the objective. However, one sample each in water, sediment and tissue (juvenile coho) collected nearest to the BC Hydro facility in Mahood Creek, was 3, 10 and 4 times higher than the relevant objectives, respectively.

While there has been improvement in fecal coliform levels at the downstream Serpentine River site since 1990, there has not been a significant improvement at the upstream site. There have been improvements in fecal coliform levels in all three tributaries since 1990, although 2009 levels did exceed long-term objectives in both seasons. Since 1990, there have also been improvements in ammonia, nitrite and suspended solids in the Serpentine main stem and tributaries. The most notable difference was a decline in DO conditions during the fall period compared to previous sampling periods.

The **WQI rating** for the **Serpentine River** was only **Fair** during 2009 fall sampling, which was a decline from a Good rating in 2002. However, summer 2009 sampling yielded a better rating of Good. **Latimer, Mahood and Hyland Creeks** had **Good** ratings in both summer and fall of 2009, which was similar to those found in 2002. Thus, conditions in the Serpentine River and its tributaries do not appear to be adequate at times for the protection of aquatic life, particularly during first flush periods when diffuse oxygen-demanding substances are entering the system.

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1.0 INTRODUCTION

The Little Campbell, Serpentine, and Nicomekl Rivers are located in the Fraser-Delta area of the Lower Mainland and drain into Boundary Bay (Figure 1). In 1988, provisional water quality objectives for these tributaries were set to assist Metro Vancouver (formerly the Greater Vancouver Regional District) in preparing a Liquid Waste Management Plan for the Fraser-Delta area (MEP, 1988a).

In the Fraser-Delta area, agricultural and urban runoff is the primary influence affecting water quality in the Little Campbell, Nicomekl, and Serpentine River watersheds. Diffuse agricultural sources can influence ammonia, phosphorus, biochemical oxygen demand, and fecal coliform concentrations in these watersheds (MEP, 1988b). Urban stormwater runoff can also be a potential source of fecal coliforms and metals, such as lead and zinc (MEP, 1988a). In the Serpentine River watershed, polychlorinated biphenyl (PCBs) contamination from stormwater runoff has also occurred from a BC Hydro facility in the Mahood/Bear Creek watershed.

Monitoring of bacteriological indicators in these tributaries is important to protect the most sensitive designated uses, primary-contact recreation and irrigation. Important bacteriological indicators include fecal coliforms, *Escherichia coli* (*E. coli*) and enterococci. While fecal coliforms have historically been used as the primary indicators, *E. coli* and enterococci are considered to be better indicators of the presences of gastrointestinal disease causing organisms, and are thus included in current provincial monitoring programs (MEP, 1988c).

Due to the potential for nutrient and contaminant inputs from human activities, other important water quality parameters in these tributaries include ammonia, nitrate, nitrite, dissolved oxygen, pH, suspended solids, turbidity and lead. Ammonia is of particular concern due to its toxicity to aquatic organisms, particularly fish, at higher concentrations. Additionally, ammonia toxicity increases at higher temperatures and pH values (MEP, 1988a). Nitrite is also toxic to aquatic life and can be formed when ammonia is oxidized (MEP, 1988a). Dissolved oxygen is essential for respiration by most aquatic organisms and thus is an important environmental indicator. Suspended solids are of concern as they contribute to turbidity and can smother fish spawning grounds, as well as benthic macroinvertebrate habitat, upon settling. Suspended solids are also a concern as they can be associated with other contaminants such as metals, hydrocarbons and PCBs. Aquatic life is particularly sensitive to trace metals, such as lead, which can enter freshwater systems from stormwater runoff. PCBs are of concern in the Serpentine River system due to its persistence in the environment, and its ability to bioaccumulate and biomagnify in organisms.

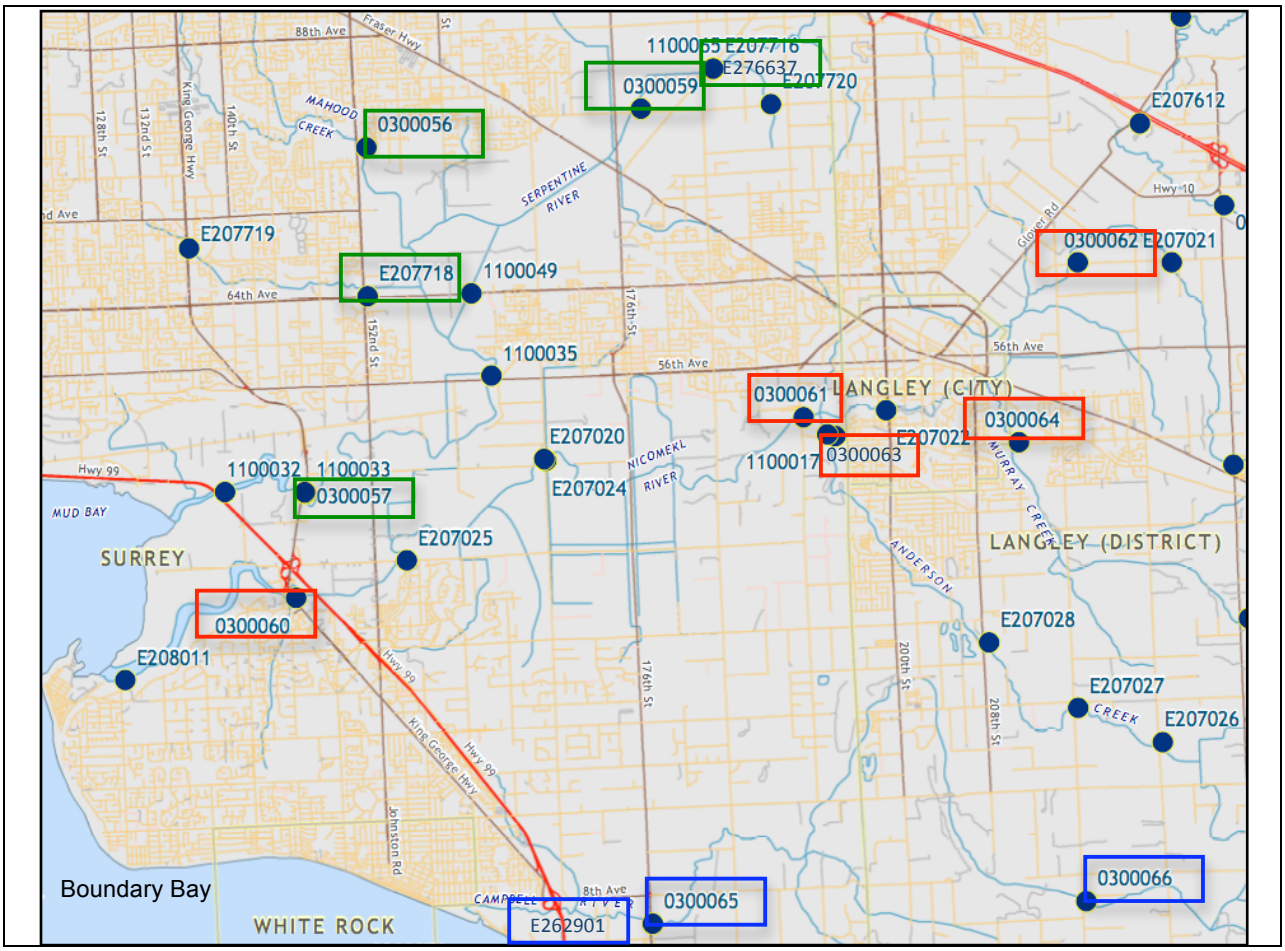

Figure 1 Sampling sites in the Serpentine River (green boxes), Nicomekl River (red boxes), and Little Campbell River (blue boxes)

Objectives for fecal coliforms, ammonia, nitrate, nitrite, suspended solids, tubidity, dissolved oxygen, pH, lead and PCBs were first set in the Little Campbell, Nicomekl, and Serpentine Rivers in 1988 (see Appendix A; MEP, 1988a). They were subsequently checked in 1989 (MOE, 1990) and 1990 (MOE, 1991). In 1991, only ammonia was monitored (MOELP, 1993a) and in 1992, all parameters were monitored except pH, lead, and PCBs (MOELP, 1993b). Water quality monitoring was conducted in 1999-2000, and objectives were monitored most recently in 2002 (MWLAP, 2003).

Since water quality indicators were last monitored in these watersheds in 2002, it was a priority to monitor these environmental indicators in 2009. The current results are compared with results obtained over the past 40 years, covering the periods from 1971-1983, 1988-1990, 1999-2000 and 2002. The CCME Water Quality Index was also determined for the three rivers and their tributaries in 2009, which rates water quality based on objective attainment results. The three river systems will be addressed separately in Sections 2.0 (Little Campbell River), 3.0 (Nicomekl River) and 4.0 (Serpentine River).

2.0 LITTLE CAMPBELL RIVER

2.1 Overview

The Little Campbell River (LCR) is approximately 30 km in length and flows from Aldergrove Lake Park to Semiahmoo Bay (Figure 2). The 65 km^2 drainage basin includes four main tributaries: Fergus Creek, Sam Hill Creek, Jacobsen Creek and Highland Creek. The LCR watershed was logged early in the century and is now primarily an agricultural area, with some recreational and urban development (MEP, 1988a).

In 1988, objectives were developed to protect water uses in the drainage area for irrigation, livestock watering, aquatic life, wildlife, and primary-contact recreation (MEP, 1988a). In subsequent objectives attainment monitoring from 1988 to 1992, objectives for dissolved oxygen were not met at the upstream LCR site (0300066). At the downstream site (0300065), objectives for fecal coliforms, suspended solids concentrations, and nitrite were exceeded from 1988 to 1990. In 2002, there was an improvement in water quality indicators and most objectives were met, except for DO at the upstream site, which remained low (MWLAP, 2003). Since objectives have not been checked in the Little Campbell since 2002, it was a priority to monitor these objectives in 2009. Additional sampling was conducted in 1999 and 2000, which are also included in this report.

2.2 Water Uses

Historically, water was withdrawn from the Little Campbell River for irrigation, livestock watering, as well as golf course irrigation and lawn watering (MEP, 1988a). Currently, water is withdrawn for the same purposes, with irrigation and conservation for fish and wildlife being the two largest uses (see Appendix H). There is also a fish hatchery, operated by the Semiahmoo Fish and Game Club since 1983 (at 184th St.), which withdraws water from a groundwater well and discharges wastewater into the Little Campbell River. Swimming also occurs in sections of the river, near the mouth in White Rock, and at the Hazelmere Riverside Campground in the summer, which borders the river in Langley. Steelhead and cutthroat trout use the river system and coho and chum salmon spawn in the upper reaches and tributaries in the fall (MEP, 1988a).

2.3 Potential Sources of Contamination

Historically, six small operations had permits to discharge effluents within the Little Campbell River sub-basin (MEP, 1988a). These included agricultural operations, gravel washing operations, as well as residential and recreational facilities. Currently, there are only two permit-holders within the basin, a mobile home park and a recreational vehicle and tent campground.

Bedwell Bay Construction Ltd. (PE 1558) owns the Hazelmere Riverside Campground, which was first issued a permit in 1972 (amended in 1987). The mobile home park is owned by Noort Developments and Associates (formerly Del-Van Construction Ltd.) which was issued a permit (PE 4645) in 1977 (amended in 1983). Both permits allow for the discharge of treated domestic sewage to the land, via tile fields. The campground effluent treatment involves a septic tank, secondary treatment plant, effluent filter, and two disposal fields, which are approximately 30 m from the river. The mobile home park discharges treated domestic sewage to two tile fields, which are 137m from the river. The potential for contamination of water quality in the Little Campbell River is unknown.

Potential contamination from diffuse sources within the basin, include those from livestock-raising operations, agriculture, and residential septic tank tile fields, which can contribute loadings of nitrogen, phosphorus, and fecal coliforms to ground and surface waters, as well as sediments to surface waters (MEP, 1988a). Urban stormwater runoff may also be a problem in some areas especially in the Fergus Creek tributary where recent shopping mall and residential development has been occurring.

2.4 Methodology

2.4.1 Field Methodology

In 2009, three monitoring locations were sampled on the main stem of the Little Campbell River (LCR). Two of these sites include an upstream LCR site at 216th St (EMS 0300066) and a downstream LCR site at 176th St (EMS 0300065), for which data have been available since 1971 (see Figure 2 photos). In 2009, a new site was sampled (EMS E262901), near the mouth, for which no historical data are available.

Sampling in 2009 was carried out five times in 30 days in both the dry summer period (August 5, 12, 19, 26 and September 2) and wet fall period (October 27, November 3, 10, 17 and 24). These time periods thus included sampling before and after the first flush events in 2009, which occurred on October 25 and 29/30 (see Appendix B). Bacteriological indicators monitored included fecal coliforms, *E. coli* and enterococci (site E262901 only). Water quality indicators included suspended solids, turbidity, ammonia, nitrate, nitrite and lead. Field measurements were taken at the surface with a calibrated YSI 556 Multi Probe System (YSI Environmental) and included water temperature, dissolved oxygen, pH and specific conductance. Photographs of the sampling sites were taken on November 21, 2002. Precipitation data from a weather station at the Vancouver International Airport was obtained from Environment Canada for the 2009 sampling periods.

Grab samples were collected at the surface, facing upstream, using high-density polyethylene bottles for both bacteriological and water chemistry samples. Water samples for metals analysis were preserved by Maxxam Analytics upon delivery of the samples. Field sampling quality control was addressed by including blind field and trip

blank samples, and by collecting blind triplicate samples at one site on each sampling date (see Appendix F). Field blanks are intended to capture sampler errors when collecting water in the field, while trip blanks are intended to capture sample bottle or deionized water contamination. Blind replicates are intended to assess lab analytical precision. Samples were kept on ice in a cooler during overnight delivery to CANTEST Ltd. (bacteriological samples) or Maxxam Analytics (chemistry samples).

2.4.1 Laboratory Methodology

The laboratories followed analytical procedures according to the British Columbia Environmental Laboratory Manual for the Analysis of Water, Wastewater, Sediment and Biological Materials (MOELP, 1994). They also employed quality assurance and control procedures, including method blanks, duplicates, and spike recoveries. These reports are available upon request.

Little Campbell River at 216th St (upstream site, 0300066)

Little Campbell River at 176th St (downstream site, 0300065)

Figure 2 Little Campbell River sampling sites

2.5 Results and Statistical Analysis

Bacteriological and water chemistry data for 2009 have been summarized in Tables 1, 3 and 4, respectively. A comparison of results with 1971-1983, 1988-1990, 1999-2000, and 2002 sampling periods are presented in Tables 2 (bacteria) and 5 (water chemistry). Raw field and water quality data are shown in Appendix C. The geometric mean was obtained for bacteriological results, with the requirement that at least five samples were collected within 30 days (MEP, 1988c). The 90th percentile was also obtained for bacteriological data using both summer and fall data, using at least five samples in 30 days. The range and average were calculated for chemical parameters. As sampling strategies changed from quarterly sampling in the 1970's and 1980's, to targeted five-week sampling in the 1990's and beyond, the statistical validity of trends could not be determined. Readily apparent trends were still noted.

The Water Quality Index (WQI) was calculated as described in CCME (2001). The factors used in the index are based on results of water quality objectives attainment and include; F_1 (Scope), the number of objectives not met; F_2 (Frequency), the frequency with which objectives are not met; and F_3 (Amplitude), the amount by which objectives are not met. Appendix G provides the numerical ranges for the rankings and descriptions of the rankings, as well as the 2009 results, which are presented using only short-term objectives, as well as both short- and long-term objectives. The 2002 WQI rankings are also provided for comparison. Since the CCME index was adapted from the BC Ministry of Environment, Lands and Parks index, the same conditions regarding data use were applied (MOELP, 1995). Some of these conditions include omitting incomplete monitoring results and using results from short-term objectives only (MOELP, 1995).

2.6 Discussion

2.6.1 Bacteriological Indicators

While bacteriological objectives were set for only fecal coliforms in 1988, it is also appropriate to use the provincial criteria for *E. coli* and enterococci levels since, as previously stated, these bacteria are considered to be better indicators of gastrointestinal disease. The objectives for fecal coliforms, and provincial criteria for *E. coli* and enterococci, in the Little Campbell River are based on primary-contact recreation criteria:

- **Fecal coliforms** – geometric mean of ≤200/100 mL & 90th percentile of ≤400/100 mL (objectives, April-October)
- ***E. coli*** (provincial standards) – geometric means of ≤77/100 mL (irrigation, crops eaten raw), ≤385/100 mL (irrigation, public/livestock access), ≤1000/100 mL (irrigation, general)
- **Enterococci** (provincial standards) – geometric mean of ≤20/100 mL (irrigation, crops eaten raw), ≤100/100 mL (irrigation, public/livestock access), ≤250/100 mL (irrigation, general)

In 2009, geometric mean (gm) objectives for fecal coliforms were met at the two downstream, but not at the upstream site in the Little Campbell River (gm=250 CFU/100 mL; Table 1). Geometric mean and 90th percentile objectives were not applied to fall samples, as they were collected in November when objectives do not apply. The most stringent provincial ***E. coli*** criterion for irrigation (crops eaten raw) was exceeded at the upstream site in the summer, and at all sites in the fall (Table 1). The most stringent provincial **enterococci** criterion was also not met at the furthest downstream site, near the mouth (E262901), during both summer and fall sampling periods. This site, however, was the only one sampled for enterococci in 2009.

It should be noted that there were differences in seasonal bacterial numbers at both downstream sites, where fecal coliform and *E. coli* numbers were 6-20 times higher, and enterococci numbers were 47 times higher near the mouth in fall compared to summer sampling periods (Table 1). Additionally, bacterial levels initially increased on October 27th, particularly near the mouth (E262901), following the first flush event on October 25th (23.2 mm, Appendix B). Following this event, bacterial levels were highest on November 10th at the upstream site (0300066), and on November 17th at the downstream site (0300065) (see Appendix C). There was also an observable spatial trend of higher bacterial results at subsequent downstream sites during the fall sampling period, likely indicating non-point source inputs along the river's length.

While maximum fecal coliform values have decreased at the upstream site (0300066) since the 1971-83 sampling period, the geometric mean did not meet the objective for the first time in 30 years and is thus of concern (Table 2). However, the downstream site (0300065) maximum and geometric mean values did not significantly differ from the 2002 sampling effort, and have shown improvements since 2000. Near the mouth (E262901), bacterial levels also improved between 2006 and 2009, with geometric means of 405 and 95 CFU/100 mL, respectively.

Table 1 Bacteriological objectives attainment in the Little Campbell River (LCR) - 2009

Variable & Objective	Site	Season	Range	Geometric mean (n=5)	90th Percentile (n=5) – Apr-Oct	Conclusion
Fecal coliforms (CFU/100 mL) gm ≤200/100 mL 90th ≤400/100 mL Apr-Oct	Upstream (0300066)	Summer	98-460	250	420	Objectives not met
		Fall	44-560	235	540	Objectives not applied
	Downstream (0300065)	Summer	62-390	142	334	Objectives met
		Fall	400-1,700	793	1416	Objectives not applied
	Near mouth (E262901)	Summer	17-460	95	340	Objectives met
		Fall	350-5,400	1,969	5080	Objectives not applied
Escherichia coli (E. coli) (CFU/100 mL) gm ≤77/100 mL (recreation criterion)	Upstream (0300066)	Summer	74-240	162	n/a	Provincial criterion not met
		Fall	35-480 (n=4)	155 (n=4)		Provincial criterion not met
	Downstream (0300065)	Summer	29-210	77		Provincial criterion met - summer
		Fall	280-1,300	699		Provincial criterion not met
	Near mouth (E262901)	Summer	12-160	50		Provincial criterion met - summer
		Fall	89-5,400	976		Provincial criterion not met
Enterococci (CFU/100 mL) gm ≤20/100 mL (recreation criterion)	Near mouth (E262901)	Summer	<1-47	21	n/a	Provincial criterion not met
		Fall	120-7,800	989		Provincial criterion not met

Notes: Summer samples collected August 5, 12, 19, 26 & September 2 (n=5); winter samples collected October 27 & November 3, 10, 17 & 24 (n=5); gm is geometric mean, 90th is 90th percentile; fecal coliform geometric mean objectives applied to summer samples only as fall samples collected in November

Table 2 Comparison of Little Campbell River bacteriological indicators, 1971 to 2009

Variable & Objective	Site	1971-1983	1988-1990	1999-2000	2002	2009 (Summer data only)	Conclusion
Fecal coliforms (CFU/100 mL) ≤200/100 mL geometric mean ≤400/100 mL 90th percentile	Upstream (0300066)	8 – 5400 *med = 130* (n=32)	4 – 251 *med = 81* **gm^1 = 101** **gm^2 = 31** **gm^4 = 63** (n=18)	1 – 93 *med = 16* (n=6)	10 – 364 *med = 21* **gm = 40** (n=5)	98 – 460 *med = 300* **gm = 250** (n=5)	Degradation since 2002 & geometric mean objective not met in 2009
	Down-stream (0300065)	49 – 9200 *med = 790* (n=32)	26 – 995 *med = 414* **gm^1*= 311** **gm^2*= 162** **gm^3*= 486** **gm^4 = 199** (n=17)	54 – 1000 *med = 170* (n=5)	21 - 410 *med = 100* **gm = 81** (n=5)	62 - 390 *med = 110* **gm = 142** (n=5)	Conditions similar to 2002 & geometric mean objective met in 2009
	Near mouth (E262901)	n/a	n/a	n/a	**2006 (Apr-Oct)** 40-22,000 *med = 300* **gm=405** (n=17)	17 - 460 *med = 94* **gm = 95** (n=5)	Geometric mean objective met in 2009

Notes: Values include range, median (*med*), and geometric mean (gm) where applicable; results that exceeded objectives are in red; gm^1 is the 1988 geometric mean (Oct 19 to Nov 17); gm^2 is the first 1989 geometric mean (Sept 25 to Oct23); gm^3 is the second 1989 geometric mean (Oct 30 to Nov 27); gm^4 is the 1990 geometric mean (Sept 25 to Oct 23); gm^n* indicates a geometric mean of 4 results

2.6.2 Water Quality Indicators

2.6.2.1 Ammonia

Objectives for ammonia-nitrogen(N) in the Little Campbell River, set to protect aquatic life, are an average 30-day and maximum concentration dependent on pH and temperature, where ammonia toxicity increases with increasing temperature and pH. In 2009, the lowest criteria for all sampling sites and all dates, to which the results were compared, were a summer (fall) average and maximum ammonia-N concentration of 0.65 mg/L (1.8 mg/L) and 0.9 mg/L (4.8 mg/L), respectively (ammonia tables in Appendix A; MOE, 2006). These objectives were met for all three sites on all dates sampled in 2009, with results well below the stated criteria (Table 3). Objectives for ammonia-N concentrations have also been met in the previous attainment monitoring efforts from 1988 to 2002. Ammonia-N conditions have improved at the upstream site (0300066) since 1983 and at the downstream site (0300065) since 1990 (Table 5).

2.6.2.2 Nitrite

Objectives for nitrite-nitrogen(N) in the Little Campbell River, set to protect aquatic life, are an average 30-day and maximum concentration dependent on chloride concentration. Most chloride values were >10 mg/L, so the 0.2 mg/L (average) and 0.6 mg/L (maximum) objectives apply (see chloride table in Appendix A). These objectives were met at all three sites on all dates sampled in 2009 (Table 3). Nitrite-N concentrations were similar at all three sites in 2009 and have been stable and adequate in the river over the last 40 years (Table 5).

2.6.2.3 pH

The objective range for pH in the Little Campbell River is 6.5 to 8.5. This objective was met at all three sites in November 2009, but was exceeded on one occasion near the mouth (pH 8.9; E262901) and at the downstream site (pH 8.6, 0300065) during the summer sampling period (Table 4). This objective was also met in previous attainment monitoring and pH levels have been relatively stable at both sites since 1990 (Table 5).

Table 3 Water quality objectives attainment in the Little Campbell River (ammonia, nitrite & nitrate) - 2009

Variable & Objective	Site	Season	Range	Arithmetic mean (n=5)	Conclusion
Ammonia-N (mg/L) 0.65 mg/L (summer) & 1.8 mg/L (fall) average 0.9 mg/L (summer) & 4.8 mg/L (fall) maximum	Upstream (0300066)	Summer	0.023-0.282	0.099	Objectives met
		Fall	<0.005-0.040	0.018	
	Downstream (0300065)	Summer	<0.005-0.022	0.01	Objectives met
		Fall	0.007-0.033	0.019	
	Near mouth (E262901)	Summer	<0.005-0.056	0.021	Objectives met
		Fall	<0.005-0.121	0.054	
Nitrite-N (mg/L) 0.2 mg/L average 0.6 mg/L maximum (when chloride >10 mg/L)	Upstream (0300066)	Summer	<0.002-0.002	0.002	Objectives met
		Fall	0.004-0.02	0.011	
	Downstream (0300065)	Summer	0.004-0.009	0.006	Objectives met
		Fall	0.010-0.014	0.012	
	Near mouth (E262901)	Summer	0.002-0.017	0.007	Objectives met
		Fall	0.003-0.017	0.010	
pH 6.5 to 8.5	Upstream (0300066)	Summer	6.8-7.9	7.4	Objective met
		Fall	7.1-7.5	7.3	
	Downstream (0300065)	Summer	7.7-8.6	8.2	Objective not met Aug 5, 19
		Fall	7.3-8.1	7.7	Objective met
	Near mouth (E262901)	Summer	7.4-8.9	8.1	Objective not met Aug 19
		Fall	7.0-7.7	7.3	Objective met

Notes: Summer samples collected August 5, 12, 19, 26 & September 2 (n=5); winter samples collected October 27 & November 3, 10, 17 & 24 (n=5); values in red exceed objectives.

2.6.2.4 Suspended Solids

The objective for suspended solids in the Little Campbell River is a 10 mg/L maximum increase over upstream concentrations when upstream levels are ≤100 mg/L. In 2009, this objective was met at both downstream sites during summer sampling (Table 4). However, during fall sampling this objective was not met at the downstream site (0300065) on one occasion, with a maximal increase of 15 mg/L, and near the mouth on three occasions, with maximal increases of 21-48 mg/L (Table 4). Some improvements have been observed over previous attainment monitoring results at the downstream site (0300065), where objectives were exceeded 50% of the time in 1988, 1989, and 1990

(Table 5). Sources of suspended solids can be from diffuse stormwater, construction activities and agricultural runoff.

2.6.2.5 Turbidity

The objective for turbidity in the Little Campbell River is a 5 NTU maximum increase over upstream levels when upstream levels are ≤50 NTU. In 2009, this objective was met at both downstream sites during summer sampling (Table 4). However, during fall sampling this objective was not met at both downstream sites on four occasions, with maximal increases of 7-23 NTU (Table 4). As with suspended solids, these increases may originate from diffuse stormwater, construction activities and agricultural sources. Turbidity data are not available for comparison from previous sampling efforts, but should continue to be monitored in the future.

2.6.2.6 Dissolved Oxygen

The objectives for dissolved oxygen (DO) in the Little Campbell River are a minimum of 6.0 mg/L (and long-term minimum objective of 8.0 mg/L) from June-October, or a minimum of 11.0 mg/L when salmonid eggs, larvae or alevin are present. In 2009, the latter objective was applied to the fall data since salmon spawn in October and November. In 2009, these objectives were not met on any date at the upstream location, with DO values ranging from 0.1 to 4.7 mg/L in both seasons (0300066, Table 4).

The upstream site also failed to meet these objectives 80-100% of the time during attainment monitoring from 1988 to 2002. This is in contrast with the downstream site (0300065), which consistently met DO objectives between 1971 and 2002 (Table 5). However, in the fall of 2009, DO objectives were not met on any occasion, with levels ranging from 3.0-6.3 mg/L (Table 4). Near the mouth (E262901), DO levels were higher in the summer (4.9-12.6 mg/L) but were also low in November (2.6-6.5 mg/L). Such depressions of oxygen during first flush periods may be caused by diffuse sources of oxygen-demanding substances from both natural and agricultural sources. This is of particular concern for aquatic life, which require high DO levels in the fall when spawning. The cause of the historically poor DO conditions at the upstream site is also likely related to the very low flow conditions at the upstream site.

2.6.2.7 Lead

While objectives for lead were not set for the Little Campbell River in 1988, historical and 2009 results are included in Table 5 for reference purposes (raw data in Appendix C). While high detection limits made accurate quantification of lead concentrations difficult in the past, there appears to have been an improvement in lead levels since 1983 (Table 5). Additionally, current lead levels are similar to those found in 2002 and meet objectives set for the Nicomekl River. This suggests adequate protection of water quality, in terms of lead contamination, at the present time.

2.6.3 *Water Quality Index Rating*

In 2009, the CCME Water Quality Index (WQI) rating was Fair (index=65) during **fall** sampling in the **Little Campbell River** (LCR). This is an improvement over the Marginal rating found in 2002 (index=52). It is interesting to note that the 2009 **summer** rating was also Marginal (index=53). The poor 2002 and 2009 ratings were largely influenced by extremely poor dissolved oxygen (DO) conditions at the upstream site. WQI ratings were also calculated using both short- and long-term objectives, which were generally lower than using only short-term objectives as the long-term minimum DO objective is even higher (see Appendix G). It should be noted that uses for recreation, irrigation, and livestock watering would likely be protected and suitable at both sites since dissolved oxygen is mainly required for aquatic life.

Table 4 Water quality objectives attainment in the Little Campbell River (suspended solids, turbidity, dissolved oxygen & lead) – 2009

Variable & Objective	Site	Season	Range	Mean (n=5)	Conclusion
Suspended solids (mg/L) <10 mg/L increase when upstream ≤100 mg/L (10% maximum increase when upstream >100 mg/L)	Upstream (0300066)	Summer	25-37	30	Upstream reference site
		Fall	<1-5	2	
	Downstream (0300065)	Summer	2-4	2	Objective met
		Fall	3-20	8	Objective not met Nov 17 (increase of 15 mg/L)
	Near mouth (E262901)	Summer	4-12	7	Objective met
		Fall	5-49	23	Objective not met Oct 27, Nov 10, 17 (increases of 48, 21, 25 mg/L respectively)
Turbidity (NTU) ≤5 NTU increase when upstream ≤50 NTU (10% maximum increase when upstream >50 NTU)	Upstream (0300066)	Summer	29.7-47.7	37.3	Upstream reference site
		Fall	1.4-7.7	3.7	
	Downstream (0300065)	Summer	2.0-3.5	2.7	Objective met
		Fall	5.7-26.1	11.7	Objective not met Oct 27, Nov 17, 24 (increases of 8, 22, 7 NTU respectively)
	Near mouth (E262901)	Summer	2.6-5.5	3.9	Objective met
		Fall	4.6-27.2	13.6	Objective not met Oct 27, Nov 10, 17, 24 (increases of 15, 7, 23, 7 NTU respectively)
Dissolved Oxygen (mg/L) 6 mg/L minimum 8 mg/L minimum (long-term) Jun-Oct 11 mg/L minimum when eggs present	Upstream (0300066)	Summer	0.1-0.3	0.2	6 mg/L minimum objective not met all dates
		Fall	1.8-4.7	3.2	11 mg/L objective not met all dates
	Downstream (0300065)	Summer	5.4-7.1	6.4	6 mg/L objective not met Aug 12, 26
		Fall	3.0-6.3	4.9	11 mg/L objective not met all dates
	Near mouth (E262901)	Summer	4.9-12.6	8.7	6 mg/L objective not met Aug 26
		Fall	2.6-6.5	4.2	11 mg/L objective not met all dates
Lead (µg/L) 5 µg/L average 10 µg/L maximum (Nicomekl River objective – for reference only)	Upstream (0300066)	Summer	0.023-0.199	0.088	For reference purposes
		Fall	0.080-0.337	0.186	
	Downstream (0300065)	Summer	0.028-0.066	0.048	
		Fall	0.118-0.374	0.197	
	Near mouth (E262901)	Summer	0.10-0.42	0.2	
		Fall	0.18-0.58	0.4	

Notes: Summer samples collected August 5, 12, 19, 26 & September 2 (n=5); winter samples collected October 27 & November 3, 10, 17 & 24 (n=5)

Table 5 Comparison of Little Campbell River water quality indicators from 1971 to 2009

Variable & Objective	Site	1971-1983	1988-1990	1999-2000	2002 (Fall)	2009 (Fall)	Conclusion
Ammonia-N (mg/L)	Upstream 0300066	<0.01 – 0.389 ave = 0.071 (n=34)	<0.005 – 0.038 ave = 0.019 (n=18)	<0.005 – 0.064 ave = 0.023 (n=7)	<0.005 – 0.027 ave = 0.01 (n=5)	<0.005 – 0.04 ave = 0.018 (n=5)	Conditions improving & stable
	Down-stream 0300065	<0.01 – 0.32 ave = 0.078 (n=33)	<0.005 – 0.141 ave = 0.057 (n=18)	0.014 – 0.039 ave = 0.02 (n=6)	<0.005 – 0.027 ave = 0.01 (n=5)	0.007 – 0.033 ave = 0.019 (n=5)	
Nitrite-N (mg/L) 0.2 mg/L average 0.6 mg/L maximum (when chloride >10 mg/L)	Upstream 0300066	<0.005 – 0.024 ave = 0.008 (n=39)	<0.005 – 0.008 ave = 0.006 (n=18)	<0.002 – 0.006 ave = 0.004 (n=7)	<0.002 – 0.011 ave = 0.005 (n=5)	0.004 – 0.02 ave = 0.011 (n=5)	Conditions adequate & stable
	Down-stream 0300065	<0.005 – 0.036 ave = 0.013 (n=38)	<0.005 – 0.032 ave = 0.017 (n=18)	0.007 – 0.026 ave = 0.02 (n=6)	0.01 – 0.025 ave = 0.019 (n=5)	0.01 – 0.014 ave = 0.012 (n=5)	
Suspended solids (mg/L) <10 mg/L increase when upstream ≤100 mg/L	Upstream 0300066	1 – 48 ave = 10 (n=37)	1 – 201 ave = 27 (n=17)	<5 – 21 ave = 9 (n=7)	2 – 8 ave = 5 (n=5)	<1 – 5 ave = 2 (n=5)	Upstream reference site
	Down-stream 0300065	2 – 78 ave = 16 **(max inc 2–76 mg/L**, n=35**)**	3 – 46 ave = 18 **(max inc 13–27 mg/L**, n=17**)**	<5 – 10 ave = 7 (max inc 2 – 3 mg/L, n=5)	1 – 11 ave = 4 (max inc 9 mg/L, n=5)	3 – 20 ave = 8 **(max inc 15 mg/L,** n=5**)**	Some improvement since 1990
	Near mouth E262901	n/a	n/a	n/a	n/a	5 – 49 ave = 23 **(max inc 21-48 mg/L,** n=5**)**	Objective not met
Turbidity (NTU) <5 NTU increase when upstream ≤50 NTU	Upstream 0300066					1.4 – 7.7 ave = 3.7 (n=5)	Upstream reference site
	Down-stream 0300065					5.7 – 26.1 ave = 11.7 **(max inc 5-22 NTU,** n=5**)**	Objective not met
	Near mouth E262901					4.6 – 27.2 ave = 13.6 **(max inc 7-23 NTU,** n=5**)**	Objective not met
Dissolved Oxygen (mg/L) 6 mg/L minimum **Long-term** 8 mg/L minimum	Upstream 0300066	**2.3 – 13.1** ave = 6.48 (n=38)	**1.3 – 6.5** (n=20)	**0.25 – 7.1 ave = 2.8** (n=7)	**0.12 – 3.15 ave = 1.14** (n=5)	**1.8 – 4.7 ave = 3.2** (n=5)	Conditions poor but improving
	Down-stream 0300065	8.1 – 14.2 ave = 10.65 (n=36)	6.1 – 11.4 (n=20)	8.5 – 11.8 ave = 9.85 (n=6)	9.1 – 13.1 ave = 10.9 (n=5)	**3.0 –** 6.3 ave = 4.9 (n=5)	Conditions deteriorated in 2009
pH 6.5 to 8.5	Upstream 0300066	**6.3** – 7.6 (n=39)	6.5 – 7.5 (n=10)	6.65 – 7.32 (n=7)	6.7 – 7.6 (n=5)	7.1 – 7.5 (n=5)	Conditions good & stable
	Down-stream 0300065	6.9 – 8.6 (n=38)	7.1 – 7.8 (n=10)	7.29 – 7.79 (n=5)	7.4 – 8 (n=5)	7.3 – 8.1 (n=5)	
Total Lead (µg/L) ≤5 µg/L average 10 µg/L maximum (Nicomekl R objectives)	Upstream 0300066	<1 – 18 **ave = 3** (n=22)	n/a	0.34 (n=1) Oct 12/00	0.04 – 0.19 ave = 0.11 (n=5)	0.08 – 0.34 ave = 0.19 (n=5)	Conditions adequate & stable since 2000 (for reference purposes)
	Down-stream 0300065	<1 – 4 ave = 2 (n=29)	n/a	0.09 (n=1) Oct 12/00	0.07 – 0.22 ave = 0.14 (n=5)	0.12 – 0.37 ave = 0.20 (n=5)	

Notes: Values include: range, median (med) and geometric mean (gm), where applicable; results that exceeded objectives are in bold.

3.0 NICOMEKL RIVER

3.1 Overview

The Nicomekl River is approximately 34 km long and extends from Clayton and Langley to Mud Bay (MEP, 1988a; Figure 1). This 149 km^2 drainage basin includes two major tributaries, Anderson and Murray Creeks, which are approximately 15 km and 12 km in length, respectively. In 1988, objectives were developed to protect water uses in the Nicomekl River for aquatic life, irrigation, livestock watering, and wildlife (MEP, 1988a). In subsequent attainment monitoring from 1988 to 1992, objectives for fecal coliforms, suspended solids, nitrite, dissolved oxygen (DO), and pH were not met at times in the Nicomekl main stem. In the tributaries, objectives for fecal coliforms and suspended solids were exceeded in only Murray Creek in 1988 and 1989. In 2002, most objectives were met except for DO on a few occasions when the higher minimum objective of 11 mg/L was applied to fall data (MWLAP, 2003). Since objectives have not been checked in the Nicomekl River and its tributaries since 2002, it was a priority to monitor these objectives in 2009. Additional sampling was conducted in 1999 and 2000, which will also be included in this report.

3.2 Water Uses

Historically, water was withdrawn from the Nicomekl River for irrigation, livestock watering, land improvement (pond construction), drinking water, and industrial use (MEP, 1988a). Currently, water is withdrawn mainly for irrigation of field crops, as well as for ponds for floating logs, fish culture, or fur farming (see Appendix H). Steelhead and cutthroat trout use the river system and coho salmon spawn in the upper reaches and tributaries (MEP, 1988a). There is also a fish hatchery on the river (at 232nd St. in Langley), operated by the Nicomekl Enhancement Society since 1992, which withdraws water directly from, and discharges wastewater back to, the Nicomekl River. There is currently no primary-contact recreation in the Nicomekl River.

3.3 Potential Sources of Contamination

Historically, ten operations had permits to discharge effluents within the Nicomekl River sub-basin (MEP, 1988a). These included agricultural operations, industrial operations, gravel washing operations, schools, and residential facilities. The closed City of Langley landfill (PR 1898) was also a known contaminant source to Pleasantdale Creek, a tributary of the Nicomekl River. Although a leachate collection system was installed, site inspections in the 1990's suggested that the creek was still receiving some landfill leachate flow. Currently, there are five permit-holders within the basin, including a mobile home park, two schools, a concrete ready-mix batch plant, and a polystyrene foam manufacturing plant.

The mobile home park, owned by 405834 B.C. Ltd. (PE 218); Noel Booth Elementary School (PE 6323); and Brookswood Junior Secondary School (PE 3148) hold permits allowing for the discharge of treated domestic sewage to tile fields, which are near to tributaries joining the Nicomekl River. The mobile home park, a permit-holder since 1968, discharges effluent to tile fields that are very close to two small tributaries to Anderson Creek, Krawse and MacPherson Creeks. The tile fields at Noel Booth School, a permit-holder since 1981, are approximately 100m from Anderson Creek, while the tile fields at Brookswood School (permit first issued in 1974) are very near to a small tributary to Murray Creek. The potential for contamination of water quality in these tributaries and to the Nicomekl River from these point source discharges to land is unknown.

Mansonville Plastics Ltd. (PE 4413), a polystyrene foam manufacturing plant, holds a permit allowing for discharge of uncontaminated cooling water (≤32ºC) to a ditch flowing to the Nicomekl River, as well as to the land. The permit, first issued in 1976, also allows for effluent discharge from boiler blowdown to a steel tank in a gravel pit. The concrete ready-mix batch plant, owned by Rempel Bros. Concrete Ltd. (PE 11370), has held a permit since 1994 allowing for discharge of two types of effluent. Excess process and stormwater is discharged to the ground, after pH adjustment, while stormwater from non-process areas of the site is discharged to a municipal ditch and eventually to Logan Creek, a tributary to the Nicomekl River. The discharges from this plant are within 500 m of one Nicomekl tributary and within 800 m of another.

Potential contamination from diffuse sources within the Nicomekl watershed, include those from agriculture, septic tank tile fields, and from urban stormwater runoff from the City of Langley area (MEP, 1988a). Contaminants from septic fields include nutrients and fecal coliforms, while stormwater can be a potential source of metals (e.g. lead and zinc) and fecal coliforms (MEP, 1988a).

3.4 Methodology

3.4.1 Field Methodology

On the Nicomekl River, three locations were sampled on the main stem, as well as one location each on Murray Creek and Anderson Creek (Figure 1). Data are generally available for these sites since 1972. Sites on the Nicomekl River (Figure 3) include an upstream site (EMS 0300062), a midstream site (EMS 0300061), and downstream site near the mouth (EMS 0300060), as well as sites in Murray Creek (EMS 0300064) and Anderson Creek (EMS 0300063).

Sampling in 2009 was carried out five times in 30 days in both the dry summer period (August 5, 12, 19, 26 and September 2) and wet fall period (October 27, November 3, 10, 17 and 24). This time period thus included sampling before and after the first flush events in 2009, on October 25 and 29/30 (see Appendix B). Bacteriological indicators monitored included fecal coliforms, *E. coli* and enterococci. Water quality indicators

included suspended solids, turbidity, ammonia, nitrate, nitrite and lead. Field measurements were taken at the surface with a calibrated YSI 556 Multi Probe System (YSI Environmental) and included water temperature, dissolved oxygen, pH and specific conductance. Photographs of the sampling sites were taken on November 21, 2002. Precipitation data from a weather station at the Vancouver International Airport was obtained from Environment Canada for the 2009 sampling periods.

Nicomekl River at 64th Ave (upstream site, 0300062)

Nicomekl River at 192nd St (midstream site, 0300061)

Nicomekl River at Hwy 99A (downstream site, 0300060)

Anderson Creek at Colebrook Rd (0300063)

Murray Creek at 48th Ave (0300064)

Figure 3 Nicomekl River sampling sites

Grab samples were collected at the surface, facing upstream, using high-density polyethylene bottles for both bacteriological and water chemistry samples. Water samples for metals analysis were preserved by Maxxam Analytics upon delivery of the samples. Field sampling quality control was addressed by including blind field and trip blank samples, and by collecting blind triplicate samples at one site on each sampling date (see Appendix F). Field blanks are intended to capture sampler errors when collecting water in the field, while trip blanks are intended to capture sample bottle or deionized water contamination. Blind replicates are intended to assess lab analytical precision. Samples were kept on ice in a cooler during overnight delivery to CANTEST Ltd. (bacteriological samples) or Maxxam Analytics (chemistry samples).

3.4.2 Laboratory Methodology

The laboratories followed analytical procedures according to the British Columbia Environmental Laboratory Manual for the Analysis of Water, Wastewater, Sediment and Biological Materials (MOELP, 1994). They also employed quality assurance and control procedures, including method blanks, duplicates, and spike recoveries. These reports are available upon request.

3.5 Results and Statistical Analysis

Bacteriological and water chemistry data for 2009 have been summarized in Tables 6, 8 and 9, respectively. A comparison of results with 1972-1983, 1988-1990, 1999-2000, and 2002 sampling periods are presented in Tables 7, 10 and 11. Raw field and water quality data are shown in Appendix D. The geometric mean was obtained for bacteriological results, with the requirement that at least five samples were collected within 30 days (MEP, 1988c). For sites with triplicate results, the median was used for data analysis to reduce bias. The range and average were calculated for chemical parameters and metals. As sampling strategies changed from quarterly sampling in the 1970's and 1980's, to targeted five-week sampling in the 1990's and beyond, the statistical validity of trends could not be determined. Readily apparent trends were still, however noted.

The Water Quality Index was calculated as described in CCME (2001). The factors used in the index are based on results of water quality objectives attainment and include; F_1 (Scope), the number of objectives not met; F_2 (Frequency), the frequency with which objectives are not met; and F_3 (Amplitude), the amount by which objectives are not met. Appendix G gives numerical ranges for the rankings and descriptions of the rankings, as well as 2002 and 2009 findings. Since the CCME index was adapted from the BC Ministry of Environment, Lands and Parks index, the same conditions regarding data use were applied (MOELP, 1995). Some of these conditions include omitting incomplete monitoring results and using results from short-term objectives only (MOELP, 1995).

3.6 Discussion

3.6.1 Bacteriological Indicators

While bacteriological objectives were set for only fecal coliforms in 1988, it is appropriate to also use the provincial criteria for *E. coli* levels since, as previously stated, these bacteria are considered to be better indicators of gastrointestinal disease. The objectives for fecal coliforms, and provincial criteria for *E. coli* and enterococci, in the Nicomekl River system are based on irrigation criteria:

- **Fecal coliforms** (objectives) – geometric mean (geomean) of ≤1000/100 mL and maximum of ≤4000/100 mL (Apr-Oct), with a long-term objective of ≤200/100 mL (year round, geomean)
- ***E. coli*** (provincial standards) – geometric means of ≤77/100 mL (irrigation, crops eaten raw), ≤385/100 mL (irrigation, public/livestock access), ≤1000/100 mL (irrigation, general)
- **Enterococci** (provincial standards) – geometric mean of ≤20/100 mL (irrigation, crops eaten raw), ≤100/100 mL (irrigation, public/livestock access), ≤250/100 mL (irrigation, general)

In 2009, objectives for **fecal coliforms**, applied to summer data, were met at all the sites sampled in the Nicomekl River and its tributaries (Table 6). However, the year round long-term objective was only met in the summer in Anderson Creek and in two main stem sites (upstream and near the mouth). The long-term objective was met at all sites in 2002, indicating a worsening of conditions in both tributaries and the midstream Nicomekl site.

The ***E. coli*** provincial criterion for irrigation was exceeded at all Nicomekl River sites in 2009 during fall sampling (geomeans of 169-317 CFU/100 mL), and at most sites during summer sampling (geomeans of 14-405 CFU/100 mL), when the most stringent criterion for crops eaten raw was applied (Table 6). However, less stringent irrigation criteria were met at all sites during both seasons. The **enterococci** provincial criterion for irrigation (crops eaten raw) was also exceeded near the mouth in 2009, although this was the only site sampled.

Since 1983, there has been general improvement in bacteriological conditions in the Nicomekl River, both up- and downstream (Table 7). However, bacteriological conditions appear to have degraded at the midstream Nicomekl River site and in the Murray and Anderson Creek tributaries compared to 2002. This is cause for concern and may indicate poor control of non-point source agricultural releases.

Table 6 Bacteriological objectives attainment in the Nicomekl River and its tributaries - 2009

Variable & Objective	Site	Season	Range	Geometric mean (n=5)	Conclusion
Fecal coliforms (CFU/100 mL) gm ≤1000/100 mL max ≤4000/100 mL Apr-Oct **Long-term** ≤200/100 mL geometric mean (year round)	Murray Cr (0300064) - tributary	Summer	94-1,500	293	Long-term objective not met
		Fall	47-1,100	238	
	Anderson Cr (0300063) - tributary	Summer	130-290	192	Objectives met
		Fall	23-980	206	Long-term objective not met
	Upstream (0300062)	Summer	84-440	176	Objectives met
		Fall	130-1,900	361	Long-term objective not met
	Midstream (0300061)	Summer	290-1,300	641	
		Fall	270-1,200	478	
	Near mouth (0300060)	Summer	29-320	111	Objectives met
		Fall	130-1,400	394	Long-term objective not met
Escherichia coli (E. coli) (CFU/100 mL) gm ≤77/100 mL (irrigation criterion, crops eaten raw)	Murray Cr (0300064) - tributary	Summer	37-1,500	131	Provincial criterion not met
		Fall	40-700	200	
	Anderson Cr (0300063) - tributary	Summer	35-240	131	
		Fall	17-660	169	
	Upstream (0300062)	Summer	40-430	72	Provincial criterion met
		Fall	89-710	259	Provincial criterion not met
	Midstream (0300061)	Summer	230-1,300	405	
		Fall	120-880	317	
	Near mouth (0300060)	Summer	4-160	14	Provincial criterion met
		Fall	80-880	268	Provincial criterion not met
Enterococci (CFU/100 mL) gm ≤20/100 mL (irrigation criterion, crops eaten raw)	Near mouth (0300060)	Summer	2-76	12	Provincial criterion not met
		Fall	100-2,100	637	

Notes: Summer samples collected August 5, 12, 19, 26 & September 2 (n=5); winter samples collected October 27 & November 3, 10, 17 & 24 (n=5); gm is geometric mean, 90th is 90th percentile; fecal coliform geometric mean objectives applied to summer samples only as fall samples collected in November.

3.6.2 Water Quality Indicators

3.6.2.1 Ammonia

The ammonia-nitrogen(N) objectives to protect aquatic life in the Nicomekl River and its tributariesare an average 30-day and maximum concentration dependent on pH and temperature, where ammonia toxicity increases with increasing temperature and pH. In 2009, the lowest criteria for all of the Nicomekl sites in summer (fall), to which all results were compared, were an average and maximum ammonia-N concentration of 0.21 mg/L (1.62 mg/L) and 1.57 mg/L (8.4 mg/L), respectively (MOE, 2006). These objectives were met for all sites, on all dates sampled in 2009, with results well below the stated criteria (Table 8). Objectives for ammonia-N concentrations have also been met in previous attainment monitoring efforts from 1988 to 2002. Ammonia-N conditions have generally improved in the Nicomekl River main stem and in Murray Creek since 1990, while ammonia levels have remained fairly stable and relatively low in Anderson Creek over the past 30 years (Table 10).

Table 7 Comparison of bacteriological indicators in the Nicomekl River and its tributaries from 1972 to 2009

Variable & Objective	Site	1973-1983[a]	1988-1990	1999-2000	2002	2009 (Summer only)	Conclusion
Fecal coliforms (colonies/100 mL) ≤1000/100 mL geometric mean ≤4000/100 mL Maximum (Apr-Oct) **Long-term** ≤200/100 mL geometric mean (year round)	Murray Cr (0300064) - tributary	79 – >2400 *med = 350* (n=21)	12 – 3500 *med = 305* **gm^1 = 292** **gm^2 * = 149** **gm^3 * = 819** **gm^4 = 226** (n=18)	6 – 120 *med = 63* (n=6)	17 – 140 *med = 34* **gm = 43** (n=5)	94 – 1500 *med = 250* **gm = 293** (n=5)	Degradation since 2002
	Anderson Cr (0300063) - tributary	14 – 1600 *med = 175* (n=20)	78 – 575 *med = 160* **gm^1 = 218** **gm^2 = 182** **gm^3 * = 211** **gm^4 = 179** (n=19)	24 – 160 *med = 77* (n=7)	34 - 190 *med = 50* **gm = 57** (n=5)	130 - 290 *med = 190* **gm = 192** (n=5)	Degradation since 2002
	Nicomekl (0300062) Upstream	207 – >2400 *med = 920* (n=47)	<2 – 18400 *med = 450* **gm^1 = 220** **gm^2 = 201** **gm^3 * = 760** **gm^4 = 895** (n=19)	<1 – 3400 *med = 160* (n=6)	58 – 220 *med = 89* **gm = 102** (n=5)	84 – 440 *med = 150* **gm = 176** (n=5)	Significant improvement (since 1990)
	Nicomekl (0300061) Midstream	50 – **9200** *med = 790* (n=45)	n/a	93 – 1100 *med = 220* (n=6)	67 – 350 *med = 120* **gm = 147** (n=5)	290 – 1300 *med = 670* **gm = 641** (n=5)	Degradation since 2002
	Nicomekl (0300060) Near mouth	<2 – **9200** *med = 95* (n=38)	2 – 3100 *med = 158* **gm^1 = 375** **gm^2 = 45** **gm^3 * = 390** **gm^4 = 249** (n=19)	1 – 120 *med = 19* (n=6)	17 – 1000 *med = 65* **gm = 80** (n=5)	29 – 320 *med = 220* **gm = 111** (n=5)	General improvement (since 1983)

Notes: Values include range, median (*med*), and geometric mean (gm) where applicable; results that exceeded long-term objectives are in red; gm^1 is the 1988 geometric mean (Oct 19 to Nov 17); gm^2 is the first 1989 geometric mean (Sept 25 to Oct23); gm^3 is the second 1989 geometric mean (Oct 30 to Nov 27); gm^4 is the 1990 geometric mean (Sept 25 to Oct 23); gm^{n}* indicates a geometric mean of 4 results; [a] Results taken from tabulated data (MEP, 1988a)

3.6.2.2 Nitrite

Objectives for nitrite-nitrogen(N) in the Nicomekl River, set to protect aquatic life, are an average 30-day and maximum concentration dependent on chloride concentration. The 0.20 mg/L (30-day average) and 0.60 mg/L (maximum) nitrite-N criteria were used, based on chloride concentrations >10 mg/L (see chloride table in Appendix A). These objectives were met for all sites, on all dates sampled in 2009 (Table 8). Nitrite-N conditions have been fairly stable and relatively low in the Nicomekl main stem and in its tributaries over the last 40 years (Table 10).

Table 8 Water quality objectives attainment in the Nicomekl River and its tributaries (ammonia, nitrite & pH) – 2009

Variable & Objective	Site	Season	Range	Mean (n=5)	Conclusion
Ammonia-N (mg/L) 0.21 mg/L (summer) & 1.62 mg/L (fall) average 1.57 mg/L (summer) & 8.4 mg/L (fall) maximum	Murray Cr (0300064)	Summer	<0.005-0.016	0.007	Objective met
		Fall	<0.005-0.043	0.018	
	Anderson Cr (0300063)	Summer	all <0.005	<0.005	
		Fall	0.010-0.041	0.020	
	Upstream (0300062)	Summer	<0.005-0.019	0.008	Objective met
		Fall	0.019-0.066	0.033	
	Midstream (0300061)	Summer	<0.005-0.038	0.012	
		Fall	<0.005-0.032	0.016	
	Near mouth (0300060)	Summer	<0.005-0.176	0.066	
		Fall	0.057-0.153	0.094	
Nitrite-N (mg/L) 0.2 mg/L average 0.6 mg/L maximum (when chloride >10 mg/L)	Murray Cr (0300064)	Summer	0.004-0.016	0.008	Objective met
		Fall	0.010-0.016	0.012	
	Anderson Cr (0300063)	Summer	<0.002-0.007	0.005	
		Fall	0.013-0.023	0.018	
	Upstream (0300062)	Summer	0.004-0.007	0.006	Objective met
		Fall	0.006-0.018	0.014	
	Midstream (0300061)	Summer	0.008-0.015	0.012	
		Fall	0.012-0.020	0.016	
	Near mouth (0300060)	Summer	<0.002-0.033	0.017	
		Fall	0.010-0.041	0.022	
pH 6.5 to 8.5 0.2 maximum increase when upstream <8.5	Murray Cr (0300064)	Summer	7.7-8.1	7.9	Objective met
		Fall	7.3-7.8	7.5	
	Anderson Cr (0300063)	Summer	7.8-8.1	7.9	
		Fall	7.3-7.7	7.4	
	Upstream (0300062)	Summer	7.7-8.0	7.8	Objective met
		Fall	7.4-7.6	7.5	
	Midstream (0300061)	Summer	7.7-8.1	7.9	
		Fall	7.1-7.6	7.3	
	Near mouth (0300060)	Summer	7.7-8.6	8.1	
		Fall	7.4-7.8	7.5	

Notes: Summer samples collected August 5, 12, 19, 26 & September 2 (n=5); winter samples collected October 27 & November 3, 10, 17 & 24 (n=5)

3.6.2.3 pH

The objective range for pH in the Nicomekl River and its tributaries is 6.5 to 8.5. An additional objective is a 0.2 maximum increase when the upstream pH is <8.5. The pH range objective was met for all sites and seasons sampled in 2009 (Table 8). However, there was one maximum increase exceedence at the downstream site (0300060) on November 17, when the pH increased 0.3 units. Since 1988, pH conditions have been relatively stable or have shown slight improvements, particularly in minimum pH values, at both the mid- and downstream main stem sites (Table 10). Conditions have also remained relatively stable in Anderson and Murray Creeks over the past 40 years.

3.6.2.4 Suspended Solids

The objective for suspended solids in the Nicomekl River is a 10 mg/L maximum increase over upstream concentrations when upstream suspended solids are ≤100 mg/L. In 2009, this objective was met on all dates at the midstream site (0300061), but was not met on one occasion during each season at the downstream site (0300060). Maximal increases of 11 mg/L on both occasions slightly exceeded the objective (Table 9). This is an improvement over previous attainment monitoring results where objectives were exceeded by larger amounts at the downstream site during the 1988-90 and 1999-00 sampling periods (Table 11).

Suspended solid concentrations have remained below objectives at the midstream Nicomekl site since the 1999-00 sampling period (Table 11). It should be noted, however, that the highest suspended solid levels were observed in Anderson Creek, where conditions have historically been relatively low. Murray Creek recorded elevated suspended solids levels in the 1988-90 sampling effort but has been relatively stable since 1999. This may merit further study, and should include both up- and downstream sites so that objectives can be applied.

3.6.2.5 Turbidity

The objective for turbidity in the Nicomekl River is a 5 NTU maximum increase over upstream levels when upstream levels are ≤50 NTU. In 2009, this objective was only met at the midstream site (0300061) in the summer, while slight exceedences of 6-15 NTU were recorded at the downstream site (0300060) during both seasons (Table 9). The objective was also not met on one occasion at the midstream site during fall sampling, although the increase was minimal (6 NTU). As with suspended solids, these increases likely originate from diffuse stormwater and agricultural sources. Turbidity data were not available for comparison from previous sampling efforts, but should continue to be monitored in the future.

3.6.2.6 Dissolved Oxygen

The objectives for dissolved oxygen (DO) in the Nicomekl River are a minimum of 6.0 mg/L (long-term minimum objective of 8.0 mg/L) from June-October, or a minimum of 11.0 mg/L when salmonid eggs, larvae or alevin are present (i.e. fall). Similarly, the objectives for Murray and Anderson Creeks are a minimum DO of 8.0 mg/L, or a minimum of 11.0 mg/L when salmonid eggs, larvae or alevin are present (i.e. fall). Thus, in 2009, the relevant objectives were applied depending on the season.

As in 2002, objectives were not met during 2009 fall sampling in the Nicomekl main stem, although DO values were considerably lower in 2009 (2.6-6.9 mg/L, Table 9). DO levels were also low in the tributaries in the fall (3.1-6.8 mg/L) and did not meet the 11 mg/L minimum objective on any date in 2009. DO levels were higher during 2009 summer sampling, where objectives were met in the main stem and in Anderson Creek,

but not in Murray Creek (6.5-9.4 mg/L). The tributaries consistently met higher DO objectives in previous attainment monitoring and DO conditions were fairly stable at the mid- and upstream Nicomekl sites, as well as the tributaries until 2002 (Table 11). The reasons for the degraded conditions observed during the fall first flush period of 2009 are unclear but merit concern for possible further study.

3.6.2.7 Lead

Objectives for total lead were set for only the Nicomekl River main stem in 1988, and are a 30-day mean of ≤5 µg/L and a maximum of 10 µg/L. Lead objectives were met in 2009 for the three sites sampled on the Nicomekl main stem (Table 9). These objectives have also been met in previous attainment monitoring from 1988-90 and 2002. While high detection limits made accurate quantification of lead concentrations difficult in the past, lead levels appear to be relatively low and stable in the Nicomekl River (Table 11). Current lead levels in Murray and Anderson Creeks are also meeting objectives set for the Nicomekl main stem.

3.6.3 Water Quality Index Rating

In 2009, the calculated CCME Water Quality Index (WQI) ratings for the **Nicomekl River, Murray Creek and Anderson Creek** were Fair during **fall** sampling, with values of 77, 79 and 79, respectively. This is a decline from 2002, when ratings were Good for all three waterbodies (values of 91 each), indicating deteriorating conditions (see Appendix G). During **summer** sampling, the WQI ratings were considerably higher, with values of 81 (Nicomekl), 89 (Murray) and 100 (Anderson). The 2009 fall index value was particularly influenced by low DO at all sites (2.6-6.9 mg/L), which was compared to the DO objective of 11 mg/L when salmonid eggs, larvae or alevin are present, i.e. during the fall period. While conditions in this river system did not appear to be protective enough of aquatic life during the first flush period in 2009, it may still be considered suitable for aquatic life at other times of the year, as well as for irrigation and livestock watering uses.

Table 9 Water quality objectives attainment in the Nicomekl River and its tributaries (suspended solids, turbidity, dissolved oxygen & lead) – 2009

Variable & Objective	Site	Season	Range	Mean (n=5)	Conclusion
Suspended solids (mg/L) <10 mg/L increase when upstream ≤100 mg/L (10% maximum increase when upstream >100 mg/L)	Murray Cr (0300064)	Summer	1-6	3	Tributary conditions
		Fall	5-52	16	
	Anderson Cr (0300063)	Summer	<1-1	1	Tributary conditions
		Fall	1-65	22	
	Upstream (0300062)	Summer	3-4	2.6	Upstream reference site
		Fall	<1-37	12.2	
	Midstream (0300061)	Summer	3-7	4	Objective met
		Fall	8-31	15	
	Near mouth (0300060)	Summer	6-14	11	Objective not met Aug 12 (increase of 11 mg/L)
		Fall	10-25	15	Objective not met Nov 3 (increase of 11 mg/L)
Turbidity (NTU) ≤5 NTU increase when upstream ≤50 NTU (10% maximum increase when upstream >50 NTU)	Murray Cr (0300064)	Summer	1.4-7.1	2.8	Tributary conditions
		Fall	8.3-27.1	13.6	
	Anderson Cr (0300063)	Summer	0.5-0.9	0.7	Tributary conditions
		Fall	1.3-19.2	8.2	
	Upstream (0300062)	Summer	3.1-3.7	3.4	Upstream reference site
		Fall	1.2-31.2	13.6	
	Midstream (0300061)	Summer	2.1-4.4	3.0	Objective met
		Fall	6.9-35.1	16.3	Objective not met Nov 3 (increase of 6 NTU)
	Near mouth (0300060)	Summer	6.3-11.9	8.4	Objective not met Aug 5 & 19 (increases of 9 & 6 NTU respectively)
		Fall	13.4-28.9	19.2	Objective not met Oct 27 & Nov 3 (increases of 9 & 15 NTU respectively)
Dissolved Oxygen (mg/L) 6 mg/L minimum 8 mg/L minimum (long-term) Jun-Oct 11 mg/L minimum when eggs present	Murray Cr (0300064)	Summer	6.5-9.4	7.6	6 mg/L minimum objective met
		Fall	3.1-6.8	5.3	11 mg/L objective not met any date
	Anderson Cr (0300063)	Summer	8.9-10.4	9.6	8 mg/L minimum long-term objective met
		Fall	3.4-6.4	5.2	11 mg/L objective not met any date
	Upstream (0300062)	Summer	6.6-8.0	7.2	6 mg/L minimum objective met
		Fall	2.8-5.8	4.7	11 mg/L objective not met any date
	Midstream (0300061)	Summer	7.5-9.9	8.8	6 mg/L minimum objective met
		Fall	2.8-5.8	4.4	11 mg/L objective not met any date
	Near mouth (0300060)	Summer	3.5-11.3	7.0	6 mg/L minimum objective not met Aug 12, Sep 2
		Fall	2.6-6.9	4.6	11 mg/L objective not met any date
Lead (µg/L) ≤5 µg/L average 10 µg/L maximum	Murray Cr (0300064)	Summer	0.023-0.092	0.053	Objectives met
		Fall	0.127-0.365	0.201	
	Anderson Cr (0300063)	Summer	0.012-0.020	0.016	
		Fall	0.040-0.377	0.167	
	Upstream (0300062)	Summer	0.056-0.452	0.156	
		Fall	0.107-0.372	0.204	
	Midstream (0300061)	Summer	0.203-0.565	0.353	
		Fall	0.301-0.794	0.620	
	Near mouth (0300060)	Summer	0.132-0.154	0.143 (n=4)	
		Fall	0.361-0.950	0.555	

Notes: Summer samples collected August 5, 12, 19, 26 & September 2 (n=5); winter samples collected October 27 & November 3, 10, 17 & 24 (n=5)

Table 10 Comparison of water quality indicators in the Nicomekl River and its tributaries from 1972 to 2009 (ammonia, nitrite & pH)

Variable & Objective	Site	1972-1983	1988-1990	1999-2000	2002 (Fall)	2009 (Fall)	Conclusion
Ammonia-N (mg/L) Comparison of ranges and means	Murray Cr (0300064) - tributary	0.014 – 0.161 ave = 0.055 (n=16) 1974-77	<0.005 – 0.273 ave = 0.059 (n=18)	0.006 – 0.02 ave = 0.012 (n=7)	<0.005 – 0.024 ave = 0.009 (n=5)	<0.005 – 0.043 ave = 0.018 (n=5)	Conditions fairly stable & adequate (since 1990)
	Anderson Cr (0300063) - tributary	<0.01 – 0.11 ave = 0.032 (n=6) 1973-74	<0.005 – 0.068 ave = 0.021 (n=19)	<0.005 – 0.008 ave = 0.006 (n=8)	<0.005 – 0.103 ave = 0.027 (n=5)	0.010 – 0.041 ave = 0.020 (n=5)	Conditions fairly stable & adequate
	Nicomekl R (0300062) Upstream	<0.005 – 0.525 ave = 0.092 (n=40) 1974-83	0.007 – 0.177 ave = 0.059 (n=19)	<0.005 – 0.116 ave = 0.032 (n=7)	<0.005 – 0.069 ave = 0.026 (n=5)	0.019 – 0.066 ave = 0.033 (n=5)	Conditions fairly stable & adequate (since 1983)
	Nicomekl R (0300061) Midstream	<0.005 – 0.434 ave = 0.090 (n=37) 1974-83	n/a	0.018 – 0.05 ave = 0.034 (n=7)	<0.005 – 0.048 ave = 0.019 (n=5)	<0.005 – 0.032 ave = 0.016 (n=5)	
	Nicomekl R (0300060) Near mouth	<0.005 – 0.428 ave = 0.127 (n=38) 1974-83	0.047 – 0.446 ave = 0.179 (n=19)	<0.005 – 0.069 ave = 0.043 (n=7)	<0.005 – 0.06 ave = 0.033 (n=5)	0.057 – 0.153 ave = 0.094 (n=5)	Conditions fairly stable & adequate (since 1990)
Nitrite-N (mg/L) Comparison of ranges and means	Murray Cr (0300064) - tributary	<0.005 – 0.036 ave = 0.009 (n=24) 1972-77	<0.005 – 0.026 ave = 0.013 (n=18)	0.004 – 0.019 ave = 0.008 (n=7)	0.006 – 0.021 ave = 0.015 (n=5)	0.010 – 0.016 ave = 0.012 (n=5)	Conditions fairly stable & adequate
	Anderson Cr (0300063) - tributary	<0.005 – 0.015 ave = 0.006 (n=24) 1972-78	<0.005 – 0.015 ave = 0.009 (n=19)	0.005 – 0.011 ave = 0.008 (n=8)	0.01 – 0.057 ave = 0.027 (n=5)	0.013 – 0.023 ave = 0.018 (n=5)	
	Nicomekl R (0300062) Upstream	0.005 – 0.034 ave = 0.013 (n=50)	0.009 – 0.043 ave = 0.023 (n=18)	0.008 – 0.027 ave = 0.013 (n=7)	0.008 – 0.072 ave = 0.031 (n=5)	0.006 – 0.018 ave = 0.014 (n=5)	Conditions fairly stable & adequate
	Nicomekl R (0300061) Midstream	<0.005 – 0.040 ave = 0.014 (n=47)	n/a	0.008 – 0.018 ave = 0.012 (n=7)	0.014 – 0.042 ave = 0.028 (n=5)	0.012 – 0.020 ave = 0.016 (n=5)	
	Nicomekl R (0300060) Near mouth	<0.005 – 0.127 ave = 0.027 (n=48)	0.019 – 0.061 ave = 0.036 (n=19)	0.005 – 0.02 ave = 0.016 (n=7)	0.013 – 0.074 ave = 0.035 (n=5)	0.010 – 0.041 ave = 0.022 (n=5)	
pH 6.5 to 8.5 0.2 maximum increase when upstream pH >8.5	Murray Cr (0300064) - tributary	7.0 – 8.3 (n=20) 1972-73	7.2 – 7.7 (n=10)	7.2 – 7.8 (n=7)	7.5 – 7.7 (n=5)	7.3 – 7.8 (n=5)	Conditions stable & adequate
	Anderson Cr (0300063) - tributary	7.0 – 8.0 (n=20) 1972-77	7.4 – 7.9 (n=10)	7.3 – 7.8 (n=8)	7.4 – 7.9 (n=5)	7.3 – 7.7 (n=5)	
	Nicomekl R (0300062) Upstream	6.9 – 8.1 (n=46)	7.1 – 7.9 (n=11)	7.1 – 7.7 (n=7)	7.3 – 7.7 (n=5)	7.4 – 7.6 (n=5)	Conditions stable & adequate
	Nicomekl R (0300061) Midstream	7.0 – 8.4 (n=43)	n/a	7.1 – 7.7 (n=7)	7.3 – 7.8 (n=5)	7.1 – 7.6 (n=5)	
	Nicomekl R (0300060) Near mouth	6.5 – 9.3 (n=44)	**6.4** – 7.9 (n=10)	7.0 – 7.9 (n=7)	7.1 – 7.7 (n=5)	7.4 – 7.8 (n=5)	General improvement (since 1990)

Values include ranges and averages (ave) [1972-1983 results taken from tabulated data (MEP, 1988a)]. Results that exceeded objectives are in bold.

Table 11 Comparison of water quality indicators in the Nicomekl River and its tributaries from 1972 to 2009 (suspended solids, dissolved oxygen & lead)

Variable & Objective	Site	1972-1983	1988-1990	1999-2000	2002 (Fall)	2009 (Fall)	Conclusion
Suspended solids (mg/L) <10 mg/L increase when upstream ≤100 mg/L (10% maximum increase when upstream >100 mg/L)	Murray Cr (0300064) - tributary	2 – 55 ave = 10 (n=16) 1974-77	1 – 90 ave = 14 **(max inc 76 mg/L in 1989)** (n=18)	<5 – 13 ave = 6 (max inc 8 mg/L in 1999) (n=7)	<1 – 8 ave = 4 (tributary) (n=5)	5 – 52 ave = 16 (tributary) (n=5)	General improvement (since 1989)
	Anderson Cr (0300063) - tributary	1 – 42 ave = 7 (n=16) 1974-77	<1 – 15 ave = 5 (max inc 5 mg/L in 1989) (n=19)	<5 – 6 ave = 5 (max inc 1 mg/L in 1999) (n=8)	<1 – 8 ave = 3 (tributary) (n=5)	1 – 65 ave = 22 (tributary) (n=5)	Conditions good & stable
	Nicomekl R (0300062) Upstream	3 – 87 ave = 19 (n=41)	3 – 188 ave = 21 (n=19)	<5 – 6 ave = 5 (n=7)	1 – 7 ave = 4 (n=5)	<1 – 37 ave = 12 (n=5)	Upstream reference site
	Nicomekl R (0300061) Midstream	3 – 54 ave = 14 (n=35) 1973-83	n/a	<5 – 8 ave = 6 (max inc 3 mg/L) (n=7)	3 – 10 ave = 6 (6 mg/L max inc) (n=5)	8 – 31 ave = 15 (7 mg/L max inc) (n=5)	Conditions good & stable
	Nicomekl R (0300060) Near mouth	3 – 60 ave = 18 (n=39) 1974-83	12 – 87 ave = 23 **(max inc 12 - 83 mg/L)** (n=19)	7 – 34 ave = 17 **(max inc 23 - 29 mg/L)** (n=7)	5 – 13 ave = 9 (9 mg/L max inc) (n=5)	10 – 25 ave = 15 (11 mg/L max inc) (n=5)	General improvement (since 1990)
Dissolved Oxygen (mg/L) 8 mg/L minimum (11 mg/L when salmonids present)	Murray Cr (0300064) - tributary	9.9 – 13.3 ave = 11.7 (n=23) 1972-77	9.5 – 13.2 (n=20)	8.6 – 11.8 ave = 10.13 (n=7)	9.57 – 13.29 ave = 10.90 (n=5)	3.1 – 6.8 ave = 5.3 (n=5)	Conditions degraded since 2002
	Anderson Cr (0300063) - tributary	10.2 – 13.5 ave = 11.4 (n=23) 1972-77	9.4 – 12.0 (n=19)	8.8 – 10.8 ave = 9.88 (n=8)	9.30 – 11.92 ave = 10.74 (n=5)	3.4 – 6.4 ave = 5.2 (n=5)	
Dissolved Oxygen (mg/L) 6 mg/L minimum **Long-term** 8 mg/L minimum (11 mg/L when salmonids present)	Nicomekl R (0300062) Upstream	7.8 – 14.1 ave = 10.8 (n=49)	8.2 – 11.1 (n=20)	8.8 – 10.4 ave = 9.13 (n=7)	9.19 – 12.04 ave = 10.47 (n=5)	2.8 – 5.8 ave = 4.7 (n=5)	Conditions degraded since 2002
	Nicomekl R (0300061) Midstream	7.5 – 13.3 ave = 10.5 (n=43)	n/a	7.8 – 10.8 ave = 9.37 (n=7)	8.16 – 11.87 ave = 10.18 (n=5)	2.8 – 5.8 ave = 4.4 (n=5)	
	Nicomekl R (0300060) Near mouth	**1.3** – 17.9 ave = 10.2 (n=46)	**4.3** – 10.8 (n=20)	6.7 – 11.0 ave = 8.79 (n=7)	6.37 – 9.98 ave = 8.25 (n=5)	2.6 – 6.9 ave = 4.6 (n=5)	
Total Lead (µg/L) ≤5 µg/L average 10 µg/L maximum	Murray Cr (0300064) - tributary	<1 – <3 med = 1 (n=19) 1972-77	n/a	0.08 (n=1) Oct 12/00	<0.01 – 0.24 ave = 0.14 (n=5)	0.13 – 0.37 ave = 0.20 (n=5)	Conditions stable & adequate
	Anderson Cr (0300063) - tributary	<1 – 5 med = 2 (n=19) 1972-77	n/a	0.02 (n=1) Oct 12/00	<0.01 – 0.22 ave = 0.06 (n=5)	0.04 – 0.38 ave = 0.17 (n=5)	
	Nicomekl R (0300062) Upstream	<1 – <100 med = 2 (n=39)	n/a	1.76 (n=1) Oct 12/00	0.05 – 0.32 ave = 0.18 (n=5)	0.11 – 0.37 ave = 0.20 (n=5)	Conditions stable & adequate
	Nicomekl R (0300061) Midstream	<1 – <100 med = 1 (n=31)	n/a	0.48 (n=1) Oct 12/00	0.37 – 2.15 ave = 1.01 (n=5)	0.30 – 0.79 ave = 0.62 (n=5)	
	Nicomekl R (0300060) Near mouth	<1 – <100 med = 3 (n=35)	n/a	0.4 (n=1) Oct 12/00	0.22 – 0.77 ave = 0.50 (n=5)	0.36 – 0.95 ave = 0.56 (n=5)	

Values include ranges and averages (ave) [1972-1983 results taken from tabulated data (MEP, 1988a)]. Results that exceeded objectives are in bold.

4.0 SERPENTINE RIVER

4.1 Overview

The Serpentine River is approximately 35 km long, with three major tributaries: Latimer Creek, Mahood (Bear) Creek, and Hyland Creek (MEP, 1988a; Figure 1). The Serpentine River also flows into Mud Bay, just north of the Nicomekl River. The Serpentine drainage basin (116 km^2) is composed of an upland component, which drains a large urban/commercial/industrial area containing Mahood Creek, and a lowland component containing 22 km of ditches and dyked channels running through predominantly agricultural land (MEP, 1988a). It is also important to note that much of the precipitation entering the system results in direct runoff, due to the relatively impervious nature of the soils (stony marine clays and till) in the tributaries (MEP, 1988a). A large 10-acre detention basin, Surrey Lake, was also developed in 2001 in the lower reaches of Mahood Creek, largely to aid in preventing floods in the agricultural lowlands. Additionally, the confluence of Latimer Creek with the Serpentine River has been moved back to the creek's original flow path, north of 83A Ave. The Ministry sampling station has thus been moved accordingly.

In 1988, objectives were developed to protect water uses in the Serpentine River for aquatic life, irrigation, livestock watering, and wildlife (MEP, 1988a). In subsequent objectives attainment monitoring from 1988 to 1992, objectives for suspended solids, nitrite, dissolved oxygen (DO), and pH were often not met in the Serpentine River main stem. In the tributaries, objectives for fecal coliforms (all creeks), suspended solids (Latimer and Mahood), nitrite (Latimer only), and dissolved oxygen (Latimer only) were often exceeded from 1988 to 1990. In 2002, the suspended solid objective was exceeded on one occasion, and the DO objective was not met at all sites when the higher minimum objective of 11 mg/L was applied (MWLAP, 2003). Since objectives have not been checked in the Serpentine River and its tributaries since 2002, it was a priority to monitor these objectives in 2009. Additional sampling was conducted in 1999 and 2000, which will also be included in this report.

4.2 Water Uses

Historically, water was withdrawn from the Serpentine River and its tributaries for livestock watering, drinking water, and industrial use, although the majority was withdrawn for irrigation (MEP, 1988a). Currently, water is withdrawn mainly for irrigation and storage for fish and wildlife conservation (see Appendix H). Constructed works for fish and wildlife conservation purposes are also a significant use of water in Latimer Creek. Steelhead and cutthroat trout use the river system and coho salmon spawn in the upper headwater reaches and tributaries (MEP, 1988a). The Tynehead Hatchery (at 96th Ave), operated by the Serpentine Enhancement Society since 1983, also withdraws water directly from, and discharges wastewater back to, the Nicomekl River. There is currently no primary-contact recreation in the Serpentine River.

4.3 Potential Sources of Contamination

Historically, seven operations had permits to discharge effluents within the Serpentine River sub-basin (MEP, 1988a). These included a BC Hydro facility, four industrial operations, a trailer park, and a shopping centre. Currently, there are three permit-holders within the basin, including BC Hydro, a plastic container manufacturing and filling plant, and a chemical storage and handling plant.

BC Hydro (PE 6026) has held a permit since 1981 to discharge stormwater from special waste storage (waste oil and PCB waste), electrical equipment repair, and diesel generator facilities to Mahood Creek via a storm drain. While the stormwater is treated by oil separation before discharge, permit inspections have revealed maintenance problems with the oil separator in the past. This has led to discharges of PCBs into Mahood Creek, and PCBs have been found in stream sediments downstream of the site. Harcros Chemicals Canada Inc. (PE 6448) is also permitted to discharge stormwater, after oil separation treatment, to a tributary of Mahood Creek. This chemical storage and handling plant was first issued a permit in 1983. Polybottle Group Ltd. (PE 2361), a permit-holder since 1974, is authorized to discharge cooling water (≤24°C) to a ditch that drains into Hyland Creek.

Potential contamination from diffuse sources within the Serpentine watershed include those from agriculture and urban stormwater, due to the proximity of highly populated areas to the headwaters of the Serpentine River and Mahood Creek (MEP, 1988a). Urban stormwater contamination can lead to increased chemical and fecal coliform loadings, with the associated high flow leading to scouring of salmonid spawning channels in these upper reaches (MEP, 1988a).

4.4 Methodology

4.4.1 Field Methodology

On the Serpentine River, two locations were sampled on the main stem and one location was sampled in each of Latimer, Mahood, and Hyland Creeks (Figure 1). Data are generally available for these sites since 1972. Sites on the Serpentine River (see Figure 4 photos) included an upstream (EMS 0300059) and downstream site (EMS 0300057), as well as sites in Latimer Creek (EMS E276637), Mahood Creek (EMS 0300056), and Hyland Creek (EMS E207718). Latimer Creek was sampled at Harvie Rd. in 2009 after being re-routed in 2002 (see Section 4.1). Historical data from previous sites (i.e. 1100065 and E207716) are used for comparison because of their proximity to the current site.

Sampling in 2009 was carried out five times in 30 days in both the dry summer period (August 5, 12, 19, 26 and September 2) and wet fall period (October 27, November 3, 10, 17 and 24). This time period thus included sampling before and after the first flush

events in 2009, on October 25 and 29/30 (see Appendix B). Bacteriological indicators monitored included fecal coliforms, *E. coli* and enterococci. Water quality indicators included suspended solids, turbidity, ammonia, nitrate, nitrite and lead. Field measurements were taken at the surface with a calibrated YSI 556 Multi Probe System (YSI Environmental) and included water temperature, dissolved oxygen, pH and specific conductance. Photographs of the sampling sites were taken on November 21, 2002. Precipitation data from a weather station at the Vancouver International Airport was obtained from Environment Canada for the 2009 sampling periods.

Latimer Creek at Harvie Rd
(1100065)

Serpentine River at 80th Ave
(upstream site, 0300059)

Mahood Creek at 152nd St
(0300056)

Hyland Creek at 152nd St
(E207718)

Serpentine River at Hwy 99A
(downstream site, 0300057)

Figure 4 Serpentine River sampling sites

Grab samples were collected at the surface, facing upstream, using high-density polyethylene bottles for both bacteriological and water chemistry samples. Water samples for metals analysis were preserved by Maxxam Analytics upon delivery of samples. Field sampling quality control was addressed by including blind field and trip blank samples, and by collecting blind triplicate samples at one site on each sampling date (see Appendix F). Grab samples were collected at the surface, facing upstream, using high-density polyethylene bottles for both bacteriological and water chemistry samples. Water samples for metals analysis were preserved by Maxxam Analytics upon delivery of the samples. Field sampling quality control was addressed by including blind field and trip blank samples, and by collecting blind triplicate samples at one site on each sampling date (see Appendix F). Field blanks are intended to capture sampler errors when collecting water in the field, while trip blanks are intended to capture sample bottle or deionized water contamination. Blind replicates are intended to assess lab analytical precision. Samples were kept on ice in a cooler during overnight delivery to CANTEST Ltd. (bacteriological samples) or Maxxam Analytics (chemistry samples).

4.4.2 Laboratory Methodology

The laboratories followed analytical procedures according to the British Columbia Environmental Laboratory Manual for the Analysis of Water, Wastewater, Sediment and Biological Materials (MOELP, 1994). They also employed quality assurance and control procedures, including method blanks, duplicates, and spike recoveries. These reports are available upon request.

4.5 Results and Statistical Analysis

Bacteriological and water chemistry data for 2009 have been summarized in Tables 12, 14 and 15, respectively. A comparison of results from 1972-1983, 1988-1990, 1999-2000 and 2002 sampling periods are presented in Tables 13, 16 and 17. Raw field and water quality data are shown in Appendix E. The geometric mean was obtained for bacteriological results, with the requirement that at least five samples were collected within 30 days (MEP, 1988c). The range and average were calculated for chemical parameters and metals. PCB data are also included from water, sediment and tissue samples collected in 2008 from the Mahood Creek and Serpentine River watersheds. Data were collected by a consultant for BC Hydro and are also included in Appendix E (Azimuth Consulting Group, 2009).

As sampling strategies changed from quarterly sampling in the 1970's and 1980's, to targeted five-week sampling in the 1990's and beyond, the statistical validity of trends could not be determined. Readily apparent trends were still, however noted.

The Water Quality Index was calculated as described in CCME (2001). The factors used in the index are based on results of water quality objectives attainment and include; F_1 (Scope), the number of objectives not met; F_2 (Frequency), the frequency with which objectives are not met; and F_3 (Amplitude), the amount by which objectives are not met. Appendix G gives numerical ranges for the rankings and descriptions of the rankings, as well as 2002 and 2009 ratings. Since the CCME index was adapted from the BC Ministry of Environment, Lands and Parks index, the same conditions regarding data use were applied (MOELP, 1995). Some of these conditions include omitting incomplete monitoring results and using results from short-term objectives only (MOELP, 1995).

4.6 Discussion

4.6.1 Bacteriological Indicators

While bacteriological objectives were set for only fecal coliforms in 1988, it is also appropriate to use the provincial criteria for *E. coli* and enterococci levels, as stated in previous sections. As with the Nicomekl River, the objectives for fecal coliforms, and provincial criteria for *E. coli* and enterococci, in the Serpentine River system are based on irrigation criteria:

- **Fecal coliforms** (objectives) – geometric mean of ≤1000/100 mL and maximum of ≤4000/100 mL (Apr-Oct), with a long-term objective of ≤200/100 mL (year round, geometric mean)
- ***E. coli*** (provincial standards) – geometric means of ≤77/100 mL (irrigation, crops eaten raw), ≤385/100 mL (irrigation, public/livestock access), ≤1000/100 mL (irrigation, general)
- **Enterococci** (provincial standards) – geometric mean of ≤20/100 mL (irrigation, crops eaten raw), ≤100/100 mL (irrigation, public/livestock access), ≤250/100 mL (irrigation, general)

In 2009, short-term objectives for **fecal coliforms** were met at all sites sampled on the Serpentine River and its tributaries (Table 12). It should be noted that Mahood Creek had the highest bacterial levels in both seasons. The long-term objective was only met once during summer sampling (Serpentine River, near mouth), and only once during fall sampling (Latimer Creek). While bacterial levels were higher in 2009 than in 2002 at most sites, there is still a general improvement over previous monitoring efforts (Table 13).

The most stringent provincial ***E. coli*** criterion for irrigation (crops eaten raw) was exceeded at all sites during fall sampling, and at most sites during summer sampling (Table 12). Only the Serpentine River site sample, near the mouth (0300057), met this criterion during the summer of 2009. Additionally, all provincial **enterococci** criteria for

irrigation were exceeded at this Serpentine River site in the fall, while the crops eaten raw criterion (20 CFU/100 mL) was exceeded during the summer sampling (Table 12).

Since 1990, there has been a general to significant improvement in bacteriological conditions in the Serpentine River and its tributaries, although bacterial levels were higher in 2009 compared to 2002 (Table 13). This is particularly the case for the tributaries which recorded very high maximum and geometric mean results for fecal coliforms in 1989 and 1990. Mahood Creek was still recording high maximum values as recently as 1999 and 2000 (Table 13). Given the current 2009 results, *E.coli* and enterococci levels remain a concern for irrigation (crops eaten raw) purposes in the Serpentine River and water quality for this purpose does not appear to be adequate at this time.

Table 12 Bacteriological objectives attainment in the Serpentine River and its tributaries – 2009

Variable & Objective	Site	Season	Range	Geometric mean (n=5)	Conclusion
Fecal coliforms (CFU/100 mL) gm ≤1000/100 mL max ≤4000/100 mL Apr-Oct **Long-term** ≤200/100 mL geometric mean (year round)	Latimer Cr (E276637) - tributary	Summer	50-1,100	216	Long-term objective not met
		Fall	60-490	180	Long-term objective met
	Mahood Cr (0300056) - tributary	Summer	350-1,800	576	Long-term objective not met
		Fall	200-2,600	831	
	Hyland Cr (E207718) - tributary	Summer	130-1,000 (n=4)	224	Long-term objective not met
		Fall	35-600	266	
	Serpentine (0300059) - upstream	Summer	71-1,400	202	Long-term objective not met
		Fall	120-640	335	
	Serpentine (0300057) – at mouth	Summer	26-4,000	138	Objectives met
		Fall	200-530	303	Long-term objective not met
Escherichia coli (E. coli) (CFU/100 mL) gm ≤77/100 mL (irrigation criterion)	Latimer Cr (E276637) - tributary	Summer	40-1,100	178	Provincial criterion not met (irrigation, crops eaten raw)
		Fall	45-480	140	
	Mahood Cr (0300056) - tributary	Summer	90-1,800	355	
		Fall	120-1,200	411	
	Hyland Cr (E207718) - tributary	Summer	75-<1000 (n=4)	174	
		Fall	20-360	130	
	Serpentine (0300059) - upstream	Summer	45-1,400	127	Provincial criterion not met (irrigation, crops eaten raw)
		Fall	110-380	235	
	Serpentine (0300057) – at mouth	Summer	9-1,100	33	Provincial criterion met
		Fall	60-280	160	Provincial criterion not met (irrigation, crops eaten raw)
Enterococci (CFU/100 mL) gm ≤20/100 mL (irrigation criterion)	Serpentine (0300057) – at mouth	Summer	11-510	49	Provincial criterion not met (irrigation, crops eaten raw)
		Fall	57-1,100	392	

Notes: Summer samples collected August 5, 12, 19, 26 & September 2 (n=5); winter samples collected October 27 & November 3, 10, 17 & 24 (n=5); gm is geometric mean, 90th is 90th percentile; fecal coliform geometric mean objectives applied to summer samples only as fall samples collected in November; values in red exceed objectives.

Table 13 Comparison of bacteriological objectives attainment in the Serpentine River and its tributaries from 1972 to 2009

Variable & Objective	Site	1973-1983[a]	1988-1990	1999-2000	2002 (Fall)	2009 (Summer)	Conclusion
Fecal coliforms (colonies/100 mL) ≤1000/100 mL geometric mean ≤4000/100 mL maximum **Long-term** ≤200/100 mL geometric mean	Latimer Cr (E276637) - tributary	n/a	200 – **56,900** *med = 753* **gm^1 = 909** **gm^2 = 2,345** **gm^4 = 1,193** (n=18)	42 – 610 *med = 143* (n=6)	45 – 300 *med = 120* **gm = 138** (n=5)	50 – 1,100 *med = 180* **gm = 216** (n=5)	Significant improvement (since 1990)
	Mahood (Bear) Cr (0300056) - tributary	20 – **16,000** *med = 490* (n=42)	42 – **10,600** *med = 445* **gm^1 = 528** **gm^2 = 1,195** **gm^3* = 215** **gm^4 = 382** (n=19)	88 – **26,000** *med = 510* (n=7)	34 – 1,100 *med = 190* **gm = 195** (n=5)	350 – 1,800 *med = 360* **gm = 576** (n=5)	General improvement (since 1990)
	Hyland Cr (E207718)	n/a	144 – **30,200** *med = 1,000* **gm^1* = 858** **gm^2 = 987** **gm^3* = 700** **gm^4 = 1,258** (n=19)	n/a	41 – 1,600 *med = 150* **gm = 192** (n=5)	150 – 1,000 *med = 140* **gm = 224** (n=4)	Significant improvement (since 1990)
	Serpentine (0300059) Upstream	40 – **9,200** *med = 1300* (n=55)	<2 – **7,880** *med = 133* **gm^1 = 105** **gm^2 = 105** **gm^4 = 102** (n=18)	48 – 3,200 *med = 560* (n=6)	26 – 840 *med = 400* **gm = 219** (n=5)	71 – 1,400 *med = 110* **gm = 202** (n=5)	No significant improvement (since 1990)
	Serpentine (0300057) Near mouth	<20 – **>24,000** *med = 110* (n=51)	9 – 1,490 *med = 380* **gm^1 = 257** **gm^2 = 88** **gm^3* = 730** **gm^4 = 244** (n=19)	7 – **4,200** *med = 265* (n=6)	18 – 290 *med = 149* **gm = 88** (n=5)	26 – 4,000 *med = 70* **gm = 138** (n=5)	General improvement (since 1990)

Notes: Values include: range, median (med), and geometric mean (gm); results that exceeded objectives are in bold; gm^1 is the 1988 geometric mean (Oct 19 to Nov 17); gm^2 is the first 1989 geometric mean (Sept 25 to Oct23); gm^3 is the second 1989 geometric mean (Oct 30 to Nov 27); gm^4 is the 1990 geometric mean (Sept 25 to Oct 23); gm^n* indicates a geometric mean of 4 results; [a] Results taken from tabulated data (MEP, 1988a)

4.6.2 Water Quality Indicators

4.6.2.1 Ammonia

Objectives for ammonia-nitrogen(N) in the Serpentine River and its tributaries, set to protect aquatic life, are an average 30-day and maximum concentration dependent on pH and temperature, where ammonia toxicity increases with increasing temperature and pH (see ammonia tables in Appendix A). In 2009, the lowest criteria for all of the Serpentine sites, to which all results were compared in summer (fall), was an average and maximum ammonia-N concentration of 0.49 mg/L (0.91 mg/L) and 3.61 mg/L (4.71 mg/L), respectively (MOE, 2006). These objectives were met for all the sites in 2009, with results well below the stated criteria (Table 14).

Objectives for ammonia-N concentrations have also been met in previous attainment monitoring efforts, and levels have improved in the Serpentine River main stem and in Latimer Creek since 1990 (Table 16). In Mahood and Hyland Creeks, ammonia levels have remained stable and relatively low over the past 40 years.

4.6.2.2 Nitrite

Objectives for nitrite-nitrogen(N) in the Serpentine River, set to protect aquatic life, are an average 30-day and maximum concentration dependent on chloride concentration. The 0.20 mg/L (30-day average) and 0.60 mg/L (maximum) nitrite-N criteria were used, based on chloride concentrations >10 mg/L (see chloride table in Appendix A). These objectives were met for all sites, on all dates sampled in 2009 (Table 14).

Objectives for nitrite-N concentrations were exceeded from 1988 to 1992 at both the upstream and downstream sites on the Serpentine River, as well as in Latimer Creek (1989 and 1990), when the most stringent nitrite-N criteria were applied. However, nitrite-N conditions have been fairly stable and relatively low in the Serpentine main stem and in its tributaries since 1990 (Table 16).

4.6.2.3 pH

The objective range for pH in the Serpentine River and its tributaries is 6.5 to 8.5. An additional objective is a 0.2 maximum increase when the upstream pH is <8.5. In 2009, the pH range objectives were met for all sites sampled (Table 14). However, there was one maximum increase exceedence at the downstream site (0300057) on November 17, when the pH increased 0.75 units. While the pH objectives were not met at either Serpentine site in earlier monitoring, there have been improvements in both pH ranges and maxima in the Serpentine main stem and its tributaries since 1988 (Table 16).

4.6.2.4 Suspended Solids

The objective for suspended solids in the Serpentine River is a 10 mg/L maximum increase over upstream concentrations when upstream suspended solids are ≤100 mg/L. In 2009, this objective was exceeded on one occasion at the downstream Serpentine site (0300057), with a maximum increase of 12 mg/L on November 17 (Table 15). This is an improvement over previous attainment monitoring results, where objectives were exceeded 40% of the time at the same location in 1989. While upstream sites in the three tributaries were not sampled in 2009, suspended solids concentrations were similar to those in the main stem (Table 15). There has been an improvement in suspended solid conditions at all sites since 1990 (Table 17). It is also interesting to note that the upstream Serpentine site (0300059) has typically recorded suspended solid levels similar to the downstream site (0300057).

4.6.2.5 Turbidity

The objective for turbidity in the Serpentine River is a 5 NTU maximum increase over upstream levels when upstream levels are ≤50 NTU. In 2009, this objective was met at the downstream site (0300057) during summer sampling, but was slightly exceeded on three occasions, with maximal increases of 6-8 NTU, during fall sampling (Table 15). As with suspended solids, these increases likely originate from diffuse stormwater, construction activities and/or agricultural sources. Turbidity data are not available for

comparison from previous sampling efforts, but should continue to be monitored in the future.

Table 14 Water quality objectives attainment in the Serpentine River and its tributaries (ammonia, nitrite & pH) - 2009

Variable & Objective	Site	Season	Range	Mean (n=5)	Conclusion
Ammonia-N (mg/L) 0.49 mg/L (summer) & 0.91 mg/L (fall) average 3.61 mg/L (summer) & 4.71 mg/L (fall) maximum	Latimer Cr (E276637) - tributary	Summer	0.014-0.031	0.021	Objective met
		Fall	<0.005-0.020	0.011	
	Mahood Cr (0300056) - tributary	Summer	<0.005-0.062	0.021	
		Fall	<0.005-0.579	0.128	
	Hyland Cr (E207718) - tributary	Summer	0.026-0.054	0.038	
		Fall	<0.005-0.044	0.014	
	Serpentine (0300059) - upstream	Summer	<0.005-0.191	0.060	Objective met
		Fall	<0.005-0.100	0.033	
	Serpentine (0300057) – at mouth	Summer	<0.005-0.254	0.061	
		Fall	<0.005-0.155	0.063	
Nitrite-N (mg/L) 0.2 mg/L average 0.6 mg/L maximum (when chloride >10 mg/L)	Latimer Cr (E276637) - tributary	Summer	0.005-0.009	0.007	Objective met
		Fall	0.005-0.009	0.007	
	Mahood Cr (0300056) - tributary	Summer	0.004-0.020	0.009	
		Fall	0.004-0.008	0.005	
	Hyland Cr (E207718) - tributary	Summer	0.005-0.009	0.007	
		Fall	0.004-0.014	0.008	
	Serpentine (0300059) - upstream	Summer	0.004-0.024	0.011	Objective met
		Fall	0.005-0.023	0.015	
	Serpentine (0300057) – at mouth	Summer	<0.002-0.019	0.008	
		Fall	0.010-0.034	0.021	
pH 6.5 to 8.5 0.2 maximum increase when upstream >8.5	Latimer Cr (E276637) - tributary	Summer	6.8-7.9	7.3	Objective met
		Fall	6.5-7.5	6.9	
	Mahood Cr (0300056) - tributary	Summer	7.6-8.2	7.9	
		Fall	6.9-7.3	7.1	
	Hyland Cr (E207718) - tributary	Summer	7.0-8.0 (n=4)	7.4	
		Fall	7.0-7.2	7.1	
	Serpentine (0300059) - upstream	Summer	7.6-8.2	7.9	Objective met
		Fall	7.3-7.8	7.5	
	Serpentine (0300057) – at mouth	Summer	7.0-8.1	7.7	
		Fall	7.4-8.1	7.7	

Notes: Summer samples collected August 5, 12, 19, 26 & September 2 (n=5); winter samples collected October 27 & November 3, 10, 17 & 24 (n=5)

4.6.2.6 Dissolved Oxygen

The objectives for dissolved oxygen (DO) in the Serpentine River are a minimum of 6.0 mg/L (and long-term minimum objective of 8.0 mg/L) from June-October, or a minimum of 11.0 mg/L when salmonid eggs, larvae or alevin are present (i.e. fall). Similarly, the objectives for the tributaries are a minimum DO of 8.0 mg/L, or a minimum of 11.0 mg/L when salmonid eggs, larvae or alevin are present (i.e. fall). Thus, in 2009, the relevant objectives were applied depending on the season. As in 2002, objectives were not met

during 2009 fall sampling in the Serpentine main stem, although DO values were considerably lower in 2009 (Table 15).

DO levels were higher in the tributaries, although the 11 mg/L minimum objective was not met on several occasions in Latimer and Hyland Creeks, or on any occasion in Mahood Creek in 2009. Minimal DO objectives were also not met during 2009 summer sampling on most occasions, with levels of 3.8-8.8 mg/L in the tributaries, and 3.3-9.7 mg/L in the main stem. July and August were particularly warm in 2009, with maximum temperatures reaching at least 29°C on 19 days during both months. This was reflected in warm water temperatures (>19°C) in the Serpentine main stem, which may have influenced DO levels at the time.

During previous attainment monitoring, both main stem locations failed to meet the DO objectives during the 1988-90 sampling period (Table 17). There was an improvement in DO conditions at the upstream Serpentine site from 1999 to 2002, when the long-term objective was met for the first time. DO conditions at the downstream site also improved between 1990 and 2002, although the long-term objective has never been met. The tributaries have consistently met DO objectives in previous attainment monitoring, except for Latimer Creek in 1989. DO conditions improved in Latimer Creek between 1990 and 2002, and had been relatively stable in Mahood Creek since 1983 (Table 17). Limited data are available for Hyland Creek to determine long-term trends.

4.6.2.7 Lead

While objectives for lead were not set for the Serpentine River and its tributaries in 1988, historical as well as 2009 results are included in Table 17 for reference purposes (raw data in Appendix E). While high detection limits made accurate quantification of lead concentrations difficult in the past, current lead levels are within objectives set for the Nicomekl River, in terms of average and maximum concentrations (Table 15). However, it should be noted that while lead levels in the Serpentine River were similar to main stem Nicomekl River levels, concentrations in the Serpentine tributaries were higher than those in the Nicomekl. This may warrant further study or monitoring effort.

4.6.2.8 Polychlorinated biphenyls (PCBs)

While objectives for PCBs were not checked in 2009, monitoring was conducted in 2008 in water, sediment and tissue by a consultant for BC Hydro. Objectives are maxima of 1 ng/L in water, 30 ng/g (dry weight) in sediment, and 100 ng/g (wet weight) in tissue for Mahood Creek and Serpentine River. The results are included in Appendix E and will be discussed with reference to the set objectives. The PCB concentration was highest in **water** (3.4 ng/L) and **sediment** (322 ng/g) at the mid-field Mahood Creek site, which exceeded both objectives of 1 ng/L and 30 ng/g, respectively. Water and sediment samples from sites further downstream did meet objectives, although two sediment samples from Surrey Lake were close to the objective with concentrations of 29.6 and 21.9 ng/g.

Tissue sampling showed that of the 17 fish samples collected in Mahood Creek and the Serpentine main stem, only one juvenile coho sample in the mid-field Mahood Creek site exceeded the 100 ng/g tissue objective, with a total PCB concentration of 401 ng/g (wet weight). The average tissue concentration was 59.1 ng/g (range of 4.9 to 401 ng/g, n=17), which was four times higher than the reference sample average of 13.3 ng/g (range of 6.4 to 28.5 ng/g, n=10). It should be noted that the tissue objective does not state that the data be normalized to lipid content. However, lipid-normalized data are also included in Appendix E for reference purposes.

4.6.2 Water Quality Index Rating

In 2009, the calculated CCME Water Quality Index (WQI) rating for the **Serpentine River** was Fair (index=66) during **fall** sampling, which was a decline from a rating of Good (index=81) in 2002 (Appendix G). The 2009 fall index was low due to low dissolved oxygen (DO) levels at both the upstream (2.5-5.1 mg/L) and downstream (2.4-8.1 mg/L) sites, which was compared to a DO objective of 11 mg/L when salmonid eggs, larvae or alevin are present, i.e. during the fall period. The **summer** rating was considerably better (Good), with a value of 93. Thus, conditions in the Serpentine River do not appear to be adequate at times for the protection of aquatic life, particularly during first flush periods when oxygen-demanding substances may be entering the system through stormwater runoff.

Latimer, Mahood and Hyland Creeks had Good ratings in the **fall** of 2009, with values of 86, 84 and 89, respectively. These values are similar to those found in 2002, which ranged from 82 to 91. During 2009 **summer** sampling, the WQI ratings were also Good, with values of 86 to 90. The 2009 fall ratings and values in these tributaries were mainly influenced by DO levels that were lower than the minimum 11 mg/L objective, with values ranging from 8.6-11.0 mg/L in Latimer Creek, 7.9-9.8 mg/L in Mahood Creek, and 8.7-11.0 mg/L in Hyland Creek. However, it should also be noted that DO levels were not adequately protective of aquatic life during the summer sampling period, with DO values ranging from 3.8-8.8 mg/L. Thus, conditions in the tributaries may not be adequate at times during summer months and during critical salmon-spawning periods of the fall when first flush events are also occurring.

Table 15 Water quality objectives attainment in the Serpentine River and its tributaries (suspended solids, turbidity, dissolved oxygen & lead) – 2009

Variable & Objective	Site	Season	Range	Mean (n=5)	Conclusion
Suspended solids (mg/L) <10 mg/L increase when upstream ≤100 mg/L (10% maximum increase when upstream >100 mg/L)	Latimer Cr (E276637) - tributary	Summer	3-13	6	Tributary – no upstream
		Fall	2-10	5	
	Mahood Cr (0300056) - tributary	Summer	2-5	3	Tributary – no upstream
		Fall	1-20	7	
	Hyland Cr (E207718) - tributary	Summer	3-7	5	Tributary – no upstream
		Fall	3-5	4	
	Upstream (0300059)	Summer	3-6	5	Upstream reference site
		Fall	6-11	7	Upstream reference site
	Near mouth (0300057)	Summer	7-12	9	Objective met
		Fall	8-23	13	Objective not met Nov 17 (increase of 12 mg/L)
Turbidity (NTU) ≤5 NTU increase when upstream ≤50 NTU (10% maximum increase when upstream >50 NTU)	Latimer Cr (E276637) - tributary	Summer	9.9 (n=2)	9.9	Tributary – no upstream
		Fall	5.0 (n=1)	n/a	
	Mahood Cr (0300056) - tributary	Summer	2.2-4.2 (n=2)	3.2	Tributary – no upstream
		Fall	n/a	n/a	
	Hyland Cr (E207718) - tributary	Summer	4.5-6.9 (n=2)	5.7	Tributary – no upstream
		Fall	4.3 (n=1)	n/a	
	Upstream (0300059)	Summer	3.3-7.8	5.3	Upstream reference site
		Fall	6.0-15.9	10.0	Upstream reference site
	Near mouth (0300057)	Summer	5.5-10.7	7.6	Objective met
		Fall	10.0-24.1	15.2	Objective not met Oct 27, Nov 17, 24 (increases of 6, 8, 6 NTU respectively)
Dissolved Oxygen (mg/L) 6 mg/L minimum 8 mg/L minimum (long-term) Jun-Oct 11 mg/L minimum when eggs present	Latimer Cr (E276637) - tributary	Summer	3.8-6.5	5.0	Objectives not met
		Fall	8.6-11.0	9.8	
	Mahood Cr (0300056) - tributary	Summer	5.4-8.8	7.1	
		Fall	7.9-9.8	9.0	
	Hyland Cr (E207718) - tributary	Summer	4.2-6.3 (n=4)	5.6	
		Fall	8.7-11.0	10.2	
	Upstream (0300059)	Summer	3.5-9.7	6.2	Objectives not met
		Fall	2.5-5.1	4.1	
	Near mouth (0300057)	Summer	3.3-9.5	6.6	
		Fall	2.4-8.1	4.8	
Lead (µg/L) ≤5 µg/L average 10 µg/L maximum (Nicomekl objective)	Latimer Cr (E276637) - tributary	Summer	0.7-1.1	0.9	Objective met
		Fall	<0.2-0.6	0.4	
	Mahood Cr (0300056) - tributary	Summer	0.7-5.2	1.9	
		Fall	0.2-1.3	0.6	
	Hyland Cr (E207718) - tributary	Summer	0.8-3.3	1.6	
		Fall	0.3-0.5	0.4	
	Upstream (0300059)	Summer	0.192-0.339	0.240	Objective met
		Fall	0.268-0.501	0.386	
	Near mouth (0300057)	Summer	0.134-0.292	0.217	
		Fall	0.299-0.784	0.549	

Notes: Summer samples collected August 5, 12, 19, 26 & September 2 (n=5); winter samples collected October 27 & November 3, 10, 17 & 24 (n=5)

Table 16 Comparison of water quality indicators in the Serpentine River and its tributaries from 1972 to 2009 (ammonia, nitrite & pH)

Variable & Objective	Site	1972-1983	1988-1990	1999-2000	2002 (Fall)	2009 (Fall)	Conclusion
Ammonia-N (mg/L) Comparison of ranges and means	Serpentine R (0300059) Upstream	0.006 – 0.582 ave = 0.215 (n=52) 1974-83	0.006 – 0.495 ave = 0.252 (n=18)	0.091 – 0.55 ave = 0.201 (n=7)	<0.005 – 0.276 ave = 0.072 (n=5)	<0.005 – 0.100 ave = 0.033 (n=5)	Conditions improving (since 1999)
	Serpentine R (0300057) Near mouth	<0.005 – 0.532 ave = 0.142 (n=52) 1974-83	0.008 – 1.06 ave = 0.405 (n=19)	0.01 – 0.151 ave = 0.076 (n=7)	<0.005 – 0.279 ave = 0.065 (n=5)	<0.005 – 0.155 ave = 0.063 (n=5)	Conditions improving (since 1990)
	Latimer Cr (E276637) - tributary	n/a	0.019 – 1.5 ave = 0.345 (n=18)	<0.005 – 0.033 ave = 0.024 (n=7)	<0.005 – 0.011 ave = 0.007 (n=5)	<0.005 – 0.020 ave = 0.011 (n=5)	
	Mahood Cr (0300056) - tributary	0.008 – 0.38 ave = 0.063 (n=38)	<0.005 – 0.082 ave = 0.03 (n=19)	0.009 – 0.036 ave = 0.026 (n=8)	<0.005 – 0.016 ave = 0.008 (n=5)	<0.005 – 0.579 ave = 0.128 (n=5)	Conditions stable
	Hyland Cr (E207718) - tributary	n/a	<0.005 – 0.051 ave = 0.021 (n=20)	n/a	<0.005 – <0.005 ave = <0.005 (n=5)	<0.005 – 0.044 ave = 0.014 (n=5)	
Nitrite-N (mg/L) Comparison of ranges and means	Serpentine R (0300059) Upstream	0.005 – 0.048 ave = 0.021 (n=61)	0.016 – 0.179 ave = 0.053 (n=18)	0.01 – 0.03 ave = 0.019 (n=7)	0.02 – 0.084 ave = 0.038 (n=5)	0.005 – 0.023 ave = 0.015 (n=5)	Conditions stable & adequate (since 1990)
	Serpentine R (0300057) Near mouth	<0.005 – 0.246 ave = 0.022 (n=61)	<0.005 – 0.083 ave = 0.035 (n=19)	<0.002 – 0.02 ave = 0.012 (n=7)	0.013 – 0.049 ave = 0.024 (n=5)	0.010 – 0.034 ave = 0.021 (n=5)	
	Latimer Cr (E276637) - tributary	n/a	<0.005 – 0.165 ave = 0.031 (n=18)	0.006 – 0.02 ave = 0.011 (n=7)	0.008 – 0.026 ave = 0.013 (n=5)	0.005 – 0.009 ave = 0.007 (n=5)	
	Mahood Cr (0300056) - tributary	0.005 – 0.029 ave = 0.013 (n=46)	0.006 – 0.02 ave = 0.01 (n=19)	0.005 – 0.019 ave = 0.01 (n=8)	0.003 – 0.037 ave = 0.017 (n=5)	0.004 – 0.008 ave = 0.005 (n=5)	
	Hyland Cr (E207718) - tributary	n/a	<0.005 – 0.026 ave = 0.01 (n=20)	n/a	0.013 – 0.04 ave = 0.023 (n=5)	0.004 – 0.014 ave = 0.008 (n=5)	
pH 6.5 to 8.5 0.2 maximum increase when upstream pH >8.5	Serpentine R (0300059) Upstream	**6.3** – 7.8 (n=58)	**5.8** – 7.1 (n=10)	6.91 – 7.35 (n=7)	6.9 – 7.8 (n=5)	7.3 – 7.8 (n=5)	Conditions stable & adequate (since 1990)
	Serpentine R (0300057) Near mouth	**6.2 – 8.9** (n=61)	**6.1** – 7.7 (n=10)	6.83 – 7.79 (n=7)	7 – 7.8 (n=5)	7.4 – 8.1 (n=5)	
	Latimer Cr (E276637) - tributary	n/a	6.7 – 7.6 (n=10)	6.94 – 7.56 (n=7)	7.3 – 7.7 (n=5)	6.5 – 7.5 (n=5, lab)	
	Mahood Cr (0300056) - tributary	6.8 – 8.0 (n=44)	6.9 – 7.9 (n=10)	7.25 – 7.83 (n=8)	7.5 – 7.8 (n=5)	6.9 – 7.3 (n=5, lab)	
	Hyland Cr (E207718) - tributary	n/a	6.8 – **8.9** **(1.1 – 1.6 max inc in 1988/90)** (n=10)	n/a	7.3 – 7.8 (n=5)	7.0 – 7.2 (n=5, lab)	

Notes: values include: ranges and average (ave) [1971-1983 results taken from tabulated Data (MEP, 1988a)]; results that exceeded objectives are in bold.

Table 17 Comparison of water quality indicators in the Serpentine River and its tributaries from 1972 to 2002 (suspended solids, dissolved oxygen & lead)

Variable & Objective	Site	1972-1983	1988-1990	1999-2000	2002 (Fall)	2009 (Fall)	Conclusion
Suspended solids (mg/L) <10 mg/L increase when upstream ≤100 mg/L (10% maximum increase when upstream >100 mg/L)	Serpentine R (0300059) Upstream	7 – 84 ave = 26 (n=44) 1974-83	7 – 55 ave = 24 (n=18)	<5 – 64 ave = 20 (n=7)	5 – 38 ave = 13 (n=5)	6 – 11 ave = 7 (n=5)	Upstream reference site
	Serpentine R (0300057) Near mouth	9 – 57 ave = 24 (n=49)	8 – 54 ave = 23 **(max inc 31 mg/L, 1989)** (n=19)	7 – 16 ave = 11 (max inc 3 – 5 mg/L) (n=7)	7 – 16 ave = 12 **(11 mg/L max inc)** (n=5)	8 – 23 ave = 13 **(12 mg/L max inc)** (n=5)	General improvement (since 1989)
	Latimer Cr (E276637) – tributary	n/a	4 – 66 ave = 14 **(max inc 11 mg/L, 1990)** (n=18)	<5 – 6 ave = 5 (no increase, upstream higher) (n=7)	2 – 11 ave = 4 (no upstream site) (n=5)	2 – 10 ave = 5 (no upstream site) (n=5)	General improvement (since 1990)
	Mahood Cr (0300056) – tributary	1 – 129 ave = 17 (n=37) 1974-83	1 – 162 ave = 30 **(max inc 58 – 118 mg/L)** (n=19)	<5 – 6 ave = 5 (no increase, upstream higher) (n=8)	1 – 5 ave = 3 (no upstream site) (n=5)	1 – 20 ave = 7 (no upstream site) (n=5)	Significant improvement (since 1990)
	Hyland Cr (E207718) – tributary	n/a	3 – 160 ave = 29 **(max inc 5 – 105 mg/L)** (n=18)	n/a	2 – 13 ave = 6 (no upstream site) (n=5)	3 – 5 ave = 4 (no upstream site) (n=5)	
Dissolved Oxygen 6 mg/L minimum **Long-term** 8 mg/L minimum (11 mg/L when salmonids present)	Serpentine R (0300059) Upstream	(0.06 – 16.7 ave = 8.2 (n=48)	**1.4** – 9.2 (n=20)	**3.6** – 9.4 ave = 6.30 (n=7)	**7.87 – 10.28** ave = 9.04 (n=5)	**2.5 – 5.1** ave = 4.1 (n=5)	Conditions degraded since 2002 (long-term not met in 2009)
	Serpentine R (0300057) Near mouth	**2.7** – 15.6 ave = 9.4 (n=44)	**4.1** – 10.0 (n=20)	6.0 – 10.0 ave = 8.03 (n=7)	**7.04 – 10.28** ave = 7.87 (n=5)	**2.4 – 8.1** ave = 4.8 (n=5)	Conditions degraded since 2002 (long-term not met in 2009)
Dissolved Oxygen 8 mg/L minimum (11 mg/L when salmonids present)	Latimer Cr (E276637) – tributary	n/a	**4.3** – 10.8 (n=20)	**7.4** – 12.2 ave = 9.61 (n=7)	**8.9** – 11.9 ave = 10.3 (n=5)	**8.6** – 11.0 ave = 9.8 (n=5)	Conditions stable since 1999 but objectives not met
	Mahood Cr (0300056) – tributary	8.5 – 13.4 ave = 10.9 (n=36) 1974-83	8.6 – 13.2 (n=20)	**7.5** – 11.0 ave = 9.55 (n=7)	**8.7** – 11.7 ave = 10.0 (n=5)	**7.9 – 9.8** ave = 9.0 (n=5)	Conditions slightly degraded since 2002
	Hyland Cr (E207718) – tributary	n/a	8.1 – 11.4 (n=20)	n/a	**8.4 – 10.4** ave = 9.1 (n=5)	**8.7 – 11.0** ave = 10.2 (n=5)	Conditions fairly stable since 1990
Total Lead (µg/L) ≤5 µg/L average 10 µg/L maximum (Nicomekl R objectives)	Serpentine R (0300059) Upstream	<1 – <100 med = 5 (n=39)	n/a	0.69 (n=1) Oct 12/00	0.34 – 1.21 ave = 0.77 (n=5)	0.27 – 0.50 ave = 0.39 (n=5)	Condition stable & adequate
	Serpentine R (0300057) Near mouth	<1 – <100 med = 4 (n=39)	n/a	0.52 (n=1) Oct 12/00	0.27 – 0.92 ave = 0.59 (n=5)	0.30 – 0.78 ave = 0.55 (n=5)	
	Latimer Cr (E276637) – tributary	n/a	n/a	0.18 (n=1) Oct 12/00	0.06 – 0.55 ave = 0.24 (n=5)	<0.2 – 0.6 ave = 0.4 (n=5)	
	Mahood Cr (0300056) – tributary	<1 – <100 med = 4 (n=36)	n/a	0.3 (n=1) Oct 12/00	0.29 – 2.29 ave = 0.94 (n=5)	0.2 – 1.3 ave = 0.6 (n=5)	
	Hyland Cr (E207718) – tributary	n/a	n/a	n/a	0.34 – 3.18 ave = 1.33 (n=5)	0.3 – 0.5 ave = 0.4 (n=5)	

Notes: values include: ranges and average (ave) [1971-1983 results taken from tabulated Data (MEP, 1988a)]; results that exceeded objectives are in bold.

5.0 CONCLUSIONS

Since water quality objectives had not been monitored since 2002, the Ministry prioritized attainment monitoring in the Little Campbell, Nicomekl, and Serpentine Rivers and their tributaries in 2009. It was also a priority to assess water quality within the three basins over the last 40 years, to determine where future efforts could be focused to deal with outstanding pollution issues or specific areas of concern. In addition, the Boundary Bay tributaries were monitored as part of a larger monitoring collaboration through the *Boundary Bay Assessment and Monitoring Program* partnership led by Metro Vancouver.

The Little Campbell River

In 2009, objectives for fecal coliforms, pH, ammonia, and nitrite were generally met at all three sites sampled in the Little Campbell River, although there were seasonal differences. **Objectives for dissolved oxygen (DO) were not met in either season, while suspended solids and turbidity objectives were not met in the fall**.

During **summer** sampling (August 2009), objectives were not met for fecal coliforms at the upstream site, while there were minor exceedences of the pH objective at the downstream sites. It should also be noted that the provincial recreation criterion for *E. coli* was met in the summer at downstream sites, but not at the upstream site. During **fall** sampling (November 2009), DO, suspended solids, and turbidity objectives were not met at any site, particularly during the first flush period in late October 2009. Similar to historical levels, DO was particularly low at the upstream site, ranging from 0.1-0.3 mg/L in the summer, and 1.8-4.7 mg/L in the fall. Thus, DO remains a concern in the river, as does bacterial levels at times. While objectives for suspended solids and turbidity were not met in 2009, there has been some improvement since 1990.

The **Water Quality Index (WQI) rating** for the Little Campbell River was **Fair (index=65) in the fall of 2009**, which was an improvement over the Marginal rating (index=52) of 2002. The summer 2009 rating was also Fair, with the same index value. **Thus, while water use for aquatic life is still not adequately protected in the Little Campbell River, due mainly to DO and sedimentation conditions**, uses for recreation, irrigation, and livestock watering appear to be adequate at this time.

The Nicomekl River and its tributaries

In 2009, objectives for fecal coliforms, ammonia, nitrite, suspended solids, pH and lead were generally met in the Nicomekl River and its tributaries, with a few exceptions. Minimum DO objectives were not met in summer on several occasions in the Nicomekl main stem and the tributaries, and was not met at any time in the fall due to a higher DO minimum (11 mg/L) and lower DO values (2.6-6.9 mg/L). The turbidity objective was also not met on several occasions in the Nicomekl main stem during fall sampling,

although the exceedences were not large. Additionally, the provincial *E. coli* criterion was generally not met in either summer or fall, particularly in the tributaries.

In general, water quality indicators in the Nicomekl main stem and tributaries are stable or have improved since 1972. However, fecal coliform levels were found to be higher in 2009 at the midstream Nicomekl site and in the tributaries than in 2002. Additionally, DO levels were significantly lower at both Nicomekl and tributary sites in 2009 compared to previous years. This is of particular concern for aquatic life, which require high DO levels in the fall when spawning.

The **WQI ratings** for the **Nicomekl River and its tributaries** were **Fair in the fall of 2009** (indices of 77 to 79), which was a decline from the 2002 Good ratings for all three waterbodies (index values of 91). The summer 2009 ratings were considerably better, with Good ratings for Nicomekl River (index value=81) and Murray Creek (index value=89), and an Excellent rating for Anderson Creek (index value=100). **Water use for aquatic life, however, may not be adequately protected at times in the Nicomekl River and tributaries, due mainly to low DO conditions**. Other uses, including irrigation and livestock watering, are protected at this time.

The Serpentine River and its tributaries

Objectives for fecal coliforms, ammonia, nitrite, suspended solids, and pH were generally met in 2009 at sites in the Serpentine River and its tributaries, with some exceptions. The provincial *E. coli* criterion and long-term fecal coliform objective were not met at both Serpentine sites in the fall, while suspended solids and turbidity objectives were not met at the downstream site on several occasions. Minimum DO objectives were not met in summer or fall on several occasions in the Serpentine main stem and the tributaries. DO values were particularly low in the main stem during fall sampling (2.4-8.1 mg/L), which is a degradation of conditions since 2002. This may indicate an influx of oxygen-demanding substances from stormwater and agricultural sources during first flush periods.

While there has been improvement in fecal coliform levels at the downstream Serpentine River location since 1990, there has not been a significant improvement at the upstream location. There have been improvements in fecal coliform levels in all three tributaries since 1990, although 2009 levels did exceed long-term objectives. Since 1990, there have also been improvements in ammonia, nitrite and suspended solids in the Serpentine main stem and tributaries. The most notable difference was a decline in DO conditions during the fall period compared to previous sampling periods. This is of particular concern for aquatic life and salmonids, which are spawning in the Serpentine's tributaries during this period when the first flush is also occurring. PCB sampling in Mahood Creek and the Serpentine main stem in 2008 showed levels generally below the objective, except in a water, sediment and tissue (juvenile coho) sample collected nearest to the BC Hydro facility in Mahood Creek, which were 3, 10 and 4 times higher than the relevant objectives, respectively.

The **WQI rating** for the **Serpentine River** was **Fair** (index=66) during 2009 fall sampling, which was a decline from a Good rating in 2002 (index=81). The summer 2009 rating was considerably better, with a Good rating and index value of 93. Latimer, Mahood and Hyland Creeks had Good ratings in 2009, with values of 86, 84 and 89, respectively. These values are similar to those found in 2002, which ranged from 82 to 91. During 2009 summer sampling, the WQI ratings were also Good. While the WQI ratings are good, **conditions in the Serpentine River and its tributaries do not appear to be adequate at times for the protection of aquatic life, particularly during first flush periods when fish spawning also occurs.**

6.0 RECOMMENDATIONS

To ensure **dissolved oxygen, bacteriological and suspended solids conditions continue to improve in the Little Campbell, Nicomekl, and Serpentine Rivers**, it is recommended that:

- priority be given to reducing the anthropogenic contributions through education, source identification and where necessary, compliance and enforcement.
- the source(s) of continuing bacteriological contamination in all three rivers be identified and remediated. Future monitoring should focus on further identifying sources within the three watersheds and use this information to address and remediate.
- where necessary, the Ministry continues to support joint initiatives aimed at investigating bacteriological contaminant sources in the Little Campbell River system. The Ministry may also contribute limited staff resources and/or funding to the further development of a Watershed Management Plan for the drainage.
- the Ministry continue to participate with the Boundary Bay Assessment and Monitoring Program partnership.

7.0 REFERENCES

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Water Quality Objectives for Boundary Bay Tributaries					
Watershed	**Little Campbell River**	**Mahood, Latimer and Hyland Creeks**	**Serpentine River**	**Nicomekl River**	**Anderson and Murray Creeks**
Designated Water Use	***aquatic life, wildlife, irrigation, livestock watering, primary-contact recreation***	***aquatic life, wildlife, irrigation, livestock watering***			
Fecal Coliform MPN/100mL	≤200 MPN/100 mL as a geometric mean (Apr-Oct), ≤400 MPN/100 mL as a 90th percentile (Apr-Oct)	≤1000 MPN/100 mL as a geometric mean (Apr-Oct), ≤4000 MPN/100 mL as a maximum (Apr-Oct)			
	n/a	≤200 MPN/100 mL as a geometric mean year round (long-term objective)			
Total Suspended Solids	10 mg/L maximum increase when upstream values are ≤ 100 mg/L, 10% maximum increase when upstream values > 100 mg/L				
Turbidity	5 NTU maximum increase when upstream values are ≤50 NTU, 10% maximum increase when upstream values >50 NTU				
Dissolved Oxygen	6.0 mg/L minimum (Jun-Oct)	8.0 mg/L minimum	6.0 mg/L minimum (Jun-Oct)		8.0 mg/L minimum
	8.0 m/gL minimum longterm (Jun-Oct)	n/a	8.0 m/gL minimum longterm (Jun-Oct)		n/a
	11.0 m/gL minimum when salmonid eggs, larvae or alevin are present				
Ammonia - N	30-day average and maximum for protection of aquatic life - pH & temperature dependent (**see Ammonia Tables)**				
Nitrite - N	0.2 mg/L (average) and 0.6 mg/L (maximum) when chloride >10 mg/L for protection of aquatic life				
Periphyton chlorophyll *a*	50 mg/m^2 maximum average	100 mg/m^2 maximum average (long-term objective)		100 mg/m^2 maximum average	
pH	6.5 to 8.5	6.5 to 8.5 or 0.2 maximum increase when u/s is <8.5			
Lead	n/a			0.005 mg/L average, 0.010 mg/L max	n/a
PCBs	n/a	0.001 ug/L maximum in water; 0.03 ug/g dry weight maximum in bottom surface sediments; 0.1 ug/g wet wt in whole small fish subject to predation; 0.5 ug/g wet wt in muscle of larger fish eaten by humans		n/a	

link: http://www.env.gov.bc.ca/wat/wq/objectives/boundarybay/boundarybay.html

Water quality guidelines for nitrite to protect aquatic life (MEP, 1988b)

Chloride Concentration (mg/L)	Maximum Nitrite Concentration (mg/L-N)	30-day Average Nitrite Concentration (mg/L-N)
< 2	0.06	0.02
2 – 4	0.12	0.04
4 – 6	0.18	0.06
6 – 8	0.24	0.08
8 – 10	0.30	0.10
> 10	0.60	0.20

Average 30-day Concentration of Total Ammonia Nitrogen for Protection of Aquatic Life (mg/L of Nitrogen)

Temperature (T) in degrees Celsius

pH	T=0.0	T=1.0	T=2.0	T=3.0	T=4.0	T=5.0	T=6.0	T=7.0	T=8.0	T=9.0	T=10.0
6.5	2.08	2.05	2.02	1.99	1.97	1.94	1.92	1.9	1.88	1.86	1.84
6.6	2.08	2.05	2.02	1.99	1.97	1.94	1.92	1.9	1.88	1.86	1.84
6.7	2.08	2.05	2.02	1.99	1.97	1.94	1.92	1.9	1.88	1.86	1.84
6.8	2.08	2.05	2.02	1.99	1.97	1.94	1.92	1.9	1.88	1.86	1.84
6.9	2.08	2.05	2.02	1.99	1.97	1.94	1.92	1.9	1.88	1.86	1.84
7	2.08	2.05	2.02	1.99	1.97	1.94	1.92	1.9	1.88	1.86	1.84
7.1	2.08	2.05	2.02	1.99	1.97	1.94	1.92	1.9	1.88	1.86	1.84
7.2	2.08	2.05	2.02	1.99	1.97	1.95	1.92	1.9	1.88	1.86	1.85
7.3	2.08	2.05	2.02	1.99	1.97	1.95	1.92	1.9	1.88	1.86	1.85
7.4	2.08	2.05	2.02	2	1.97	1.95	1.92	1.9	1.88	1.87	1.85
7.5	2.08	2.05	2.02	2	1.97	1.95	1.93	1.91	1.88	1.87	1.85
7.6	2.09	2.05	2.03	2	1.97	1.95	1.93	1.91	1.89	1.87	1.85
7.7	2.09	2.05	2.03	2	1.98	1.95	1.93	1.91	1.89	1.87	1.86
7.8	1.78	1.75	1.73	1.71	1.69	1.67	1.65	1.63	1.62	1.6	1.59
7.9	1.5	1.48	1.46	1.44	1.43	1.41	1.39	1.38	1.36	1.35	1.34
8	1.26	1.24	1.23	1.21	1.2	1.18	1.17	1.16	1.15	1.14	1.13
8.1	1	0.989	0.976	0.963	0.952	0.942	0.932	0.922	0.914	0.906	0.899
8.2	0.799	0.788	0.777	0.768	0.759	0.751	0.743	0.736	0.73	0.724	0.718
8.3	0.636	0.628	0.62	0.613	0.606	0.599	0.594	0.588	0.583	0.579	0.575
8.4	0.508	0.501	0.495	0.489	0.484	0.479	0.475	0.471	0.467	0.464	0.461
8.5	0.405	0.4	0.396	0.381	0.387	0.384	0.38	0.377	0.375	0.372	0.37
8.6	0.324	0.32	0.317	0.313	0.31	0.308	0.305	0.303	0.301	0.3	0.298
8.7	0.26	0.257	0.254	0.251	0.249	0.247	0.246	0.244	0.243	0.242	0.241
8.8	0.208	0.206	0.204	0.202	0.201	0.2	0.198	0.197	0.197	0.196	0.196
8.9	0.168	0.166	0.165	0.163	0.162	0.161	0.161	0.16	0.16	0.16	0.16
9	0.135	0.134	0.133	0.132	0.132	0.131	0.131	0.131	0.131	0.131	0.131

Temperature (T) in degrees Celsius

pH	T=11.0	T=12.0	T=13.0	T=14.0	T=15.0	T=16.0	T=17.0	T=18.0	T=19.0	T=20.0
6.5	1.82	1.81	1.8	1.78	1.77	1.64	1.52	1.41	1.31	1.22
6.6	1.82	1.81	1.8	1.78	1.77	1.64	1.52	1.41	1.31	1.22
6.7	1.83	1.81	1.8	1.78	1.77	1.64	1.52	1.41	1.31	1.22
6.8	1.83	1.81	1.8	1.78	1.77	1.64	1.52	1.42	1.32	1.22
6.9	1.83	1.81	1.8	1.78	1.77	1.64	1.53	1.42	1.32	1.22
7	1.83	1.81	1.8	1.79	1.77	1.64	1.53	1.42	1.32	1.22
7.1	1.83	1.81	1.8	1.79	1.77	1.65	1.53	1.42	1.32	1.23
7.2	1.83	1.81	1.8	1.79	1.78	1.65	1.53	1.42	1.32	1.23
7.3	1.83	1.82	1.8	1.79	1.78	1.65	1.53	1.42	1.32	1.23
7.4	1.83	1.82	1.8	1.79	1.78	1.65	1.53	1.42	1.32	1.23
7.5	1.83	1.82	1.81	1.8	1.78	1.66	1.54	1.43	1.33	1.23
7.6	1.84	1.82	1.81	1.8	1.79	1.66	1.54	1.43	1.33	1.24
7.7	1.84	1.83	1.81	1.8	1.79	1.66	1.54	1.44	1.34	1.24
7.8	1.57	1.56	1.55	1.54	1.53	1.42	1.32	1.23	1.14	1.07
7.9	1.33	1.32	1.31	1.31	1.3	1.21	1.12	1.04	0.97	0.904
8	1.12	1.11	1.1	1.1	1.09	1.02	0.944	0.878	0.818	0.762
8.1	0.893	0.887	0.882	0.878	0.874	0.812	0.756	0.704	0.655	0.611
8.2	0.714	0.709	0.706	0.703	0.7	0.651	0.606	0.565	0.527	0.491
8.3	0.571	0.568	0.566	0.564	0.562	0.523	0.487	0.455	0.424	0.396
8.4	0.458	0.456	0.455	0.453	0.452	0.421	0.393	0.367	0.343	0.321
8.5	0.369	0.367	0.366	0.366	0.365	0.341	0.318	0.298	0.278	0.261
8.6	0.297	0.297	0.296	0.296	0.296	0.277	0.259	0.242	0.227	0.213
8.7	0.241	0.24	0.24	0.241	0.241	0.226	0.212	0.198	0.186	0.175
8.8	0.196	0.196	0.196	0.197	0.198	0.185	0.174	0.164	0.154	0.145
8.9	0.16	0.161	0.161	0.162	0.163	0.153	0.144	0.136	0.128	0.121
9	0.132	0.132	0.133	0.134	0.135	0.128	0.121	0.114	0.108	0.102

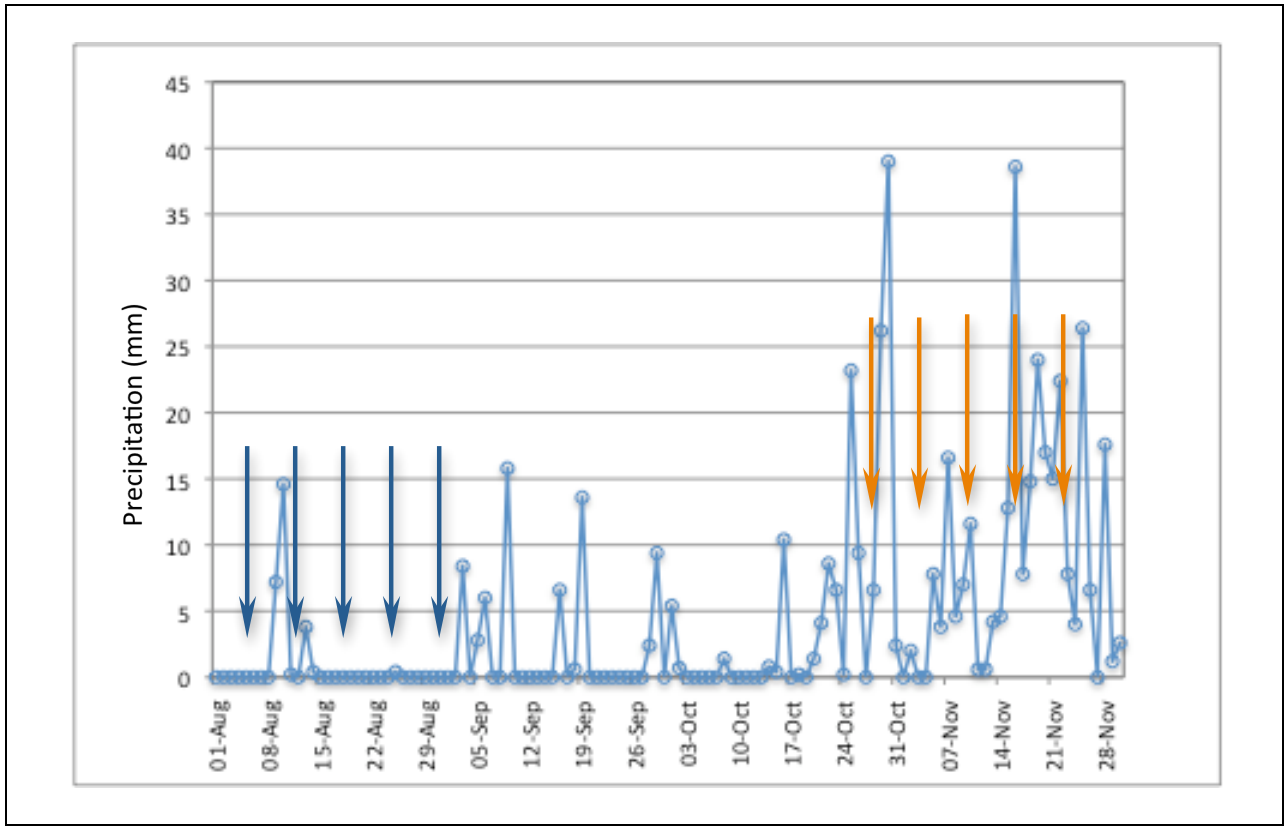
Maximum Concentration of Total Ammonia Nitrogen for Protection of Aquatic Life (mg/L of Nitrogen)

Temperature (T) in degrees Celsius

pH	T = 0.0	T = 1.0	T = 2.0	T = 3.0	T = 4.0	T = 5.0	T = 6.0	T = 7.0	T = 8.0	T = 9.0	T = 10.0
6.5	27.7	28.3	27.9	27.5	27.2	26.8	26.5	26.2	26	25.7	25.5
6.6	27.9	27.5	27.2	26.8	26.4	26.1	25.8	25.5	25.2	25	24.7
6.7	26.9	26.5	26.2	25.9	25.5	25.2	24.9	24.6	24.4	24.1	23.9
6.8	25.8	25.5	25.1	24.8	24.5	24.2	23.9	23.6	23.4	23.1	22.9
6.9	24.6	24.2	23.9	23.6	23.3	23	22.7	22.5	22.2	22	21.8
7	23.2	22.8	22.5	22.2	21.9	21.6	21.4	21.1	20.9	20.7	20.5
7.1	21.6	21.3	20.9	20.7	20.4	20.2	19.9	19.7	19.5	19.3	19.1
7.2	19.9	19.6	19.3	19	18.8	18.6	18.3	18.1	17.9	17.8	17.6
7.3	18.1	17.8	17.5	17.3	17.1	16.9	16.7	16.5	16.3	16.2	16
7.4	16.2	16	15.7	15.5	15.3	15.2	15	14.8	14.7	14.5	14.4
7.5	14.4	14.1	14	13.8	13.6	13.4	13.3	13.1	13	12.9	12.7
7.6	12.6	12.4	12	11.9	11.9	11.7	11.6	11.5	11.4	11.3	11.2
7.7	10.8	10.7	10.5	10.4	10.3	10.1	10	9.92	9.83	9.73	9.65
7.8	9.26	9.12	8.98	8.88	8.77	8.67	8.57	8.48	8.4	8.32	8.25
7.9	7.82	7.71	7.6	7.51	7.42	7.33	7.25	7.17	7.1	7.04	6.98
8	6.55	6.46	6.37	6.29	6.22	6.14	6.08	6.02	5.96	5.91	5.86
8.1	5.21	5.14	5.07	5.01	4.95	4.9	4.84	4.8	4.75	4.71	4.67
8.2	4.15	4.09	4.04	3.99	3.95	3.9	3.86	3.83	3.8	3.76	3.74
8.3	3.31	3.27	3.22	3.19	3.15	3.12	3.09	3.06	3.03	3.01	2.99
8.4	2.64	2.61	2.57	2.54	2.52	2.49	2.47	2.45	2.43	2.41	2.4
8.5	2.11	2.08	2.06	2.03	2.01	1.99	1.98	1.96	1.95	1.94	1.93
8.6	1.69	1.67	1.65	1.63	1.61	1.6	1.59	1.58	1.57	1.56	1.55
8.7	1.35	1.33	1.32	1.31	1.3	1.29	1.28	1.27	1.26	1.26	1.25
8.8	1.08	1.07	1.06	1.05	1.04	1.04	1.03	1.03	1.02	1.02	1.02
8.9	0.871	0.863	0.856	0.849	0.844	0.839	0.836	0.833	0.832	0.831	0.831
9	0.703	0.697	0.692	0.688	0.685	0.682	0.681	0.681	0.681	0.681	0.682

Temperature (T) in degrees Celsius

pH	T = 11.0	T = 12.0	T = 13.0	T = 14.0	T = 15.0	T = 16.0	T = 17.0	T = 18.0	T = 19.0	T = 20.0
6.5	25.2	25	24.8	24.6	24.5	24.3	24.2	24	23.9	23.8
6.6	24.5	24.3	24.1	23.9	23.8	23.6	23.5	23.3	23.3	23.2
6.7	23.7	23.5	23.3	23.1	23	22.8	22.7	22.6	22.5	22.4
6.8	22.7	22.5	22.3	22.2	22	21.9	21.8	21.7	21.6	21.5
6.9	21.6	21.4	21.3	21.1	21	20.8	20.7	20.6	20.5	20.4
7	20.3	20.2	20	19.9	19.7	19.6	19.5	19.4	19.3	19.2
7.1	18.9	18.8	18.7	18.5	18.4	18.3	18.2	18.1	18	17.9
7.2	17.4	17.3	17.2	17.1	16.9	16.8	16.8	16.7	16.6	16.5
7.3	15.9	15.7	15.6	15.5	15.4	15.3	15.2	15.2	15.1	15.1
7.4	14.2	14.1	14	13.9	13.9	13.8	13.7	13.6	13.6	13.5
7.5	12.6	12.5	12.4	12.4	12.3	12.2	12.2	12.1	12.1	12
7.6	11.1	11	10.9	10.8	10.8	10.7	10.7	10.6	10.6	10.5
7.7	9.57	9.5	9.43	9.37	9.31	9.26	9.22	9.18	9.15	9.12
7.8	8.18	8.12	8.07	8.02	7.97	7.93	7.9	7.87	7.84	7.82
7.9	6.92	6.88	6.83	6.79	6.75	6.72	6.69	6.67	6.65	6.64
8	5.81	5.78	5.74	5.71	5.68	5.66	5.62	5.61	5.6	5.74
8.1	4.64	4.61	4.59	4.56	4.54	4.53	4.51	4.5	4.49	4.49
8.2	3.71	3.69	3.67	3.65	3.64	3.63	3.62	3.61	3.61	3.61
8.3	2.97	2.96	2.94	2.93	2.92	2.92	2.91	2.91	2.91	2.91
8.4	2.38	2.37	2.36	2.36	2.35	2.35	2.35	2.35	2.35	2.36
8.5	1.92	1.91	1.91	1.9	1.9	1.9	1.9	1.9	1.91	1.92
8.6	1.55	1.54	1.54	1.54	1.54	1.54	1.55	1.56	1.56	1.57
8.7	1.25	1.25	1.25	1.25	1.25	1.26	1.26	1.27	1.28	1.29
8.8	1.02	1.02	1.02	1.02	1.03	1.03	1.04	1.05	1.06	1.07
8.9	0.832	0.834	0.838	0.842	0.847	0.853	0.861	0.87	0.88	0.891
9	0.684	0.688	0.692	0.698	0.704	0.711	0.72	0.729	0.74	0.752



Daily precipitation at the Vancouver International Airport from August 1 to November 30, 2009, showing summer sampling dates (dark blue arrows) and fall sampling dates (orange arrows)

Little Campbell River (LCR) raw field and bacteriological data – 2009

Site	Season	Date	pH	Specific conductance (µS/cm)	Water Temp (^{0}C)	Dissolved Oxygen (mg/L)	Fecal Coliforms (CFU/100 mL)	*E. coli* (CFU/100 mL)	Entero-cocci (CFU/100 mL)
LCR (0300066) Upstream	Summer (dry)	Aug 5	7.61	202	14.88	0.13	200	160	n/a
		Aug 12	7.34	205	12.61	0.12	300	180	
		Aug 19	7.93	208	13.65	0.25	460	240	
		Aug 26	6.80	213	12.05	0.20	360	220	
		Sep 2	7.15	192	13.36	0.11	98	74	
LCR (0300065) Downstream		Aug 5	8.58	324	16.27	7.11	110	99	n/a
		Aug 12	7.74	282	15.48	5.38	390	210	
		Aug 19	8.56	343	16.57	6.98	250	130	
		Aug 26	7.83	363	14.01	5.78	62	29	
		Sep 2	8.07	349	15.22	6.74	86	34	
LCR (E262901) near mouth		Aug 5	8.09	12040	19.88	9.21	17	12	<1
		Aug 12	7.70	1842	16.50	6.92	460	160	47
		Aug 19	8.86	9999	21.65	12.58	94	92	25
		Aug 26	7.42	14800	16.04	4.92	160	86	10
		Sep 2	8.21	11983	17.74	9.88	65	21	18
LCR (0300066) Upstream	Fall (wet)	Oct 27	7.09	212	7.38	1.90	480	480	n/a
		Nov 3	7.52	177	6.78	1.75	120	110	
		Nov 10	7.12	172	6.72	3.24	560	n/a	
		Nov 17	7.26	144	7.08	4.49	510	310	
		Nov 24	7.33	109	6.50	4.66	44	35	
LCR (0300065) Downstream		Oct 27	7.87	258	8.18	3.03	540	540	n/a
		Nov 3	8.06	242	7.72	3.59	990	990	
		Nov 10	7.59	222	7.43	5.39	860	860	
		Nov 17	7.56	154	7.65	6.01	1700	1300	
		Nov 24	7.32	135	6.90	6.28	400	280	
LCR (E262901) near mouth		Oct 27	6.98	25700	8.64	2.97	5400	5400	7800
		Nov 3	7.08	16000	8.78	2.58	350	89	120
		Nov 10	7.23	31450	7.53	3.20	4600	4600	710
		Nov 17	7.66	564	8.14	6.52	2000	2000	2900
		Nov 24	7.57	216	7.22	5.64	1700	200	490

Note: values highlighted in red exceed water quality objectives (see Appendix A)

Little Campbell River (LCR) water quality data – 2009

Site	Season	Date	Turbidity (NTU)	Total Suspended Solids (mg/L)	Ammonia -N (mg/L)	Nitrite-N (mg/L)	Nitrate-N (mg/L)	Hardness (mg/L)	Lead (µg/L)
LCR (0300066) Upstream	Summer (dry)	Aug 5	39.1	25	0.023	<0.002	<0.002	68.8	0.044
		Aug 12	34.5	27	0.070	0.002	<0.002	58.8	0.023
		Aug 19	35.6	37	0.094	0.002	<0.002	67.6	0.049
		Aug 26	47.7	34	0.282	0.002	0.005	68.6	0.199
		Sep 2	29.7	27	0.026	<0.002	0.009	67.9	0.125
LCR (0300065) Downstream		Aug 5	2.0	2	<0.005	0.004	0.276	87.6	0.056
		Aug 12	3.3	4	0.022	0.008	0.589	62.3	0.055
		Aug 19	2.3	2	<0.005	0.005	0.216	77.7	0.028
		Aug 26	3.5	<4	0.012	0.005	0.469	83.0	0.066
		Sep 2	2.6	2	<0.005	0.009	0.887	97.2	0.036
LCR (E262901) near mouth		Aug 5	4.3	7	<0.005	0.004	0.039	1240	0.42
		Aug 12	5.5	4	0.024	0.017	0.558	210	0.182
		Aug 19	2.6	8	0.005	0.002	0.023	1140	0.21
		Aug 26	3.3	12	0.056	0.006	0.037	1920	0.2
		Sep 2	4.0	6	0.015	0.008	0.136	1440	0.10
LCR (0300066) Upstream	Fall (wet)	Oct 27	3.5	1	0.024	0.020	1.35	62.0	0.144
		Nov 3	7.7	5	0.040	0.016	3.03	70.9	0.144
		Nov 10	1.4	<1	0.007	0.004	0.841	50.7	0.223
		Nov 17	3.9	5	0.013	0.008	1.38	38.0	0.337
		Nov 24	1.9	<1	<0.005	0.005	1.39	31.5	0.080
LCR (0300065) Downstream		Oct 27	11.2	6	0.019	0.014	2.18	69.9	0.201
		Nov 3	5.7	3	0.033	0.011	1.06	66.0	0.118
		Nov 10	6.6	5	0.009	0.010	0.992	66.6	0.154
		Nov 17	26.1	20	0.025	0.013	1.56	42.5	0.374
		Nov 24	8.8	7	0.007	0.011	1.43	35.6	0.140
LCR (E262901) near mouth		Oct 27	18.6	49	<0.005	0.003	1.86	1200	0.56
		Nov 3	4.6	8	0.075	0.011	0.895	1350	0.18
		Nov 10	8.7	22	0.121	0.009	0.631	3370	0.4
		Nov 17	27.2	30	0.066	0.017	1.93	81.9	0.583
		Nov 24	8.8	5	<0.005	0.012	1.64	52.3	0.195

Note: values highlighted in red exceed water quality objectives (see Appendix A)

Nicomekl River and tributaries raw field and bacteriological data (includes triplicate results) – 2009

Site	Season	Date	pH	Specific conductance (µS/cm)	Water Temp (^{0}C)	Dissolved Oxygen (mg/L)	Fecal Coliforms (CFU/100 mL)	*E. coli* (CFU/100 mL)	Entero-cocci (CFU/100 mL)
Nicomekl River (0300062) Upstream	Summer (dry)	Aug 5	7.74	339	17.44	7.95	440	430	n/a
		Aug 12	7.83	230	16.20	7.51	360	40	
		Aug 19	8.02	250	17.72	7.08	84	43	
		Aug 26	7.68	260	14.54	6.92	150	40	
		Sep 2	7.92	257	16.48	6.56	84	64	
Murray Cr (0300064) – tributary		Aug 5	8.08	171	14.67	9.44	94	37	n/a
		Aug 12	7.74	215	14.38	7.45	1500	1500	
		Aug 19	7.90	196	14.56	7.50	220	170	
		Aug 26	7.68	196	12.76	6.50	280	78	
		Sep 2	7.89	197	13.79	6.91	250	53	
Anderson Cr (0300063) – tributary		Aug 5	7.89	230	13.06	10.39	150	150	n/a
		Aug 12	7.76	229	12.34	10.15	290	160	
		Aug 19	8.05	234	13.66	9.14	240	240	
		Aug 26	7.81	235	12.04	8.94	130	35	
		Sep 2	7.86	235	13.03	9.53	190	190	
Nicomekl River (0300061) Midstream		Aug 5	7.93	323	16.17	9.86	290	230	n/a
		Aug 12	7.72	284	16.10	7.51	1300	1300	
		Aug 19	8.13	334	17.19	8.56	670	660	
		Aug 26	7.74	319	14.34	9.15	640	240	
		Sep 2	8.03	325	15.75	8.80	670	230	
Nicomekl R (0300060) Near mouth		Aug 5	8.58	1443	21.90	8.23	49, 37, 23	4, 6, 3	70, 40, 60
		Aug 12	7.76	685	19.31	3.45	320	160	76
		Aug 19	8.26	340	20.07	11.33	240, 13, 220	11, <1, 4	6, 4, 40
		Aug 26	7.91	1815	18.96	6.73	29	20	5
		Sep 2	8.14	1083	19.45	5.23	220, 230, 120	9, 27, 8	2, 1, 5
Nicomekl River (0300062) Upstream	Fall (wet)	Oct 27	7.54	226	8.34	3.81	430	430	n/a
		Nov 3	7.58	234	7.86	2.80	130	120	
		Nov 10	7.46	214	7.81	5.75	160	89	
		Nov 17	7.49	141	7.83	5.58	1900	710	
		Nov 24	7.38	149	7.43	5.70	360	360	
Murray Cr (0300064) – tributary		Oct 27	7.48	211	8.23	4.26	520	520	n/a
		Nov 3	7.81	227	7.00	3.14	47	40	
		Nov 10	7.39	190	7.59	5.93	97	75	
		Nov 17	7.48	125	7.60	6.18	1100	700	
		Nov 24	7.31	119	7.28	6.78	290	290	
Anderson Cr (0300063) – tributary		Oct 27	7.38	233	8.64	4.64	440	440	n/a
		Nov 3	7.67	253	7.00	3.43	23	17	
		Nov 10	7.26	226	8.10	5.79	98	74	
		Nov 17	7.33	153	7.88	6.41	980	660	
		Nov 24	7.38	143	7.40	5.79	380	380	
Nicomekl River (0300061) Midstream		Oct 27	7.30	231	8.93	3.41	770	770	n/a
		Nov 3	7.60	293	8.59	2.83	270	120	
		Nov 10	7.32	243	8.28	5.02	270	140	
		Nov 17	7.12	133	7.98	5.82	1200	880	
		Nov 24	7.32	162	7.47	5.04	370	280	
Nicomekl R (0300060) Near mouth		Oct 27	7.35	283	9.35	3.46	360, 440, 690	360, 440, 690	2100, 2200, 2000
		Nov 3	7.36	448	8.70	2.56	130	80	100
		Nov 10	7.50	378	8.56	3.86	290, 350, 280	180, 210, 140	470, 640, 490
		Nov 17	7.80	305	8.40	6.86	1400	880	1400
		Nov 24	7.38	398	7.25	6.09	450, 270, 410	250, 50, 330	810, 380, 730

Note: values highlighted in red exceed water quality objectives (see Appendix A)

Nicomekl River and tributaries water quality data (includes triplicate results) – 2009

Site	Season	Date	Turbidity (NTU)	Total Suspended Solids (mg/L)	Ammonia -N (mg/L)	Nitrite-N (mg/L)	Nitrate-N (mg/L)	Hardness (mg/L)	Lead (µg/L)
Nicomekl River (0300062) Upstream	Summer (dry)	Aug 5	3.1	3	<0.005	0.007	2.40	76.7	0.056
		Aug 12	3.7	3	0.019	0.006	1.65	57.7	0.075
		Aug 19	3.3	3	<0.005	0.006	1.41	67.9	0.452
		Aug 26	3.7	<4	<0.005	0.004	2.11	65.5	0.068
		Sep 2	3.3	4	0.007	0.005	2.31	77.4	0.127
Murray Cr (0300064) – tributary		Aug 5	1.9	1	<0.005	0.007	1.36	70.8	0.042
		Aug 12	7.1	6	0.016	0.016	2.08	58.9	0.070
		Aug 19	1.9	2	<0.005	0.007	1.19	81.1	0.038
		Aug 26	1.4	<4	<0.005	0.005	1.58	70.1	0.092
		Sep 2	1.6	2	<0.005	0.004	1.50	77.7	0.023
Anderson Cr (0300063) – tributary		Aug 5	0.7	<1	<0.005	0.006	3.04	87.8	0.017
		Aug 12	0.8	1	<0.005	<0.002	3.46	67.6	0.012
		Aug 19	0.8	1	<0.005	0.007	3.11	85.9	0.017
		Aug 26	0.5	<4	<0.005	0.006	3.39	83.4	0.015
		Sep 2	0.9	1	<0.005	0.005	3.34	90.2	0.020
Nicomekl River (0300061) Midstream		Aug 5	2.1	3	<0.005	0.010	1.56	99.8	0.565
		Aug 12	4.4	7	0.038	0.015	1.60	78.8	0.455
		Aug 19	3.3	3	<0.005	0.011	1.73	87.1	0.231
		Aug 26	2.7	<4	<0.005	0.008	2.22	88.9	0.311
		Sep 2	2.7	3	0.006	0.014	2.68	96.4	0.203
Nicomekl R (0300060) Near mouth		Aug 5	11.9, 12.5	11, 11	<0.005, <0.005	<0.002, <0.002	<0.002, <0.002	180, 202	0.139, 0.163
		Aug 12	6.4	14	0.176	0.033	0.917	118	0.132
		Aug 19	9.7, 9.4	11, 11	0.065, 0.067	0.030, 0.032	0.252, 0.401	89.8, 84.3	0.154, 0.133
		Aug 26	7.9	12	0.011	0.005	0.005	226	0.146
		Sep 2	6.3, 4.8	6, 7	0.073, 0.075	0.013, 0.013	0.082, 0.081	176, 174	0.629*, 0.145
Nicomekl River (0300062) Upstream	Fall (wet)	Oct 27	13.5	9	0.034	0.017	4.64	65.4	0.218
		Nov 3	1.2	<1	0.019	0.006	0.737	49.2	0.107
		Nov 10	8.1	4	0.021	0.018	3.06	67.1	0.163
		Nov 17	31.2	37	0.066	0.015	2.99	42.0	0.372
		Nov 24	13.9	10	0.025	0.015	2.16	43.3	0.161
Murray Cr (0300064) – tributary		Oct 27	14.0	7	<0.005	0.016	5.34	60.1	0.217
		Nov 3	9.1	5	0.013	0.010	3.39	66.5	0.132
		Nov 10	8.3	5	0.008	0.012	3.67	60.7	0.164
		Nov 17	27.1	52	0.043	0.011	2.83	38.5	0.365
		Nov 24	9.6	11	0.019	0.013	2.11	35.3	0.127
Anderson Cr (0300063) – tributary		Oct 27	6.3	9	0.013	0.023	2.86	70.7	0.179
		Nov 3	1.3	1	0.018	0.013	2.91	81.7	0.040
		Nov 10	2.3	3	0.010	0.020	2.46	79.1	0.077
		Nov 17	19.2	65	0.041	0.017	2.17	44.7	0.377
		Nov 24	11.7	30	0.018	0.016	2.19	44.1	0.160
Nicomekl River (0300061) Midstream		Oct 27	18.0	14	0.008	0.019	2.99	60.2	0.794
		Nov 3	6.9	8	0.029	0.012	2.34	86.5	0.543
		Nov 10	10.2	10	<0.005	0.014	2.09	70.5	0.745
		Nov 17	35.1	31	0.032	0.013	1.87	36.7	0.715
		Nov 24	11.5	14	0.008	0.020	1.70	43.4	0.301
Nicomekl R (0300060) Near mouth		Oct 27	22.1, 27.6	17, 14	0.075, 0.045	0.021, 0.024	4.68, 4.88	83.2, 87.8	0.627, 0.727
		Nov 3	15.9	12	0.153	0.041	5.84	140	0.361
		Nov 10	13.4, 14.1	10, 9	0.076, 0.081	0.021, 0.022	3.96, 4.03	137, 136	0.397, 0.401
		Nov 17	28.9	25	0.108	0.019	3.51	84.4	0.950
		Nov 24	15.9, 17.0	12, 12	0.057, 0.080	0.010, 0.017	2.47, 2.46	77.4, 78.4	0.438, 0.414

(0. value may be erroneous

Note: values highlighted in red exceed water quality objectives (see Appendix A)

Serpentine River and tributaries raw field and bacteriological data – 2009

Site	Season	Date	pH	Specific conductance (µS/cm)	Water Temp (^{0}C)	Dissolved Oxygen (mg/L)	Fecal Coliforms (CFU/100 mL)	*E. coli* (CFU/100 mL)	Entero-cocci (CFU/10 0 mL)
Latimer Cr (E276637)* – tributary	Summer (dry)	Aug 5	7.9 (lab)	302 (lab)	n/a	3.8	470	270	n/a
		Aug 12	7.3 (lab)	n/a		5.4	1100	1100	
		Aug 19	6.8 (lab)	230 (lab)		3.8	100	100	
		Aug 26	7.1 (lab)	250 (lab)		5.7	180	150	
		Sep 2	7.2 (lab)	230 (lab)		6.5	50	40	
Serpentine River (0300059) Upstream		Aug 5	7.92	260	20.38	6.22	110	45	n/a
		Aug 12	7.55	229	19.11	3.45	1400	1400	
		Aug 19	8.17	258	21.53	9.73	71	68	
		Aug 26	8.02	254	17.69	7.39	93	88	
		Sep 2	7.62	326	19.63	4.32	330	86	
Mahood (Bear) Cr (0300056)* - tributary		Aug 5	8.2 (lab)	251 (lab)	n/a	5.4	350	350	n/a
		Aug 12	8.0 (lab)	191 (lab)		8.8	1800, 2400	1800, 2400	
		Aug 19	7.6 (lab)	220 (lab)		6.4	360	180	
		Aug 26	7.7 (lab)	240 (lab)		8.5	800	550	
		Sep 2	8.0 (lab)	220 (lab)		6.3	350	90	
Hyland Cr (E207718)* - tributary		Aug 5	8.0 (lab)	346 (lab)	n/a	4.2	150	95	n/a
		Aug 12	7.4 (lab)	330 (lab)		6.3	n/a	n/a	
		Aug 19	n/a	n/a		n/a	1000	<1000	
		Aug 26	7.0 (lab)	280 (lab)		6.1	130	130	
		Sep 2	7.1 (lab)	280 (lab)		5.9	130	75	
Serpentine River (0300057) - at mouth		Aug 5	8.09	2434	23.08	8.10	26	10	130
		Aug 12	7.61	2801	19.90	3.33	4000	1100	510
		Aug 19	8.11	301	20.14	9.48	120	11	20
		Aug 26	6.95	634	19.32	5.07	58	36	20
		Sep 2	7.68	1578	19.89	6.94	70	9	11
Latimer Cr (E276637)* – tributary	Fall (wet)	Oct 27	6.6 (lab)	140 (lab)	n/a	9.5	290	160	n/a
		Nov 4	7.5 (lab)	213 (lab)		8.6	60, 35	45, 25	
		Nov 9	6.7 (lab)	153 (lab)		10.0	200	180	
		Nov 17	7.1 (lab)	71 (lab)		10.0	490	480	
		Nov 24	6.5 (lab)	82 (lab)		11.0	110	85	
Serpentine River (0300059) Upstream		Oct 27	7.34	252	9.48	3.10	360	250	n/a
		Nov 3	7.76	300	8.48	2.53	460	310	
		Nov 10	7.64	137	8.21	4.78	330	220	
		Nov 17	7.39	112	8.26	5.06	640	380	
		Nov 24	7.45	149	7.79	4.79	120	110	
Mahood (Bear) Cr (0300056)* - tributary		Oct 27	7.3 (lab)	180 (lab)	n/a	7.9	720	260	n/a
		Nov 4	6.9 (lab)	170 (lab)		8.0	200	120	
		Nov 9	7.1 (lab)	110 (lab)		9.5	1100	540	
		Nov 17	7.2 (lab)	110 (lab)		9.8	2600	1200	
		Nov 24	7.2 (lab)	110 (lab)		9.8	960	580	
Hyland Cr (E207718)* - tributary		Oct 27	7.2 (lab)	295 (lab)	n/a	9.5	440, 530	250, 290	n/a
		Nov 4	7.0 (lab)	230 (lab)		8.7	35	20	
		Nov 9	7.1 (lab)	140 (lab)		11.0	480	340	
		Nov 17	7.1 (lab)	130 (lab)		11.0	600	360	
		Nov 24	7.1 (lab)	140 (lab)		11.0	300	60	
Serpentine River (0300057) - at mouth		Oct 27	7.38	204	9.04	4.02	280	280	1100
		Nov 3	7.74	371	8.79	2.44	200	60	57
		Nov 10	7.67	302	8.33	3.51	390	210	360
		Nov 17	8.14	184	8.69	8.10	530	210	1000
		Nov 24	7.55	206	7.53	5.88	220	140	410

(0. Sampled by the City of Surrey
Note: values highlighted in red exceed water quality objectives (see Appendix A)

Serpentine River and tributaries water quality data – 2009

Site	Season	Date	Turbidity (NTU)	Total Suspended Solids (mg/L)	Ammonia -N (mg/L)	Nitrite-N (mg/L)	Nitrate-N (mg/L)	Hardness (mg/L)	Lead (µg/L)
Latimer Cr (E276637)* – tributary	Summer (dry)	Aug 5	9.9	13	0.014	0.006	0.296	74.5	1.0
		Aug 12	n/a	3	0.031	0.009	0.318	51.2	0.7
		Aug 19	9.9	7	0.023	0.008	0.394	58.1	0.7
		Aug 26	n/a	3	0.020	0.007	0.456	64.4	0.9
		Sep 2		3	0.015	0.005	0.483	59.2	1.1
Serpentine River (0300059) Upstream		Aug 5	5.4	3	0.069	0.008	0.022	72.0	0.192
		Aug 12	5.8	6	0.191	0.024	0.450	51.1	0.220
		Aug 19	4.2	5	<0.005	0.013	0.084	76.7	0.339
		Aug 26	3.3	4	0.010	0.004	0.013	72.4	0.196
		Sep 2	7.8	6	0.026	0.008	0.036	83.3	0.253
Mahood (Bear) Cr (0300056)* - tributary		Aug 5	2.2	2	<0.005	0.006	0.241	98.4	5.2
		Aug 12	n/a, 2.3	2, 2	0.028, 0.032	0.007, 0.007	0.636, 0.636	68.0	0.7
		Aug 19	4.2	5	0.006	0.007	0.650	93.2	1.5
		Aug 26	n/a	3	0.062	0.020	0.823	107	1.5
		Sep 2		2	<0.005	0.004	0.566	87.6	0.7
Hyland Cr (E207718)* - tributary		Aug 5	4.5	3	0.052	0.009	0.144	123	0.8
		Aug 12	6.9	6	0.054	0.008	0.248	72.3	1.5
		Aug 19	n/a	6	0.048	0.007	0.180	110	1.2
		Aug 26		7	0.035	0.006	0.190	115	3.3
		Sep 2		5	0.026	0.005	0.164	103	1.4
Serpentine River (0300057) Downstream		Aug 5	10.7	12	<0.005	<0.002	0.002	316	0.134
		Aug 12	7.4	10	0.254	0.015	0.240	297	0.25
		Aug 19	5.5	7	0.038	0.019	0.070	67.1	0.248
		Aug 26	6.1	9	<0.005	0.002	0.007	101	0.292
		Sep 2	8.1	8	<0.005	<0.002	0.020	217	0.163
Latimer Cr (E276637)* – tributary	Fall (wet)	Oct 27	n/a	5	0.020	0.009	1.81	55.7	0.3
		Nov 4	5.0	2, 2	0.009, 0.016	0.006, 0.006	0.953, 0.921	63.4	<0.2
		Nov 9	n/a	3	<0.005	0.005	1.06	43.9	0.4
		Nov 17		10	0.007	0.007	1.51	37.6	0.6
		Nov 24		4	0.017	0.009	1.21	37.1	0.3
Serpentine River (0300059) Upstream		Oct 27	10.6	7	0.031	0.021	4.81	80.9	0.393
		Nov 3	6.0	6	0.100	0.023	2.09	78.7	0.303
		Nov 10	9.3	7	<0.005	0.010	1.57	44.4	0.501
		Nov 17	15.9	11	0.016	0.005	1.80	34.0	0.464
		Nov 24	8.0	6	0.014	0.014	1.88	44.0	0.268
Mahood (Bear) Cr (0300056)* - tributary		Oct 27	n/a	2	<0.005	0.008	2.11	88.0	0.4
		Nov 4		1	0.030	0.006	1.13	92.3	0.2
		Nov 10		7	<0.005	0.004	1.28	53.7	0.7
		Nov 17		20	0.579	0.005	1.89	55.9	1.3
		Nov 24		6	0.021	0.004	1.38	53.9	0.6
Hyland Cr (E207718)* - tributary		Oct 27	4.3	3, 3	0.011, 0.008	0.014, 0.016	2.53, 2.53	109	0.4
		Nov 3	n/a	3	0.044	0.012	1.42	108	0.4
		Nov 10		5	<0.005	0.005	1.04	63.0	0.5
		Nov 17		5	<0.005	0.007	2.34	76.6	0.5
		Nov 24		3	<0.005	0.004	1.77	69.9	0.3
Serpentine River (0300057) Downstream		Oct 27	16.4	16	0.049	0.016	2.47	62.7	0.784
		Nov 3	10.0	8	0.155	0.034	2.75	111	0.299
		Nov 10	12.0	9	0.074	0.021	2.91	104	0.499
		Nov 17	24.1	23	0.031	0.010	1.76	57.8	0.756
		Nov 24	13.7	9	<0.005	0.023	2.57	65.5	0.405

(0. Sampled by the City of Surrey

Note: values highlighted in red exceed water quality objectives (see Appendix A)

PCB Results from BC Hydro water, sediment and tissue sampling in Mahood/Bear Creek, Surrey Lake & Serpentine River – 2008 (Source: Azimuth Consulting Group, 2009)

Site	PCB congener				Objective
	Aroclor 1242	Aroclor 1254	Aroclor 1260	Sum	
PCBs in water (ng/L)					
Mahood (mid-field 1)	2.84	0.294	0.277	3.411	1 ng/L maximum in water (sum of Aroclor 1242, 1254 and 1260)
Mahood (far-field 2)	0.076	0.066	<0.0027	0.145	
Surrey Lake (mid-lake)	0.125	0.069	0.021	0.215	
Surrey Lake (eastern perimeter)	0.109	0.051	0.016	0.176	
Mahood (mouth)	0.153	0.073	0.043	0.269	
Serpentine (upstream of split)	0.075	<0.0058	0.046	0.126	
Serpentine (upstream of Bear Cr)	0.132	0.097	0.051	0.280	
Serpentine (downstream of Bear Cr)	0.123	0.246	0.097	0.466	
Serpentine (downstream of Bear Cr) – 2	0.096	0.109	0.030	0.235	
Serpentine (downstream of merge)	0.053	0.061	0.023	0.137	
Serpentine (mouth)	0.123	0.038	0.007	0.169	
PCBs in sediment (ng/g, dry weight)					
Mahood (mid-field 1)	294	21.1	6.63	321.73	30 ng/g dry weight maximum in bottom surface sediments (sum of Aroclor 1242, 1254 and 1260)
Mahood (far-field 2)	n/a				
Surrey Lake (mid-lake)	9.76	11.7	8.17	29.63	
Surrey Lake (eastern perimeter)	7.04	8.91	5.97	21.92	
Mahood (mouth)	0.52	3.34	5.33	9.19	
Serpentine (upstream of split)	0.46	3.94	2.3	6.70	
Serpentine (upstream of Bear Cr)	n/a				
Serpentine (downstream of Bear Cr)	n/a				
Serpentine (downstream of Bear Cr) – 2	n/a				
Serpentine (downstream of Bear Cr) – bank	0.7	2.53	1.49	4.82	
Serpentine (downstream of merge)	0.59	1.44	0.90	2.93	
Serpentine (mouth)	n/a				
Serpentine (mouth-east transect 1)	0.15	0.40	0.17	0.72	
Serpentine (mouth-west transect 2)	0.17	0.44	0.15	0.76	
Total PCBs in tissue (ng/g, wet weight), values in brackets are total PCBs, normalized to lipid (ng/g lipid)					
Sample sites	**Juvenile coho**	**Cutthroat trout**	**Rainbow trout**	**Three-spine stickleback**	**Prickly sculpin**
Mahood (mid-field 1)	401 (8605)	60.7 (1124)			
Mahood (far-field 2)	35.3 (654)	50.9 (1851)	31.9 (708), 33.6 (612)	72.7 (1364)	
Surrey Lake	22.7 (414)			31.6 (1963)	35.2 (882), 44.1 (723), 26 (415)
Mahood/Bear outflow				4.9 (571)	47.8 (898)
Serpentine (upstream)				12.8 (309)	
Serpentine (native channel downstream)				10.8 (603)	82.5 (3556)
Reference sites					
Nicomekl River				28.5 (463)	
Anderson Creek	17.6 (524)		12 (186), 8.6 (121), 9.6 (243)		8.4 (162), 6.4 (450), 7.5 (479)
King Creek		15.2 (422), 19.1 (681)			

Note: Values in red exceed objectives

Field and trip blanks – 2009

Site	Season	Date	Fecal Coliforms (CFU/100 mL)	*E. coli* (CFU/100 mL)	Turbidity (NTU)	Total Suspended Solids (mg/L)
Trip Blank	Summer	Aug 5	(<1, <1 Sry)		(0.1, 0.2 Sry)	(<1, <1 Sry)
		Aug 19	<1	<1	<0.1	<1
	Fall	Oct 27	(<1 Sry)		(<0.1 Sry)	(<1 Sry)
		Nov 10	<1	<1	<0.1	<1
Field Blank	Summer	Aug 5	<1	<1	<0.1	<1
		Aug 12	(<1 Sry)	(<1 Sry)	(0.1 Sry)	(<1 Sry)
		Aug 19	<1, (<1 Sry)	<1, (<1 Sry)	0.1, (0.2 Sry)	<1, (<1 Sry)
		Aug 26	<1 (Sry)	<1 (Sry)	(0.3 Sry)	(<1 Sry)
		Sep 2	<1, (<1 Sry)	<1, (<1 Sry)	<0.1 (0.1 Sry)	<1, (<1 Sry)
	Fall	Oct 27	<1, (<1 Sry)	<1, (<1 Sry)	<0.1 (0.1 Sry)	<1, (<1 Sry)
		Nov 4	<1 (Sry)	<1 (Sry)	(<0.1 Sry)	(<1 Sry)
		Nov 10	<1, (<1 Sry)	<1, (<1 Sry)	<0.1, (<0.1 Sry)	<1, (<1 Sry)
		Nov 17	<1 (Sry)	<1 (Sry)	(0.1 Sry)	(<1 Sry)
		Nov 24	<1, (<1 Sry)	<1, (<1 Sry)	<0.1, (<0.1 Sry)	<1, (<1 Sry)
Site		**Date**	**Ammonia-N (mg/L)**	**Nitrite-N (mg/L)**	**Nitrate-N (mg/L)**	**Lead (µg/L)**
Trip Blank	Summer	Aug 5	(<0.005, <0.005 Sry)	(<0.002, <0.002 Sry)	(<0.002, 0.002 Sry)	(<0.2 Sry)
		Aug 19	<0.005	<0.002	<0.002	<0.005
	Fall	Oct 27	(<0.005 Sry)	(<0.002 Sry)	(<0.002 Sry)	(<0.2 Sry)
		Nov 10	<0.005	<0.002	0.003	0.011
Field Blank	Summer	Aug 5	<0.005	<0.002	<0.002	0.006
		Aug 12	(<0.005 Sry)	(<0.002 Sry)	(0.005 Sry)	(<0.2 Sry)
		Aug 19	<0.005, (<0.005 Sry)	<0.002, (<0.002 Sry)	<0.002, (<0.002 Sry)	<0.005, (<0.2 Sry)
		Aug 26	(<0.005 Sry)	(<0.002 Sry)	(0.002 Sry)	<0.2 (Sry)
		Sep 2	<0.005, (<0.005 Sry)	<0.002, (<0.002 Sry)	0.003, (0.002 Sry)	<0.005, (0.6 Sry)
	Fall	Oct 27	<0.005, (0.006 Sry)	<0.002, (<0.002 Sry)	<0.002, (0.007 Sry)	<0.005, (<0.2 Sry)
		Nov 4	(<0.005 Sry)	(<0.002 Sry)	(0.006 Sry)	<0.2 (Sry)
		Nov 10	<0.005, (<0.005 Sry)	<0.002, (<0.002 Sry)	0.002, (<0.002 Sry)	<0.005, (<0.2 Sry)
		Nov 17	(<0.005 Sry)	(<0.002 Sry)	(<0.002 Sry)	<0.2 (Sry)
		Nov 24	<0.005 (0.006 Sry)	<0.002, (<0.002 Sry)	0.004, (0.005 Sry)	<0.005, (<0.2 Sry)

Note: Sry denotes the City of Surrey

CCME Water Quality Index (WQI) values for the Little Campbell, Nicomekl & Serpentine River water quality in 2002 and 2009

Fall Water Quality Index Values		2002		2009				Status – Comparison between 2002 & 2009 (short-term objectives)
Waterbody	River	WQI Value	Ranking	WQI Value	Ranking	WQI Value	Ranking	
		Short-term objectives only		Short-term objectives only		Both short- & long-term objectives (for reference only)		
Little Campbell River		52	Marginal	65	Fair	65	Fair	Improvement (Marginal to Fair)
Nicomekl River & tributaries	Nicomekl River	91	Good	77	Fair	73	Fair	Decline (Good to Fair)
	Anderson Creek	91	Good	79	Fair	75	Fair	
	Murray Creek	91	Good	79	Fair	74	Fair	
Serpentine River & tributaries	Serpentine River	81	Good	66	Fair	63	Marginal	
	Latimer Creek	91	Good	86	Good	87	Good	No change (still Good)
	Mahood/Bear Creek	91	Good	84	Good	76	Fair	
	Hyland Creek	82	Good	89	Good	82	Good	

Note: PCB data from 2008 not included in Serpentine River WQI calculation

Summer Water Quality Index Values – 2009 (for reference purposes)					
Waterbody	River	WQI Value	Ranking	WQI Value	Ranking
		Short-term objectives only		Both short- & long-term objectives (for reference only)	
Little Campbell River		53	Marginal	45	Marginal
Nicomekl River & tributaries	Nicomekl River	81	Good	74	Fair
	Anderson Creek	100	Excellent	100	Excellent
	Murray Creek	89	Good	84	Good
Serpentine River & tributaries	Serpentine River	93	Good	82	Good
	Latimer Creek	86	Good	81	Good
	Mahood/Bear Creek	90	Good	84	Good
	Hyland Creek	88	Good	83	Good

Note: PCB data from 2008 not included in Serpentine River WQI calculation

Relationship between CCME Water Quality Index (WQI) values and rankings, and descriptions of rankings (CCME, 2001)

Ranking	Index Value	Description
Excellent	95-100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels
Good	80-94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels
Fair	65-79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels
Marginal	45-64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels
Poor	0-44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels

Water Uses and Withdrawals in Boundary Bay Tributaries – 2010

Water Use (Code)	Water Usage (m^3/year)						
	Little Campbell River	Nicomekl River	Anderson Creek	Murray Creek	Serpentine River	Latimer Creek	Mahood Creek
Domestic (01A)	830	3,319	**3,319**	3,153	2,738	n/a	n/a
Ponds (02E)	n/a	446,550	n/a	n/a	n/a		
Watering (02F)	113,702	n/a	n/a	**3,700**	165,286	n/a	**60,305**
Fire Protection (02I12)	44,781	n/a			n/a		
Greenhouses (02I17)	n/a	46,461	n/a	n/a	n/a		
Nurseries (02I22)	n/a	46,256	n/a	n/a	40,335	n/a	n/a
Stockwatering (02I31)	22,401	830	n/a	n/a	n/a	597	n/a
Irrigation-Local Authority (03A)	n/a	**2,317,092**	n/a	n/a	n/a		
Irrigation (03B)	**507,145**	**2,102,763***	n/a	**65,621**	**703,947***	**29,110**	**48,723**
Land Improvement (04A)	n/a	996	**16,593**	n/a	n/a		
Conservation-Stored Water (11A)	n/a	n/a			**1,233,480**	n/a	n/a
Conservation-Use of Water (11B)	**357,303**	n/a			142,858	n/a	n/a
Conservation-Construction Works (11C)	n/a	n/a			n/a	**178,494**	n/a

Water Use Definitions

Domestic (01A) - water is used in a household, which is interpreted as a dwelling, and the number of dwellings within the appurtenant land is 4 or less. In addition to the use of water in a dwelling the water may be used:

a) on a garden not exceeding 1/4 acre in area;
b) for stock or poultry being raised as pets or of a number sufficient only to sustain the licensee's family with food; or to
c) maintain a system for fire protection of the licensee's home.

In instances where the licensee uses the water for one of the specific domestic purposes defined above, the purpose may be expressed as "Domestic (watering of garden)", "Domestic (Stock watering)", or as "Domestic (fire protection)", where use does not exceed 100 gal/day.

Ponds (02E) - ponds for floating logs, fish culture, or fur farming
Watering (02F) - water used for watering of golf courses, ornamental gardens, parks or similar properties.
Fire Protection (02I12) - a standby system is maintained to fight fires.
Greenhouses (02I17) - water is used for intensive indoor propagation of fruit, vegetables, and or plants.
Nurseries (02I22) - water is used in a commercial plant marketing operation.
Stockwatering (02I31) - water is used in ranching operations, pig farms, poultry farms, dairies and similar enterprises.
Irrigation-Local Authority (03A) - water is used for irrigation by a water district incorporated under an Act, municipality, improvement district, water utility under the *Water Utility Act* or development district.
Irrigation (03B) - water is used on cultivated lands and hay meadows to nourish crops.
Land Improvement (04A) - water is diverted or impounded to protect property, to facilitate the development of park or the reclamation, drainage or other improvement of land. Ponds for aesthetic purposes are included in this purpose.
Conservation-Stored Water (11A) - water is stored for conserving fish or wildlife.
Conservation-Use of Water (11B) - water is used for conserving fish or wildlife.
Conservation-Construction Works (11C) - works are constructed for conserving fish or wildlife.

Notes: Two largest water uses are bolded in each waterbody; * Includes ditch withdrawals.

IR3-44 Marine Water Quality – Baseline: Coal Particles in Water

Information Source(s)

EIS Section 4.0, Volume 2: Section 9.6, and Section 9.7.

Context

In Section 9.6 of the EIS, the Proponent stated that coal particles, which are lower in density than most rock or mineral matter, tend to remain in suspension longer than coarser grained sediments, and are subject to sediment transport and settling processes similar to finer-grained materials. However, there is no description of how coal dust released from Westshore terminals could affect baseline water quality conditions in the local study area.

Information Request

Provide an assessment of how coal dust from Westshore terminals would affect baseline water quality conditions in the areas with measurable coal content in sediment, as denoted by Figure 9.6-7 of the EIS.

VFPA Response

Coal dust introduced from Westshore Terminals was evaluated in the local study area (LSA) through the examination of coal in sediment samples (EIS Section 9.6.6.2) and through the characterisation of total suspended solids (TSS) and turbidity (EIS Section 9.7.6.4).

As described in EIS Section 9.7.6.4, TSS and turbidity levels near Roberts Bank exhibit high seasonal and spatial variability due to Fraser River discharge. Suspended sediment concentrations in Fraser River waters vary seasonally, typically ranging from 500 mg/L (milligrams per litre) to 1,000 mg/L during spring freshet, between 100 mg/L to 200 mg/L in late summer and fall, and between 50 mg/L to 100 mg/L during low flows in the winter season (McLean et al. 1999). The suspended sediments in the Fraser River influence TSS concentrations and turbidity in the estuarine waters at Roberts Bank (as illustrated in EIS Figure 9.5-9). The majority of suspended sediments in the LSA originate from sediments discharged from the Fraser River, and comparatively, coal dust is a very minor contributor to TSS levels, and only within the localised area in the vicinity of Westshore Terminals.

As described in EIS Section 9.6.6.2, most sediment samples analysed for coal in the LSA had concentrations less than the analytical detection limit (1%), and the maximum observed content was up to 2.9% on the east side for Westshore Terminal Berth 1 near the intermediate transfer pit, as shown in EIS Figure 9.6-7. Percent coal concentrations within the vicinity of Westshore Terminals measured in 2012 to 2013 have decreased compared to a 1999 study, which showed a mean concentration of 3.6% and maximum concentrations of 10.5% and 11.9% (Johnson and Bustin 2006). The improved effectiveness of control measures to reduce

fugitive coal dust releases from Westshore Terminals and a general re-distribution of historical deposits since 1999 through re-suspension and settlement in more quiescent areas of Roberts Bank, as shown in EIS Figure 9.6-7, are likely contributing factors to decreasing coal concentrations at Roberts Bank.

Changes to baseline water quality conditions in areas with measurable coal content (i.e., greater than 1% coal) incorporated into sediments in the LSA are not expected to be detectable. This is because concentrations of detectable settled coal in these localised areas are low (< 2.9% near the coal terminal, and 1.2% to 2.2% in the upper intertidal zone on the north side of the Roberts Bank causeway) and the marine environment provides for substantive dilution and buffering capacity (Ahrens and Morrisey 2005).

References

Ahrens, M. J. and D. Morrisey. 2005. Biological Effects of Unburnt Coal in the Marine Environment. Oceanography and Marine Biology 43:69-122.

Johnson, R., and R. M. Bustin. 2006. Coal Dust Dispersal around a Marine Coal Terminal (1977–1999), British Columbia: The Fate of Coal Dust in the Marine Environment. International Journal of Coal Geology 68:57–69.

McLean, D. G., M. Church, and B. Tassone. 1999. Sediment Transport along Lower Fraser River 1. Measurements and Hydraulic Computations. Water Resources Research 35:2533–2548.

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IR3-45 Marine Water Quality – Effects of Air Emissions

Information Source(s)

EIS Volume 2: Section 9.1.1

EIS Volume 5: Section 31.2

EIS Guidelines, Section 10.1.5

Context

In Section 7.1 of the Marine Shipping Addendum, the Proponent indicated that there would be incremental increases in annual emissions of gaseous and particulate matter compounds from RBT2-associated vessels in the Strait of Georgia, Haro Strait, and Juan de Fuca Strait. Further, the Proponent indicated that the cumulative annual emissions of trace organic contaminants from the transit of marine vessels associated with the Project and existing and projected future marine traffic (referred to as cumulative conditions in the EIS) are conservatively projected to increase by 20% over existing conditions.

However, the Marine Shipping Addendum did not describe how particulate matter and trace organic contaminants generated by container ships calling at Roberts Bank would affect water quality in the area around Roberts Bank and in the marine shipping area

Information Request

Describe how particulate matter and trace organic contaminants generated by marine shipping associated with the Project would affect water quality in Segment A of the marine shipping area.

VFPA Response

Particulate matter (PM) and trace organic contaminant (TOC) emissions generated by RBT2-associated vessels in transit are not expected to measurably affect water quality in Segment A (Strait of Georgia). **Table IR3-45-1**, which includes information presented in the Marine Shipping Addendum, provides a comparison of annual emissions of PM and TOCs for Segment A from large marine vessels[1] under existing conditions, from RBT2-associated vessels, and under cumulative conditions (which includes existing conditions plus projected future marine traffic including RBT2-associated vessels).

[1] Large vessels include commercial ocean-going vessels, including cargo and carrier vessels, tankers, and passenger ships.

As shown in **Table IR3-45-1**, overall emissions of PM, PM_{10}, $PM_{2.5}$, naphthalene, and benzo(a)pyrene from large vessels are projected to be lower in the future (2030) than for existing conditions (2012) due to anticipated emission reductions resulting from the following:

1) The replacement of older, higher-emitting container ships with newer, lower-emitting ships that meet tighter engine emission standards as defined by the International Maritime Organization (IMO) for ships operating in the North American Emission Control Area (ECA); and
2) The mandated use of low sulphur fuels within the ECA, as defined by the IMO (for more information refer to EIS Section 9.2.7.1 and Section 7.1.4.7 of the Marine Shipping Addendum).

Compared to existing conditions, only the gaseous contaminants (i.e., acrolein, benzene, 1,3-butadiene, acetaldehyde, and formaldehyde) are projected to increase in the future with cumulative emissions from large vessels (**Table IR3-45-1**).

Table IR3-45-1 Annual Emissions (tonnes/year) of Particulate Matter and Trace Organic Contaminants from Large Marine Vessels in Segment A

	Emissions for Existing Conditions (2012)	Incremental RBT2-associated Vessel Emissions (2030)	Cumulative Emissions (2030)
Particulate Matter (t/y)			
PM	387	7	138
PM_{10}	387	7	138
$PM_{2.5}$	356	6	127
Trace Organic Contaminants (t/y)			
Acrolein	0.5	0.03	0.61
Benzene	0.1	0.01	0.13
1,3-Butadiene	0.05	0.003	0.063
Acetaldehyde	0.4	0.04	0.53
Formaldehyde	4.2	0.3	5.0
Naphthalene	0.03	0.001	0.009
Benzo(a)pyrene	0.0004	0.00000559	0.0002

Note: Data from Marine Shipping Addendum Tables 7.1-7, 7.1-8, 7.1-14, 7.1-15, 7.1-19, and 7.1-20.

Changes in marine water quality in Segment A from the deposition of atmospheric emissions from RBT2-associated vessels would represent a very small fraction of all PM and TOCs that are generated within or have the potential to be deposited[2] to the marine environment within Segment A, for the following reasons:

[2] Deposition (wet or dry) in Segment A would depend on weather conditions (i.e., wind and precipitation).

- RBT2-associated vessels are anticipated to represent only 2 per cent of the total vessel movements (i.e., 520 movements out of 25,315 movements) in Segment A for 2030 (Table 4-7 of the Marine Shipping Addendum);
- There are numerous emission sources of PM and TOC with the potential to affect air quality and water quality in Segment A (e.g., on-road vehicles in Tsawwassen, commercial and agricultural equipment operating near Roberts Bank, fishing boats and other small craft transiting in or near Segment A). Note that **Table IR3-45-1** summarises the incremental RBT2-associated vessel PM and TOC emissions relative to existing and future annual emissions from large marine vessels only; and
- Segment A water quality is predominantly influenced by Fraser River discharge (see EIS Section 9.7.6.4), which contributes silt, clay, fine particles of organic and inorganic matter, and soluble organic compounds.

In addition, with respect to PM, approximately 97% of the PM emitted by large vessels is composed of particles with a mean diameter less than 2.5 microns ($PM_{2.5}$), which will disperse in the atmosphere (i.e., similar behaviour to gaseous contaminants). Consequently, there would be little deposition of PM emissions to surface waters.

Considering all known and potential sources of particulate and organic matter to Segment A, and the atmospheric dispersion of the majority of PM particles, marine shipping associated with the Project is not expected to affect water quality in Segment A of the marine shipping area.

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IR3-46 Coastal Conditions – Groundwater: Potable Groundwater Wells

Information Source(s)

EIS Volume 2: Section 9.1.2.1

CEAR Doc #314

Context

In Table 8-A2 of Appendix 8-A, the Proponent indicated that groundwater was excluded as a candidate component because no interactions were anticipated between adjacent groundwater feature and Project components and activities.

The Proponent's response to the Canadian Environmental Assessment Agency additional information requirement 18 in CEAR Doc #314 provided information regarding the delineation and characterization of groundwater areas/sources, and a description of groundwater flow patterns and flow rates. In this response, the Proponent concluded that Roberts Bank causeway would be expected to have little to no influence on the groundwater system for two reasons: i) it is aligned approximately parallel to the assumed direction of groundwater flow, and ii) the changes to the surficial sediments related to this feature penetrate to relatively shallow depths.

As stated by the Proponent in Section 9.1.2.1 of the EIS, there are three potable groundwater wells permitted by the British Columbia Ministry of Environment in the local Roberts Bank area within Tsawwassen Lands along Tsawwassen Drive North.

Figure 5 in Appendix 18-A of CEAR Doc #314 indicated that, in the area of Tsawwassen Lands, there is a zone of contact between shallow fresh and saline groundwater. An assessment of the potential effects of the Project on potable groundwater supplies as a result of salinity intrusions is required.

Information Request

Provide an assessment of the potential effects on potable groundwater supplies from salinity intrusions as a result of the proposed Project in the vicinity of the three groundwater wells and adjacent areas on Tsawwassen Lands.

VFPA Response

There are no anticipated Project-related changes to groundwater conditions in the vicinity of the three groundwater wells that were identified in EIS Section 9.1.2.1, nor to the adjacent areas on Tsawwassen Lands. In response to this information request, the VFPA conducted an updated search for existing potable groundwater wells, including the three groundwater wells previously identified and adjacent areas on Tsawwassen Lands. The VFPA identified that

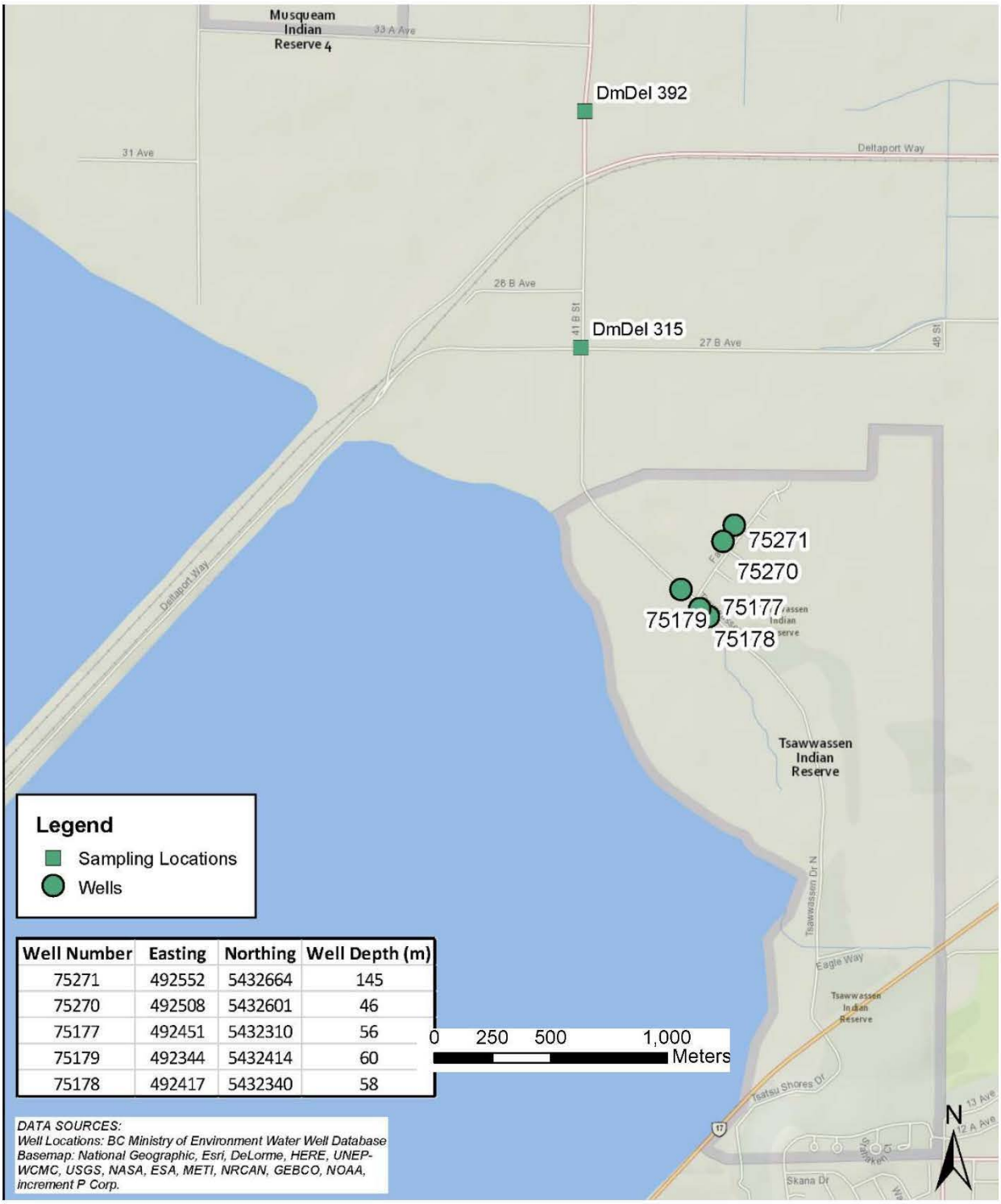
sources of potable groundwater wells currently do not exist in the area. More detailed information is provided below.

At the time the EIS was prepared, the British Columbia Ministry of Environment (MOE) Ground Water Wells and Aquifer (WELLS) database identified three potable groundwater wells in the local Roberts Banks area (EIS Section 9.1.2.1). The WELLS database currently lists five wells, including the three wells mentioned in EIS Section 9.1.2.1, all of which have been abandoned. **Figure IR3-46-1** shows the location and details of the five abandoned wells. In each case, well logs note salt water throughout the hole or that salt water was encountered, indicating that it is highly unlikely that potable water would be encountered in this area.

In addition, the Corporation of Delta 2015 Drinking Water Report (Corporation of Delta 2016) indicates that two "source" water quality sampling sites exist within the upland area to the northeast of the Roberts Bank causeway (**Figure IR3-46-1**). Site DmDel 315 is approximately 900 m from the shoreward end of the causeway at 2760 41B Street, but was abandoned in March 2015. Site DmDel 392 was commissioned as a sampling site to replace Site DmDel 315 and is located approximately 1,300 m from the end of the causeway at 3044 41B Street. Although designated as "source" sampling sites, neither site contributes to the drinking water system, as only wells located near Watershed Park, approximately 20 km from Roberts Bank are used to supply groundwater to the Corporation of Delta drinking water system. No other records of active groundwater wells in the vicinity of Roberts Bank could be located.

The context to this information request states that "Figure 5 in Appendix 18-A of CEAR Doc #314, which is based on Neilson-Welch (1999), indicated that, in the area of Tsawwassen Lands, there is a zone of contact between shallow fresh and saline groundwater." The area of Tsawwassen Lands falls within a zone where the depth to saline groundwater is between 1 m and 5 m, based on the depth contour and depths at specific test well locations. Some Tsawwassen Lands also fall within the broad oval delineating an area where "fresh groundwater was identified beneath saline groundwater", though only one test well occurs within the oval. Given the presence of shallow saline groundwater conditions, it is unlikely that a viable drinking water well could be developed within this area under existing conditions.

Figure IR3-46-1 Location and Details of Five Abandoned Wells on Tsawwassen Lands and Location of Corporation of Delta Water Sampling Sites



Well Number	Easting	Northing	Well Depth (m)
75271	492552	5432664	145
75270	492508	5432601	46
75177	492451	5432310	56
75179	492344	5432414	60
75178	492417	5432340	58

Potential Project-related Effects

EIS Section 9.7.8 describes the future changes to ocean salinity related to the Project, which will occur because of a change to local ocean currents that will redistribute Fraser River freshwater emanating from Canoe Passage. EIS Figures 9.7-9 and 9.7-10 show the predicted change based on the 50th percentile value for freshet period (May to July) and non-freshet period (October to December), respectively. No changes to salinity in the inter-causeway area are anticipated, and changes to salinity in the upper intertidal area of Roberts Bank on the north side of the causeway are expected to result in a decrease in average salinity.

Project-related changes to groundwater in upland areas, including adjacent Tsawwassen Lands, are not anticipated. As stated in CEAR Document #314[1], widening of the Roberts Bank causeway is expected to have little to no influence on the groundwater system for two reasons, namely: i) it is aligned approximately parallel to the assumed direction of groundwater flow, and ii) the changes to the surficial sediments related to this feature penetrate to relatively shallow depths. In addition, the widened causeway is physically separated from Tsawwassen Lands by the existing causeway, and the distance to the nearest Tsawwassen Lands boundary is a minimum of approximately 900 m from the causeway. Therefore, potential Project-related effects on potable groundwater supplies from salinity intrusions in the vicinity of Tsawwassen Lands are not anticipated because there are no anticipated Project-related changes to groundwater conditions in this area, and because no active drinking water wells are currently known exist nor are likely to exist in future.

References

Corporation of Delta. 2016. The Corporation of Delta 2015 Drinking Water Quality Report. Report prepared by the Corporation of Delta, Delta, B.C. 27 pp.

Neilson-Welch, L. 1999. Saline Water Intrusion from the Fraser River Estuary: A Hydrogeological Investigation Using Field Chemical Data and a Density-dependent Groundwater Flow Model. University of British Columbia, Vancouver, B.C.

[1] CEAR Document #314 From Port Metro Vancouver to the Canadian Environmental Assessment Agency re: Completeness Review - Responses to Additional Information Requirements (See reference document #271) for the Environmental Impact Statement.