APPENDIX 10-A

Species at Risk – Information on Federal and Provincial Designations

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Appendix 10-A Species at Risk – Information on Federal and Provincial Designations

In describing the existing biological setting in and around the Roberts Bank Terminal 2 Project area, several plant and animal species of conservation concern or at risk are noted. In the context of the Project, **species at risk** are considered to be those indigenous species, subspecies, populations, or ecological communities identified as being vulnerable by federal and provincial regulators.

The purpose of this appendix is to:

1) Summarise the federal and provincial organisations responsible for designating species at risk;
2) Provide definitions for list designations and risk status; and
3) Briefly describe federal requirements once the status of a species is designated to be at risk.

Federal Species at Risk Designations

The Government of Canada maintains a list of plant and animal species in Canada recognised as being at risk, or tending towards becoming at risk, under Schedule 1 of the *Species at Risk Act (SARA)*. The species classification process of identifying and assessing plant and wildlife species considered to be at risk is conducted by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), which is an independent group of experts. The formal classification recommendations developed by COSEWIC are based on status reports prepared by independent experts, and are informed by the best available scientific research, community knowledge, and traditional Aboriginal knowledge. The result is the determination of the status of wildlife species according to these designations and definitions:

- **Extinct**: A wildlife species that no longer exists.
- **Extirpated**: A wildlife species that no longer exists in the wild in Canada, but exists elsewhere.
- **Endangered**: A wildlife species that is facing imminent extirpation or extinction.
- **Threatened**: A wildlife species that is likely to become an endangered species if nothing is done to reverse the factors leading to its extirpation or extinction.
- **Special Concern**: A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.

- **Data Deficient**: A category that applies when the available information is insufficient (a) to resolve a wildlife species' eligibility for assessment or (b) to permit an assessment of the wildlife species' risk of extinction.
- **Not at Risk**: A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances.

Since *SARA* became law in June 2003, species designated at risk by COSEWIC must now be reassessed according to the new criteria of *SARA* before they can be added to Schedule 1 (known as the List of Wildlife Species At Risk). COSEWIC designations are regarded as recommendations to the federal government, which makes the final decision on whether species will be listed under *SARA*. Species with COSEWIC designations listed on *SARA* Schedules 2 and 3 are not yet officially protected under *SARA*. Once the species on Schedules 2 and 3 have been reassessed, the Schedules themselves will be eliminated, and species will simply be listed or not listed on Schedule 1. Once a species is listed under *SARA*, it becomes illegal to kill, harass, capture, or harm it in any way.

Listing of a species as Extirpated, Endangered, or Threatened under Schedule 1 also mandates the formation of a species recovery team (made up of technical experts from universities, conservation groups, industry, and government) and a recovery strategy for that species. Where recovery is feasible, a recovery strategy must: describe the particular species and its needs; identify threats to survival; identify the species' critical habitat; provide examples of activities that are likely to result in destruction of the critical habitat; set objectives for species recovery; identify information gaps that should be addressed; and state when one or more action plans relating to the strategy will be completed.

Designated **critical habitats** of Extirpated[1], Endangered, and Threatened species are also protected from destruction if the critical habitat is on federal land, the listed species is an aquatic species, or the listed species is a species of migratory birds protected by the *Migratory Birds Convention Act, 1994*.

British Columbia Species at Risk Designations

The task of identifying species at risk (also referred to as elements) provincially rests with the B.C. Conservation Data Centre (CDC), which is part of the B.C. Ministry of Environment (MOE), Environmental Protection and Sustainability Division. The CDC is also aligned with national and international organisations that cooperate to gather and exchange information

[1] Protection of critical habitats of extirpated species depends on if a recovery strategy has recommended the reintroduction of the species into the wild in Canada.

on threatened elements of biodiversity. The CDC collects and disseminates information on elements at risk in B.C. and assigns a provincial conservation status rank according to set criteria. Elements are placed on the **Red List** or **Blue List** (described below) for the purposes of setting conservation priorities, and providing more formal designations either provincially under the B.C. *Wildlife Act*.

The Red List contains elements considered to be Extirpated, Endangered, or Threatened in B.C. The Blue List includes elements of Special Concern in B.C. These elements are sensitive to or at risk from human activities or natural events, but are not Extirpated, Endangered, or Threatened. A Red or Blue List designation does not automatically confer protection to the element or its habitat; nevertheless, it does highlight species and ecological communities that have particular threats, declining population trends, or restricted distributions to provincial authorities (e.g., B.C. MOE, or B.C. Ministry of Forests, Lands and Natural Resource Operations).

Federal *SARA* Schedule 1 and provincial CDC designations for at risk species, subspecies, and ecological communities known or likely to occur within the Project area are provided for each of marine biophysical valued components described in **Sections 11.0** to **16.0**.

APPENDIX 10-B

Roberts Bank Ecopath with Ecosim and Ecospace Model Parameter Estimates

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Roberts Bank Ecosystem Model Parameter Estimates

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December 2014

HEMMERA | 20 YEARS 1994 – 2014

Technical Report/Technical Data Report Disclaimer

The Canadian Environmental Assessment Agency determined the scope of the proposed Roberts Bank Terminal 2 Project (RBT2 or the Project) and the scope of the assessment in the Final Environmental Impact Statement Guidelines (EISG) issued January 7, 2014. The scope of the Project includes the project components and physical activities to be considered in the environmental assessment. The scope of the assessment includes the factors to be considered and the scope of those factors. The Environmental Impact Statement (EIS) has been prepared in accordance with the scope of the Project and the scope of the assessment specified in the EISG. For each component of the natural or human environment considered in the EIS, the geographic scope of the assessment depends on the extent of potential effects.

At the time supporting technical studies were initiated in 2011, with the objective of ensuring adequate information would be available to inform the environmental assessment of the Project, neither the scope of the Project nor the scope of the assessment had been determined.

Therefore, the scope of supporting studies may include physical activities that are not included in the scope of the Project as determined by the Agency. Similarly, the scope of supporting studies may also include spatial areas that are not expected to be affected by the Project.

This out-of-scope information is included in the Technical Report (TR)/Technical Data Report (TDR) for each study, but may not be considered in the assessment of potential effects of the Project unless relevant for understanding the context of those effects or to assessing potential cumulative effects.

EXECUTIVE SUMMARY

Port Metro Vancouver is proposing a new multi-berth container terminal at Roberts Bank in Delta, B.C. that will provide 2.4 million twenty-foot equivalent unit containers of additional port capacity. The proposed Roberts Bank Terminal 2 (RBT2) Project is subject to a federal environmental assessment (EA) by review panel. In preparation for the EA, Port Metro Vancouver is building an Ecopath with Ecosim and Ecospace (EwE) model to assess potential changes in time and space to the productivity of the Roberts Bank ecosystem and determine potential habitat offsetting requirements for the proposed RBT2.

The study area for the model covers an area of 54.68 km^2. Dynamics in the Roberts Bank ecosystem are driven by estuarine circulation making it a highly productive environment. As part of its pre-EA work, PMV initiated a Productive Capacity Technical Advisory Group (PC-TAG) to gather input from scientific and technical experts on how the productive capacity of habitat is most appropriately defined at Roberts Bank. The PC-TAG selected the EwE model as an appropriate approach, and chose suitable focal species for assessing changes to productivity at Roberts Bank. The focal species were from one or more of the following groups: marine mammals, birds, fish, invertebrates, and marine vegetation.

The Roberts Bank ecosystem model has 58 functional groups, 28 of these were modelled as focal species groups, based on advice from the PC-TAG. This report presents the methods used to develop and build the Roberts Bank ecosystem model, including data sources and processes for estimating model parameters such as biomass, production and consumption rates, diet composition and environmental preferences for the model's functional groups. These parameters are used to assess potential changes in productivity at Roberts Bank resulting from the proposed RBT2 Project. The results of the model are described in the accompanying Roberts Bank Ecosystem Model Development and Key Run Report (ESSA 2014*a*).

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LIST OF ACRONYMS

Abbreviation	Definition
B.C.	British Columbia
CD	chart datum
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
DFO	Fisheries and Oceans Canada
EA	environmental assessment
EwE	Ecopath with Ecosim and Ecospace
LiDAR	Light Detection and Ranging
PC-TAG	Productive Capacity Technical Advisory Group
PMV	Port Metro Vancouver
RBT2	Roberts Bank Terminal 2 Project
ROV	remotely operated vehicle
SARA	*Species at Risk Act* (2002, c. 29)
SRKW	southern resident killer whale
U.S.	United States

UNITS OF MEASUREMENT

Unit of Measurement	Definition
cm/s	centimetres per second
g	gram
g/d	grams per day
kg	kilogram
kJ/mg	kilojoule per milligram
km^2	square kilometre
m	metre
m^2	square metre
mg	milligram
mg/m^2	milligram per square metre
mm	millimetre
psu	practical salinity units
t	tonnes
t/km^2	tonnes per square kilometre
°C	degree Celsius

GLOSSARY

Term	Definition
anadromous	Ascending rivers to spawn.
benthic	Dwelling on, or relating to, the bottom of a body of water.
benthopelagic	Living and feeding near the bottom as well as in midwater or near the surface.
biomass (B)	The mass of living tissue in either an individual or cumulatively across organisms in a population or ecosystem. Biomass in EwE is presented as the average biomass per unit area in a predefined time period. This model defines B as the annual average tonnes of biomass per square kilometre.
biomass turnover	The rate at which biomass is depleted and replaced.
Brey's algorithm	Brey's algorithm uses phylogeneticly based self-learning artificial neural networks to model the relationships between P/B and twenty easy-to-measure abiotic and biotic parameters in 1,252 data sets of population production for macrobenthic populations in marine and freshwater habitats. Body mass and water temperature provide the majority of explanatory power of the model. Using log-transformed data, the final predictive model estimates log (P/B) with reasonable accuracy and precision (r^2 = 0.801; residual mean square RMS = 0.083).
carapace	In crustaceans, a chitinous shield covering the back of the organism.
carnivorous	Feeding on animal tissue.
carrion	The decaying flesh of dead animals.
chart datum (CD)	The low water plane to which are referenced the depths of water over features permanently covered by the sea and the elevations of those features which are periodically covered and uncovered. In tidal waters, the Canadian Hydrographic Service uses the level of Lower Low Water, Large Tide or Lowest Normal Tide as its reference plan for chart datum.
consumption rate (Q/B)	The amount of food consumed by a group relative to its biomass over a period of time and is expressed as the ratio of consumption (Q) over biomass (B). Absolute consumption (Q) is defined as a flow and expressed in $t/km^2/yr$; B is the amount of biomass per area, resulting in Q/B being expressed as per year ($year^{-1}$).
demersal	Sinking to or lying on the bottom; living on or near the bottom and feeding on benthic organisms.
deposit feeder	An organism that derives its nutrition by consuming some fraction of a soft sediment.
depth contour	A line on a map connecting points on the ocean floor of equal depth.
detritivore	An animal feeding on dead organic material, especially decomposing plant material.
detritus	Decomposing plant material.
diurnal	Active by day or occurring daily.
echolocate	Of marine mammals, determine direction and distance of objects, including prey, using a sensory system that emits high-pitched sounds and interprets their echoes.
Ecopath	A static, mass-balanced snapshot of the ecosystem; a component of the EwE model software
Ecosim	A time dynamic simulation module; a component of the EwE model software
Ecospace	A spatial and temporal dynamic module; a component of the EwE model software

Term	Definition
ecotrophic efficiency (EE)	In ecosystem models, the fraction of the production used in the system; either passed up the food web, used for biomass accumulation, migration or export. Ecotrophic efficiency is difficult to measure directly. It varies between 0 and 1 and can be expected to approach 1 for groups with considerable predation pressure (i.e. eaten before it dies naturally).
epifaunal	Living on the surface of a substrate.
euphotic zone	The layer of sea water that receives enough sunlight for photosynthesis to occur.
focal species	These species were identified by the Productive Capacity Technical Advisory Group, are ecologically linked to many components of the ecosystem, and can provide an indication of changes in productive capacity.
functional group	Species or collections of species that share similar life history traits and ecological function and are used to represent pools of biomass in the EwE model.
grazer	A herbivore that consumes plant material or autotrophic organisms.
habitat	The area occupied by and supporting living organisms.
haul-out site	Site associated with seals, sea lions temporarily leaving the water between periods of foraging activity for sites on land or ice. Benefits of hauling-out may include predator avoidance, thermal regulation, social activity, parasite reduction and rest.
herbivorous	Feeding on plants.
hummock	A complex of algae species (including *Lola* and *Ulva* species) that have become intertwined due to tidal action and may or may not be attached to the substrate.
hyperspectral imagery	Imagery derived from subdividing the electromagnetic spectrum into very narrow bandwidths. These narrow bandwidths may be combined with or subtracted from each other in various ways to form images useful in precise terrain or target analysis.
indicator species	A species whose status provides information on the overall condition of the ecosystem and of other species in that ecosystem. Taxa that are sensitive to environmental conditions and which can therefore be used to assess environmental quality.
infaunal	Living within a soft sediment and being large enough to displace sedimentary grains.
instantaneous total mortality (Z)	Mortality rate attributed to both fishing and natural causes.
instar	A phase between two periods of molting in the development of a crab larva or other invertebrate.
intertidal	Shore area between high- and low-water marks; shallow areas along the shore and in estuaries that are exposed and covered by the tides.
life history stage	Phase in life; developmental stage, such as egg, larva, juvenile, adult.
littoral	Living in or related to the intertidal zone of the marine environment, delimited by the tide marks of low and high water.
macroalgae	Macroscopic, multicellular, benthic marine photosynthetic, nonvascular plants that contain chlorophyll α and have simple reproductive structures.
mass balance	The total amount biomass produced by a group of organisms in the ecosystem is equal to the amounts extracted from the group as a result of predation, fishing, migration, and other types of mortality. For the RBT2 model this takes approximately seven years.
metamorphose	Undergo a major structural change of body shape, e.g., change from a larval form to a juvenile or adult form.
microalgae	Microscopic, autotrophic, unicellular algae species that exist individually, or in chains or groups.

Term	Definition
mumblies	Coastal geomorphic feature that occurs as a raised ridge on the flats, from 3.0 to 3.5 m CD, formed by tidal channels running perpendicular to shore.
natural mortality (M)	The component of total mortality not caused by fishing, but by natural causes such as predation, diseases, pollution, etc… Natural mortality can be reported as either annual or instantaneous.
neritic	Of the shallow pelagic zone over the continental shelf; of nearshore ocean ecosystems.
omnivorous	Feeding on both plant and animal material.
parturition	The action of giving birth to young.
pelagic	Associated with the surface or middle depths of a body of water.
piscivorous	Feeding on fish.
polygon	A multi-sided closed area that represents the shape and location of homogeneous feature types, for example eelgrass habitat, biofilm, etc.
primary productivity	The transformation of chemical or solar energy to biomass. Most primary production occurs through photosynthesis, whereby green plants convert solar energy, carbon dioxide, and water to glucose and eventually to plant tissue. In addition, some bacteria in the deep sea can convert chemical energy to biomass through chemosynthesis.
production rate (P)	Elaboration of tissue (whether it survives or not) by a group over the period considered. In ecosystem modelling, a ratio of production over biomass is used (P/B; both expressed in the same units), which is equivalent to total mortality (Z). In the Ecopath model, production is estimated as the sum of the predation mortality, fishing mortality, net migration, biomass accumulation, and other mortality terms.
production/biomass ratio (P/B)	Elaboration of tissue (whether it survives or not) by a group over the period considered. In ecosystem modelling, a ratio of production over biomass is used (P/B; both expressed in the same units), which is equivalent to total mortality (Z).
productive capacity	This was the term defined in *Policy for the Management of Fish Habitat* up to and including November 2013 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.
productivity (ongoing productivity)	For the purposes of this report, productivity is defined as the biomass per area. This is the term defined in the Fisheries Productivity Investment Policy in November 2013. The potential sustained yield of all fish populations and their habitat that are part of or support commercial, recreational and Aboriginal fisheries.
psu	The practical salinity scale was defined by a United Nations Educational, Scientific, and Cultural Organization group in the 1970s and is based on conductivity
respiration (R)	In trophic models, a flow (or flows) of mass or energy that is (are) not directed toward, nor could be used by any other functional groups.
riparian	Relating to, living, or located on the bank of a natural watercourse, such as a river, lake or tidewater.
roost	To rest or sleep on or as if on a perch.
scavenger	An organism that feeds on dead or decomposing animals or macrophytes.
site fidelity	The tendency of an individual to return to an area previously occupied or remain in an area over an extended period.
staging area	Resting and feeding place for migratory birds.
substrate	The base on which an organism lives including: boulder, cobble, gravel, sand, silt and clay.
subtidal	The shallow water zone influenced by tides but never exposed at low tide.

Term	Definition
suspension feeder	Feeding by filtering particulate organic material from water.
taxon	A formal taxonomic unit or category of organisms (e.g., species, genus, family, order, class, etc.).
taxonomic linkages	Relationships among organisms based upon a systematic classification of groupings.
trophic level	Position in the food chain, determined by the number of energy-transfer steps to that level.
zoeae	A larval form of crustaceans.

1.0 INTRODUCTION

Port Metro Vancouver (PMV) is proposing a new multi-berth container terminal at Roberts Bank in Delta, British Columbia (B.C.) that will provide 2.4 million twenty-foot equivalent unit containers of additional port capacity. The proposed Roberts Bank Terminal 2 Project (RBT2) is subject to a federal environmental assessment (EA) by a review panel. In preparation for the EA, PMV is building an **Ecopath** with **Ecosim** and **Ecospace** (EwE) model to assess potential changes in time to the ongoing **productivity** of the Roberts Bank ecosystem and determine potential **habitat**[1] offsetting requirements for the proposed RBT2 Project. EwE has three main components: Ecopath is a mass balance representation of an ecosystem during a given time and is the focus of this report; Ecosim is a time dynamic simulation module for policy exploration; and Ecospace is a spatial and temporal dynamic module primarily designed for exploring impact and placement of protected areas (Christensen et al. 2005). This report presents the methods used to develop and build the Roberts Bank ecosystem model, including data sources and processes for estimating model parameters such as **biomass (B)**, **production (P)** and **consumption (Q)** rates, diet composition and environmental preferences for the EwE model's **functional groups**.

Work underway to evaluate the **mass balance** and performance of Ecopath, as well as simulations using Ecopath as input to the spatial-dynamic Ecospace components of the EwE model, are analyzed in the accompanying Roberts Bank Ecosystem Model Development and Key Run Report (ESSA 2014*a*).

1.1 STUDY AREA

The study area for the model is centred on Roberts Bank, Delta, B.C., and covers an area of 54.68 km^2. The spatial extent of the study area is confined to Roberts Bank and includes the **intertidal** and **subtidal** zones between Canoe Passage to the northwest and B.C. Ferries Terminal to the southeast (**Figure 1**). The study area is bounded by the 100 m **depth contour** to the west (defined by the spatial boundaries of the study area for the assessment of potential effects on marine fish and marine invertebrates as a result of the RBT2) and runs parallel along the shoreline to the Canada-United States (U.S.) international border in the south. There is a minor difference between study area (54.68 km^2) and the modelling area (54.58 km^2).

Roberts Bank is a highly productive estuarine environment that contributes to the productivity of many species including native eelgrass (*Zostera marina*), Dungeness crab (*Metacarcinus magister*), juvenile salmonids (*Oncorhynchus* species) and shorebirds such as western sandpiper (*Calidris mauri*). Tidal exchange between the marine water of the Strait of Georgia and fresh water from the Fraser River, combined with large areas of shallow sand- and mudflats exposed to high temperatures and ample sunlight, provide optimal conditions for the growth of **benthic** algae, diatoms, and intertidal marshes. This primary production supports a diverse ecosystem that functions as a refuge and rearing ground for juvenile fish from the Fraser River and other marine life from the Strait of Georgia. The intertidal mudflats and shallow subtidal areas also provide rich feeding habitats for migratory and wintering bird populations.

[1] Bold text indicates term defined in glossary

1.2 THE ECOPATH WITH ECOSIM AND ECOSPACE MODELLING APPROACH

Ecopath with Ecosim and Ecospace (EwE) is an ecosystem modelling approach and software that is used for ecosystem-based management throughout the world (Christensen and Walters 2005). The approach was conceptualised in the early 1980s when Jeff Polovina of the National Oceanic and Atmospheric Administration was tasked with developing an ecosystem model to integrate information from a multi-disciplinary study of ecosystem productivity in the French Frigate Shoals, northwestern Hawaiian Islands (Polovina 1984). Polovina developed a simple mass-balance model, to evaluate consistency in estimates of production for ecosystem components at all **trophic levels**, and to estimate how much demand there was for production for groups where biomass estimates were not available. Polovina called this model Ecopath, which has been under continuous development since 1990 (Christensen and Pauly 1992). Ecosim emerged in 1995 (Walters et al. 1997, 2000) and Ecospace in 1998 (Walters et al. 1999). Together, Ecopath, Ecosim and Ecospace comprise the EwE tool, which has become the most widely-applied approach to ecosystem modelling, with hundreds of published models (Colléter et al. 2013).

Computational details of this modelling approach are available in the literature (Christensen and Pauly 1992, Walters et al. 1997, 1999, 2000, Christensen and Walters 2004, Christensen et al. 2005, 2009, Steenbeek et al. 2013). Ecopath assumes the total production by a group is equal to the accumulated biomass within the group plus any biomass extracted from the group as a result of predation, fishing, migration, and other types of mortality (equation 1).

(1) Production = biomass accumulation + catches + predation + net migration + other mortality

To reduce complexity of the model, species with similar ecology are aggregated into functional groups. These groups can be defined as specifically as a **life history stage** (e.g., juvenile, adult) of a species, or as a functional guild of species that serve the same function in the ecosystem. The energy balance of each functional group is described in Ecopath by equation 2 as follows:

(2) Consumption = production + **respiration** + unassimilated food

The Roberts Bank ecosystem was modelled using version 6.5 (November 27, 2014) of the open source software package available at http://www.ecopath.org. The key steps to construct an Ecopath model are to: (i) identify the area and period for which a model is to be constructed, (ii) define the functional groups that make up the model, (iii) enter a diet matrix defining all trophic linkages by expressing the fraction that each functional group in the model represents in the diet of its consumers, (iv) enter any three of the four basic EwE parameters including biomass (B), **production/biomass ratio** (P/B), food consumption per biomass (Q/B), or **ecotrophic efficiency** (EE) for each functional group, and (v) balance the model. Balancing the model requires modifying the entries in (iii) and (iv) until input = output for each functional group.

1.3 RATIONALE FOR CHOOSING FUNCTIONAL GROUPS

As part of the pre-EA work, a **Productive Capacity** Technical Advisory Group (PC-TAG) was created to gather input from scientific and technical experts. The PC-TAG met four times between November 2012 and May 2013. There were five main parties identified as potential participants in the PC-TAG process: technical experts from government agencies, academia, non-governmental organisations, PMV and PMV consultants, and First Nations. First Nations did not participate in the PC-TAG process, however PMV has committed to share PC-TAG information and obtain input through a separate process. The PC-TAG was advisory in nature, and PMV sought to gather advice through the process in terms of how best to conduct specific EA studies for the RBT2.

Since RBT2 may introduce changes to the productivity of the marine environment, a PC-TAG was convened to solicit input on suitable methods for assessing and reporting potential changes to productivity that are quantifiable, scientifically defensible, consistent with the regulatory process, and relevant to Roberts Bank. The PC-TAG selected EwE as a suitable approach and identified **focal species** for assessing productivity at Roberts Bank. Twenty-five focal species were initially identified by the PC-TAG as biologically and socially significant. These species are modelled as single species groups, except Chinook salmon (*Oncorhynchus tshawytscha*), chum salmon (*Oncorhynchus keta*), and biofilm; which were determined to require more detailed modelling with respect to juvenile and adult life-history stages and environmental preferences. This more detailed model results in a total of 28 focal species. Specific rational for dividing salmonid species into juvenile and adult groups are related to differences in biomass, **production rate**, **consumption rates**, diet and environmental preferences. In the case of biofilm, it was determined that the focal species consisted of two separate communities; freshwater and marine. Each group has different environmental preferences and forms an important part of some migratory shorebird diets that required a detailed examination of spatial changes in Ecospace and resulted in the group being modelled as two separate focal species. In these situations in an ecosystem model, especially when each life-history stage is of importance to the overall productivity of the species, it is common to create two separate focal species

With the Roberts Bank ecosystem model, each focal species is considered as a functional group. To account for the remainder of the Roberts Bank ecosystem, an additional 30 functional groups were chosen from bioinventories completed at Roberts Bank. Aggregated functional groups reflect close **taxonomic linkages** and similarity in ecological roles due to overlap in diet and habitat preferences (**Table 1-1**).

Table 1-1 Functional Groups in the Roberts Bank Ecopath Model

Functional Group			
Marine Mammals		**Fish (continued)**	
1	Baleen whales	31	Shiner perch*
2	Dolphins and porpoises	32	Skate
3	Pinnipeds	33	Small demersal fish
4	Southern resident killer whales*	34	Starry flounder*
5	Transient killer whales*	**Invertebrates**	
Birds		35	Carnivorous zooplankton
6	American wigeon*	36	Omnivorous and herbivorous zooplankton
7	Bald eagle*	37	Dungeness crab*
8	Brant goose*	38	Epifaunal grazer
9	Diving waterbirds	39	Epifaunal omnivore
10	Dunlin*	40	Epifaunal sessile suspension feeder
11	Great blue heron*	41	Infaunal bivalve*
12	Gull and terns	42	Jellyfish
13	Raptor	43	Macrofauna*
14	Shorebirds	44	Meiofauna
15	Waterfowl	45	Orange sea pen
16	Western sandpiper*	46	Polychaetes*
Fish		47	Shrimp
17	Chinook salmon* adult	**Primary Producers**	
18	Chinook salmon* juvenile	48	Biofilm freshwater*
19	Chum salmon* adult	49	Biofilm marine*
20	Chum salmon* juvenile	50	Brown algae*
21	Salmon adult	51	Eelgrass (native)*
22	Salmon juvenile	52	Green algae*
23	Dogfish	53	Japanese eelgrass (non-native)*
24	Flatfish	54	Red algae
25	Forage fish	55	Phytoplankton
26	Herring	56	Tidal marsh*
27	Large demersal fish	57	Biomat
28	Lingcod*	**Detritus**	
29	Rockfish*	58	Detritus
30	Sandlance*		

Note: * indicates focal species identified by the PC-TAG (28)

1.4 DATA SOURCES

Whenever possible, data for the EwE model was derived from environmental and technical field studies for RBT2 which began in 2012 and are ongoing at Roberts Bank and the surrounding areas (**Table 1-2**). These studies are part of the early planning phase focused on collecting baseline inventory information to develop an understanding of current conditions in the study area. Data collection follows study designs initially created to answer questions not directly related to EwE model inputs. As a result, not all required information was available for EwE model construction through field programs. Also, not all species or functional groups were sampled for biomass in the baseline program. Some groups (i.e., birds, marine invertebrates, and marine vegetation) were better represented by the baseline data program than others (i.e., fish, marine mammals)

If field data was not available for reasons described above, information was extracted from the literature. Specifically, previously published information from the study area was given highest priority followed by published information from sites nearest to the study area. When local information was not available, studies that included sites similar to Roberts Bank were considered. Data sources included theses, peer-reviewed papers, and technical reports on EwE models constructed for the Strait of Georgia (Beattie 2001, Martell et al. 2002, Preikshot 2007, Li 2012, Preikshot et al. 2012), Hecate Strait (Ainsworth 2006), and southeast Alaska (Guénette 2005). If information from nearby or similar habitats was lacking, data specific to the species or **taxon** were considered from studies conducted in other parts of the globe. In some cases, information was derived using published algorithms and web-based databases. When information was lacking overall, EwE parameter estimates were selected based on professional judgement.

Table 1-2 Ranking of Data Sources as Basic Input for the Roberts Bank ecosystem model

Rank	Data Source
1	Field program
2	Published literature (Roberts Bank)
3	Published literature (Strait of Georgia, Hecate Strait, Northeast Pacific)
4	Published literature (general, including algorithms and web-based databases)
5	Professional judgement

1.5 MODEL PARAMETERS

1.5.1 Ecopath

Functional groups in the Ecopath model are parameterised with the following data (Christensen and Walters 2004):

- Diet composition, expressed as the proportion (from 0 to 1) of a prey that contributes as wet weight to the diet of the predator;
- Biomass (B), in tonnes per square kilometre (t/km^2);
- Production per unit biomass (P/B), in mass balance models this is equivalent to the fisheries concept of **instantaneous total mortality** (Z) (Allen 1971);
- Consumption per unit biomass (Q/B), fraction of wet weight body mass consumed annually; and
- Ecotrophic efficiency (EE), the proportion of the production that is either exported or predated upon.

Generally, three of the four model input parameters (B, P/B, Q/B or EE) are required for each **functional group** for the model to balance. The Ecopath model links the production of each group with the consumption of all groups, and uses these linkages to estimate that missing parameter, based on the mass-balance requirement of equation 1.

The matrix of the species' diet composition is presented in **Appendix A**. Diet information was extracted from the literature. When a functional group consisted of multiple species, diet was averaged for each species and then adjusted for biomass of the species in the functional group. As a result, prey items with a relatively low contribution to the functional group, but important for some species within the group may have been omitted from the final input matrix. Weighting by abundance was the preferred method; however, specific approaches are outlined in Sections 2.0 through 6.0. The resulting diet matrix incorporated in the EwE model reflects the weighted relative diet preference of the prey items to predators.

Biomasses of functional groups (**Appendix B**) were based upon data collected in the field, values available from other Ecopath models and peer-reviewed literature. Field values were attained through a series of baseline programs at Roberts Bank during 2012 and 2013. When no data for species or functional groups was available, literature values from primary sources for the Roberts Bank area or the nearest similar ecosystem (e.g., Strait of Georgia (Preikshot 2007, Li 2012, Preikshot et al. 2012), Hecate Strait (Ainsworth 2006)) were used. In a number of cases, prior EwE model inputs and estimates for the Strait of Georgia were used. Biomass estimates were calculated by multiplying abundance by the average species wet weight. For **primary productivity**, abundance was typically calculated from stem density and/or percent cover, while estimates of fauna were based upon densities and mean mass. The species abundance in tonnes (t) was then divided by the study area to provide an estimate in t/km^2. All species' biomass estimates within a functional group were summed to yield a functional group biomass estimate for the study area.

Biomass estimates were further corrected by multiplying the proportion of habitat availability in the study area to the sampled estimates from the baseline study program. Proportion of availability for each habitat occurring in the study areas was calculated using the habitat map described in Section 1.5.3 Ecopath Habitat and Substrate Map. Marine vegetation was mapped using baseline data, historic data and recent **hyperspectral imagery** (Section 1.5.3 Ecopath Habitat and Substrate Map). Fish collection points were sampled for habitat type in ArcGIS and proportion of habitat for each survey type was multiplied against biomass estimates. Marine invertebrate functional groups were assigned habitat types, with individual groups having one or more habitat types. The proportion of these habitats available was then applied against biomass estimates to correct for habitat availability. For marine mammals (with the exception of pinnipeds) and birds, the proportion of area within or outside a depth contour of the study area was used for biomass estimates.

Production and consumption rates for basic input in the Ecopath model (**Appendix B**) were also estimated. If available, taxa-specific P/B ratios were taken from primary literature. If taxa-specific P/B estimates were unavailable, then the P/B estimate of a comparable functional group was taken from EwE models constructed for areas nearest to Roberts Bank. For groups such as fish and birds, if taxa-specific P/B estimates were unavailable, **natural mortality (Z)** from the literature was considered equal to P/B (Allen 1971). In a number of cases, the literature would list the natural mortality rate of juveniles and adults. These two values were averaged[2] to get the natural mortality rate for the species. A functional group's P/B was estimated by taking the average of all available values within a functional group.

Similar to the methodology for estimating P/B values, taxa-specific Q/B ratios were taken from the primary literature or from previous EwE models. If taxa-specific Q/B estimates were not available, daily consumption rates were taken from literature. If these consumption rates were unavailable, Q/B of a comparable functional group was taken from EwE model literature. A functional group's Q/B was estimated by taking the weighted average of all available values within a functional group.

1.5.2 Ecospace

For each functional group, the Ecospace component of the model required the distributions of physical variables at Roberts Bank including depth (m), salinity (psu), wave height (m), bottom current velocity (cm/s) and **substrate type** (**Table 1-3**).

[2] Averaging method was determined based on available data. Where possible, weighted averaging was preferred. Each functional group description provides more information.

Table 1-3 Environmental Parameters for Functional Groups of the Roberts Bank Ecosystem Model

Parameter (Units)	Range	Parameter (Units)	Range	
Salinity (psu)		**Depth (m)**	**model datum**	**chart datum**
Freshwater	0 – 0.5	Intertidal	0 – 5	5 – 0
Brackish	0.5 – 18	Shallow subtidal	5 – 15	0 – -10
Freshet	18 – 25	Mid subtidal	15 –25	-10 – -20
Marine	25–32	Deep subtidal	25 – 100	-20 – -95
Bottom current (cm/s)		**Exposure (wave height, m)**		
Very low	0 – 1	Quiescent	0 – 0.1	
Low	1 – 15	Very Low	0.1 – 0.25	
Moderate	15 – 25	Low	0.25 – 1	
High	25 – 63	Moderate	1 – 2	
Sediment (mm)		**Habitat**		
Clay	<0.001 – 0.063	Mud (bare)	Clay	
Very fine sand	0.063 – 0.125	Sand (bare)	Very fine sand to coarse sand	
Fine sand	0.125 – 0.25	Rock (bare)	Gravel, cobble and boulders	
Coarse sand	0.25 – 2	Biofilm	Biofilm (Section 6.3 Biofilm)	
Fine gravel	2 – 8	Biomat	Biomat (Section 6.3 Biofilm)	
Gravel	8 – 64	Green algae	*Ulva* species (Section 6.7)	
Cobbles and boulders	≥64	Eelgrass (native)	*Zostera marina* (Section 6.6)	
			Zostera japonica (Section 6.8)	
		Brown algae	Intertidal and subtidal rockweed and kelp species (Section 6.5)	
		Orange sea pens	Sea pens (Section 5.14)	
		Tidal marsh	Brackish and salt marsh species (Section 6.11)	
		Grass	Terrestrial non-native planting of study area	

The environmental parameters were modelled across the study area to estimate their distribution pre- and post-construction of RBT2 (NHC 2014). Specifically, monthly averages of salinity, wave height, and bottom current were modelled pre- and post-construction; monthly averages of depth were modelled post-construction (NHC 2014). Depth estimates across the study area were derived from an elevation raster created from high resolution LiDAR and several bathymetric data sets interpolated to 100 m pixel resolution and referenced to a geodetic baseline. Environmental data for summer (May, June, and July) and winter (October, November, and December) were calculated as the 90th percentile range of values for

wave height and bottom current, and as the 50th percentile for salinity. The 90th percentile for wave height and bottom current were selected as this represents a more extreme threshold to model species survival and persistence in the environment. The 50th percentile was chosen for salinity since infrequent extreme values due to high daily and seasonal variation in the estuary are likely to have less effect than longer duration overall trends in salinity. Substrate was limited to modelling either hard or soft substrate with gravel size material or larger considered hard substrate. All functional group environmental preference curves used in Ecospace are presented in the results Roberts Bank Ecosystem Model Development and Key Run Report (ESSA 2014*a*).

Several different approaches were used to sample each environmental parameter for the different functional groups (**Table 1-4**). Data collected varied in the degrees of spatial information; for example, data was either geospatially referenced across the study area, geospatially referenced across a portion of the study area, or had minimal to no geospatial data for the study area. For functional groups without study area-specific geospatial information (e.g., marine mammals, fish), environmental preference values were extracted from primary literature.

Table 1-4 Value and Criteria for Ranking Environmental Preferences for the Roberts Bank Ecopath Model

Value	Criteria
0	Species does not prefer this habitat but may occur incidentally (for marine mammals, species does not occur)
1	Species occurs or prefers this habitat
2	Species strongly prefers this habitat
n/a	No available information

For functional groups with geospatial information (i.e., birds, marine invertebrates, marine vegetation), environmental preferences were created using Roberts Bank specific data supplemented with literature-derived values to fill in data gaps or confirm site-specific values.

The bird sampling design employed stratified blocks in the field that were repeatedly surveyed over time. Using ArcGIS, means and ranges for each environmental parameter were sampled for each block while a mean density of each bird functional group was also calculated. The mean densities and environmental parameters were compared for each functional group.

Invertebrate sampling design had point samples for macrofauna, meiofauna, and polychaetes. The point data were used to sample the environmental parameters for each functional group. Sea pens were mapped over time and a **polygon** of their distribution was created for the study area. Sea pen environmental preferences were sampled in the same manner as the primary producers' functional groups, using frequency histograms of environmental variables generated by ArcGIS.

Primary producers were the most comprehensively mapped groups for the study area. This spatial data allowed environmental parameters to be sampled across the study area for marine vegetation. Using ArcGIS, pixels (20 m x 20 m cells) within mapped habitat polygons were used to sample the distribution of each environmental variable by the habitat type resulting in a frequency distribution of habitat type by environmental variable. Presence/absence habitat description rules were used to combine polygons based on the underlying information of primary producers for each polygon. For instance, all polygons with the presence of eelgrass (*Zostera marina*) were added together and the frequency distribution from the combined polygons was used to describe eelgrass's environmental preferences. This approach allowed sampling of the environmental variables where the primary producers' functional groups occurred across the study area.

In addition to the environmental preferences used in the Ecospace model, habitats preferences were documented in this report. The Roberts Bank ecosystem model does not explicitly use environmental preferences for habitat; however, the information is included as it may inform future modelling.

1.5.3 Ecopath Habitat and Substrate Map

A habitat map of Roberts Bank (**Figure 1**; **Table 1-5**) was created to quantify the area of individual habitats and **substrates** and allow for estimates of biomass for each functional group. The habitat map of Roberts Bank covers an area of 54.68 km^2 and consists of 513 polygons with an average size of 0.107 km^2. Polygons were based upon historic mapping from within the study area for eelgrass (Precision Identification 2008), intertidal habitats including biofilm, biomat and tidal marsh (Catherine Berris Associates Inc. 2010), *Ulva* (Hemmera 2009), sea pens (Triton 2004), the Inter-causeway Area (Hemmera et al. 2012), and compensation habitat for Deltaport Third Berth including the subtidal reefs (Triton 2004). This original habitat map was further refined. First, hyperspectral data was acquired for the intertidal and shallow subtidal regions of the study area to help identify different vegetation patterns based on their unique reflective signatures associated with chlorophyll *α*. This imagery was primarily sourced to assess the presence and quantity of biofilm, however it proved a valuable tool to confirm distribution of various marine vegetation. In addition to the hyperspectral map, baseline information collected on percent cover of substrate and vegetation was used to further refine habitat polygons.

A quality assurance process was undertaken to confirm the accuracy of map attributes and polygon distribution. Ten percent of the polygons were systematically reviewed to ensure they correctly

represented the data and that no data entry errors were made. An additional 5% of polygons were selectively reviewed where there appeared to be outliers, where distribution of habitats was complex to predict, or where initial classification of similar or adjacent polygons had been determined to be incorrect.

Table 1-5 Areas of Identified Habitats at Roberts Bank

Habitat Type	Total Area* (ha)
Green algae	343.36
Native eelgrass	293.12
Tidal marsh	197.75
Biofilm	194.73
Non-native eelgrass	143.13
Sea pen[3]	50.88
Biomat	25.41
Grass	14.30
Brown algae	8.11
Red algae	1.01
Bare Substrate	
Sand	3583.73
Mud	600.15
Rock	10.37
TOTAL	**5468.05**

***Note:** values based on February 2014 mapping results

1.6 MODEL UNCERTAINTY AND LIMITATIONS

The development of this model involved compiling and relating data about ecosystem components into a mass balance representation. The information accounts for the ecosystem as a whole, even though input data is derived from single-species studies. Initial estimates of species-specific data may have to be revisited for the model to balance (i.e., some estimates may be adjusted through an iterative process, but will remain within the natural range for the functional group). The model is considered balanced when the results show consistent values for the following (Christensen et al. 2005):

- Estimates of EE are smaller than 1. An EE of 1 means 100% of the production of the group is being used by the system.
- P/Q values for most functional groups range between 0.10 and 0.35. This implies that the consumption for a group is between 10 and 3 times greater than its production.
- Values of total respiration/total system biomass (R/B) are consistent with the functional group's activities with high values for small organisms and top predators.

[3] Sea pens are included as they are an invertebrate habitat forming group (e.g., coral)

Although it is not the focus of this report to describe the process followed to balance the Ecopath model, it is briefly described here to highlight sources of potential error that may be taken into account when interpreting the results of the Ecospace simulations. A detailed description of the process followed to balance the Ecopath model is described in the accompanying Roberts Bank Ecosystem Model Development and Key Run Report (ESSA 2014*a*).

Solutions to balance the Ecopath model are first explored manually by iteratively changing parameters within their range of uncertainty. If a solution cannot be found, or to explore alternative mass balance solutions, a resampling Monte Carlo routine is included in EwE to accept user defined probability distributions for B, Q and P rates, EE and diet composition (Christensen and Walters 2004). Alternatively, a 'pedigree' routine has been implemented within EwE that serves a dual purpose by describing data origin, and by assigning confidence intervals to data based on their origin (Pauly et al. 2000). Another tool that explores uncertainty in EwE is the autobalance routine, which randomly selects the initial biomass and diet input parameters from a pre-defined range of values using the Pedigree routine (Kavanagh et al. 2004).

Mass balance models are deterministic and require many input parameters, some of which may be adapted from other ecosystems, Ecopath models and regions. This introduces uncertainty to the results of the model estimates. In the case of Roberts Bank, data originated from a variety of sources, including data collected from Roberts Bank; however some study designs were created to answer questions not directly related to EwE model inputs, resulting in spatially and temporally patchy information not representative of all functional groups. To fill those gaps, information was extracted from the literature, including other EwE models constructed for similar or other ecosystems near the study area (e.g. Preikshot et al. 2012). Other sources of uncertainty were introduced when, in the absence of data, values to input parameters were based on the judgement of qualified professional biologists. Finally, assumptions were made during populating basic input parameter matrices. These include:

- Biomass calculations assumed species were distributed evenly across habitat polygons.
- Diet composition was recorded in a way that was representative of all species' life stages. Efforts were made to include important prey items and place weight on prey most commonly consumed; however, prey items that may be consumed in greater quantities during some life stages may have been under-represented in the model.
- Calculation of basic biomass inputs for some functional groups depended on the area of vegetation mapped for Roberts Bank. Potential errors in vegetative cover may yield errors in the derived biomasses of some groups (e.g., fish). However, vegetation was mapped to a high degree of accuracy based on detailed hyperspectral imagery, aerial photography, and site visits.
- EwE parameter values within a functional group were averaged among species to get an overall value for the group. However, averaging was not always weighted by the relative biomass of the species comprising the functional group because information for all component species was not always available. The uncertainty associated with such concessions is likely minimal because functional groups consist of species with similar life history traits, diets, habitat and environmental preferences.

- For some functional groups, information on environmental preferences was available for a subset of the component species, which was used to make estimates for the entire group. The uncertainty associated with such concessions is likely minimal because functional groups consist of species with similar life history traits, diets, habitat and environmental preferences.
- All Project-related effects on species were only considered within the study area modelled (**Figure 1**). Physical variable analysis, described in Section 1.5.2 Ecospace, did not take into account the proposed expansion of the tug basin for the RBT2. The tug basin design was not finalised when the EwE model was being built. However, in comparison to the size of the RBT2, the tug basin is insignificant. Also, the orientation extends towards the existing terminal. Although omission of this Project element may have some localised small-scale effects in habitat extent and distribution, effects on the model results at the ecosystem level are likely insignificant as the total area is less than 0.05% of the total study area.
- Most Ecopath models are designed to capture energetic flows and balances averaged over a representative year for an ecosystem though it is possible to build models at seasonal and even smaller time-scales. This model follows the annual average convention. There is no explicit assumption about how mortality rates, consumption rates, and diet composition may have varied within this step. Also issues of seasonality were adjusted within each functional group differently to estimate annual biomass, even if productivity is not consistent throughout the year.
- Although one of EwE's primary functions is to examine how changes in fishing pressure alter a fishery or functional group, the purpose of the Roberts Bank ecosystem model is to assess the effects of the Project on the surrounding environment. For this reason fishing pressure was assumed to be constant throughout the modelling period;
- Assumptions related to data inputs for specific focal species and functional groups are further discussed in each section of the report.

The accompanying Roberts Bank Ecosystem Model Sensitivity Analyses Report analyses some of the above assumptions and uncertainties and the outcome of the model (ESSA 2014*b*)

1.7 QUALITY ASSURANCE

The confidence in a model's predictions depends highly on the quality of its inputs and settings. For this reason a comprehensive review cycle has been performed on the basic inputs to the Roberts Bank ecosystem model presented in this report to ensure that they best represent the existing conditions with the foremost accuracy and that no errors were made in data entry and model processing. In addition to the processes outlined in this report to generate the initial inputs, the following quality assurance procedures were implemented:

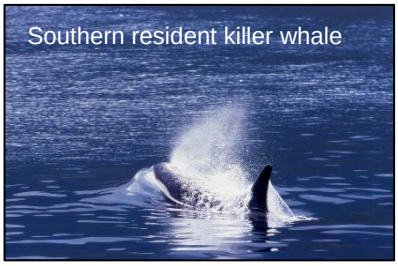
- A review of all calculations to produce final input values were checked for data entry errors and mathematical processing errors in the spreadsheets;
- The magnitude of input values (i.e., how the biomass value relates to the number of individuals observed at Roberts Bank) were reviewed by the designated lead for each ecological group (i.e., marine fish) to ensure they represent field data and observations in the Project area;

- A detailed third party review by two independent, experienced experts in both EwE modelling and the ecology of the Strait of Georgia (Dr. Carl Walters, University of British Columbia and Dr. Dave Preikshot, Madrone Environemntal Services) was undertaken with inputs revised where necessary, based upon their comments; and
- The EwE model was run in an iterative process such that the production outputs and spatial distribution maps were reviewed for erroneous or outlying outputs. All potentially erroneous outputs were reviewed to ensure there were no processing errors either with the inputs or in the running of the model. Once it was determined that all basic inputs, environmental preferences, diets and without project spatial distributions were representative of the Roberts Bank ecosystem, the final model was run.

The following Sections 2.0 through 6.0 present the basic inputs to the Roberts Bank ecosystem model after all quality assurance procedures were undertaken.

2.0 MARINE MAMMALS

Marine mammals are a culturally significant component of the marine environment at Roberts Bank. Their role as top predators in the ecosystem makes them readily identifiable indicators of ecosystem health and function. However, this EwE model was not built to provide direct information on RBT2 effects on marine mammals because important variables to assess the effects, such as underwater noise and contaminants were not considered in the model. Other models at the individual- and population-level will be used to assess the effects of the Project on southern resident killer whales (SRKW) and other marine mammals. Marine mammals were, however, included in the EwE model for their important role as top predators.



2.1 FUNCTIONAL GROUPS

The marine mammal functional groups represented in this EwE model were:

1. Baleen whales
2. Dolphins and porpoises
3. Pinnipeds
4. Southern resident killer whales*[4]
5. Transient killer whales*

Marine mammal functional groups were created to reflect ecological niches, social value, diet and trophic level. SRKW and transient killer whales were identified as focal species by the PC-TAG.

Below is a brief description of each functional group including: 1) species included in the functional group, 2) biomass and production values, 3) diet and consumption estimates, and 4) information on seasonality and environmental preferences at Roberts Bank and the Strait of Georgia. All species described below have been observed in or near the study area (Keple 2002, Stantec Consulting Ltd. 2010, Vancouver Aquarium 2013).

2.2 METHODS

Estimation of EwE model parameters for the marine mammal functional groups followed methodology described in Section 1.1 Study Area.

[4] * indicates focal species

2.3 BALEEN WHALES

2.3.1 Group Definition

Table 2-1 Species in the Baleen Whales Functional Group

Common Name	Scientific Name
North Pacific minke whale	*Balaenoptera acutorostrata*
Eastern North Pacific grey whale	*Eschrichtius robustus*
North Pacific humpback whale	*Megaptera novaeangliae*

Baleen whales are relatively rare at Roberts Bank with grey whales being the most common as they are generally found closer to shore. There have been anecdotal reports of grey whales feeding at Boundary Bay near Roberts Bank.

2.3.2 Biomass and Production

The total biomass of baleen whales in the study area was estimated to be 0.3 x 10^{-4} t/km^2. This represents a portion of the baleen whale biomass of 0.01 t/km^2 estimated for the Strait of Georgia reflecting limited presence in the area shallower than the 0 m CD contour (Preikshot 2007). Previous EwE models for the Strait of Georgia estimate the baleen whale population to consist of 79% grey whales, 17% humpbacks, and 4% minke whales (Preikshot 2007). Baleen whale biomass was adjusted to 0.005 t/km^2 during model balancing (Roberts Bank Ecosystem Model Development and Key Run Report (ESSA 2014*a*) to meet balancing requirements and be more similar to other EwE models from the Strait of Georgia of 0.01 t/km^2 (Christensen pers. comm.).

A P/B of 0.03 year^{-1} was used, assuming that the proportional contribution of each species within the functional group at Roberts Bank is similar to that of the Strait of Georgia, although minke whales may be more common than humpback whales in the study area (Preikshot 2007).

2.3.3 Diet and Consumption

Minke whales opportunistically feed on zooplankton (e.g., euphausiids and copepods), and small schooling fish (including anchovies (Engraulidae), dogfish (Squalidae), capelin (*Mallotus villosus*), sablefish (*Anoplopoma fimbria*), cod (*Gadus macrocephalus*), Pacific herring (*Clupea pallasii*), mackerel (Scombridae), Pacific salmon (*Oncorhynchus* spp.), Pacific sandlance (*Ammodytes hexapterus*), Pacific saury (*Cololabis saira*), and wolfish (*Anarhichas lupus*)) (Reeves et al. 2002). In the North Pacific, they feed on euphausiids, Japanese anchovy (*Engraulis japonicus*), Pacific saury, and walleye pollock (*Theragra chalcogramma*) (Tamura and Fujise 2002).

Eastern North Pacific grey whales have been known to consume bottom-dwelling decapods (e.g., ghost shrimp, *Neotrypaea californiensis*), amphipods (e.g., gammarid amphipod, *Ampelisca macrocephala*), isopods, polychaete worms, mollusks, and other invertebrates (Kvitek and Oliver 1986, Weitkamp et al. 1992). On the west coast of Vancouver Island near Clayquot Sound, grey whales forage primarily on mysids (Mysidae), and crab larvae (Porcellanidae) (Nelson et al. 2008).

North Pacific humpback whales feed on large zooplankton (mostly krill and copepods), and small fish (including herring, salmon, sardine, sandlance, mackerel, cod, and anchovies (Johnson and Wolman 1984, Ford et al. 1998)).

A Q/B of 13.37 year $^{-1}$ for the functional group was used (Preikshot 2007).

2.3.4 Environmental Preferences

Humpback whales migrate annually from high-latitude summer feeding grounds to low-latitude winter breeding and calving grounds (COSEWIC 2011). They are in B.C. waters mostly for summer feeding, but can be present in low numbers throughout the year.

The temporal pattern of grey whale migration is similar to that of humpback whales, however there is a small number of grey whales referred to as the ‘summer-resident community’ (COSEWIC 2004). This group of grey whales tends to feed in more temperate waters from northern California to southeast Alaska (COSEWIC 2004). Summer resident grey whales in B.C. waters are estimated in the low hundreds (COSEWIC 2004).

Little is known about minke whale movements in the North Pacific. It is likely that the animals in the extreme north migrate south in the winter but it may be possible that animals in temperate areas between B.C. and California are residents. Minke whales exhibit **site fidelity** with individuals appearing at the same site in multiple years. Minke whales are relatively rare in the Strait of Georgia and possibly only present for a portion of the year (Keple 2002).

Baleen whales can dive up to 2,000 m (Frankel et al. 1995). It is assumed that they can be found in relatively shallow water, as long as their body weight can be supported. Rankings for their environmental preferences are shown (**Table 2-2**)**.** Although grey whales are known to forage over mud scooping up and filtering benthic prey, sediment does not appear to be a determinant of grey whale distribution, as foraging also occurs in the water column targeting zooplankton (Jones et al. 1984, DFO 2010*a*).

Table 2-2 Baleen Whale Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	0	Clay	1	Very low	1	Quiescent	1	Mud	1
Brackish	1	Shallow subtidal	1	Very fine sand	1	Low	1	Very low	1	Sand	1
Freshet	1	Moderate subtidal	2	Fine sand	1	Moderate	1	Low	1	Biofilm	0
Marine	1	Deep subtidal	2	Coarse sand	1	High	1	Moderate	1	Biomat	0
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	1
										Saltmarsh	0
										Grass	0
Source											
n/a		Professional judgement		n/a		n/a		n/a		n/a	

Note: 0 indicates species do not occur in this habitat,1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

2.4 DOLPHINS AND PORPOISES

2.4.1 Group Definition

Table 2-3 Species in the Dolphins and Porpoises Functional Group

Common Name	Scientific Name
Pacific white-sided dolphin	*Lagenorhynchus obliquidens*
Pacific harbour porpoise	*Phocoena phocoena*
Dall's porpoise	*Phocoenoides dalli*

This functional group consists of dolphins and porpoises present at Roberts Bank. Harbour porpoises are the most abundant of the group and are found in the Strait of Georgia throughout the year.

2.4.2 Biomass and Production

Total biomass of dolphins and porpoises at Roberts Bank was estimated at 0.0003 t/km^2; this was derived from a previous estimate for the Strait of Georgia (Preikshot et al. 2012). Biomass estimate for the Roberts Bank ecosystem model assumed this group's presence was limited to areas deeper than 1 m CD. Dolphin and porpoise biomass was changed to 0.005 t/km^2 during model balancing (see Roberts Bank Ecosystem Model Development and Key Run Report (ESSA 2014*a*)) to meet balancing requirements produced by predation from transient killer (Christensen pers. comm.). Since ecotrophic efficency (EE) is 13, at least 13x higher B is needed, therefore, B should be 0.005 or higher. A P/B of 0.16 year^{-1} was used (Preikshot et al. 2012).

2.4.3 Diet and Consumption

Dolphins and porpoises feed mainly on small schooling fish but will on occasion prey on squid and crustaceans. Specifically, Pacific harbour porpoise feed mostly on market squid (*Loligo opalescens*) and Pacific herring, and to a lesser degree on Pacific hake (*Merluccius productus*), walleye pollock, shiner perch (*Cymatogaster aggregata*), and fathead sculpins (Pyschrolutidae) (Nichol et al. 2013). Dall's porpoise feed mostly on Pacific herring and walleye pollock and to a lesser extent on Pacific hake, fathead sculpins, lantern fish (Myctophidae), and deep sea sculpins (Bathylagidae) (Nichol et al. 2013). Pacific white-sided dolphin feed on Pacific herring, salmon, cod, shrimp, capelin, Pacific sardine (*Sardinops sagax*), squid, anchovies, rockfish (*Sebastes* spp.), pollock, hake and other small fish. In prey fragment sampling, collected near foraging dolphins in the inshore waters along the B.C. coast, herring was found the be the most common prey (59%) followed by salmon (30%), cod (6%), shrimp (3%), and capelin (1%) (Heise 1996). A Q/B of 20.06 year^{-1} for porpoises was used (Preikshot et al. 2012).

2.4.4 Environmental Preferences

Pacific white-sided dolphins are not abundant but are sighted in the Strait of Georgia during spring, summer, and fall (Keple 2002). Harbour and Dall's porpoises are present in the Strait of Georgia year-round and are more commonly sighted and thought to be more abundant than Pacific white-sided dolphins (Keple 2002, COSEWIC 2003a). Harbour porpoises in the Strait of Georgia occur in small numbers while Dall's porpoises are more abundant in winter and spring (Keple 2002).

Dolphins and porpoises can dive to at least 100 m but most of their dives are shallower than 20 m and can be found relatively close to shore (Otani et al. 1998, Chandler and Calambokidis 2003, Nysewander et al. 2005). It is assumed they can be found in relatively shallow water, as long as their body weight can be supported. Rankings for environmental preferences are available (**Table 2-4**).

Table 2-4 Dolphin and Porpoise Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	0	Clay	1	Very low	1	Quiescent	1	Mud	1
Brackish	1	Shallow subtidal	1	Very fine sand	1	Low	1	Very low	1	Sand	1
Freshet	1	Moderate subtidal	2	Fine sand	1	Moderate	1	Low	1	Biofilm	0
Marine	1	Deep subtidal	2	Coarse sand	1	High	1	Moderate	1	Biomat	0
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	1
										Saltmarsh	0
										Grass	0
Source											
n/a		Chandler and Calambokidis 2003; Nysewander et al. 2005; Professional judgement		n/a		n/a		n/a		n/a	

Note: 0 indicates species do not occur in this habitat,1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

2.5 PINNIPEDS

2.5.1 Group Definition

Table 2-5 Species in the Pinnipeds Functional Group

Common Name	Scientific Name
Pacific harbour seal	*Phoca vitulina richardsi*
Steller sea lion	*Eumetopias jubatus*
California sea lion	*Zalophus californianus*

This functional group is made up of two eared seal species (Otariidae), the Steller sea lion and California sea lion, and one species of earless seal species (Phocidae), the harbour seal. Harbour seals are the most abundant and are commonly found in the Strait of Georgia and Roberts Bank throughout the year.

2.5.2 Biomass and Production

Pinniped biomass of 0.40 t/km^2 was estimated using biomass values of the species within the functional group from previous EwE models from the Strait of Georgia (Preikshot 2007, Preikshot et al. 2012); these were adjusted to obtain the functional group biomass estimate based on each species' presence at Roberts Bank (i.e., Steller sea lions are likely less abundant at Roberts Bank than the Strait of Georgia based on known haulout locations; Jeffries et al. (2000)). Specifically, harbour seal biomass is estimated to be 0.34 t/km^2 for the Strait of Georgia using population counts and average male and female body masses (Olesiuk 2009, DFO 2010*b*, Preikshot et al. 2012). Steller sea lion biomass in the Strait of Georgia was estimated at 0.12 t/km^2 for 1960, while for 2007, biomass for Steller sea lions and Northern fur seals combined was equal to 0.14 t/km^2 (Preikshot et al. 2012). A P/B of 0.14 year^{-1} was estimated from P/B values provided for seals in previous EwE models for the Strait of Georgia (Preikshot 2007, Li 2012, Preikshot et al. 2012).

2.5.3 Diet and Consumption

Pinnipeds feed primarily on fish. Steller sea lions have been recorded to feed on walleye pollock, sand lance, Atka mackerel (*Pleurogrammus monopterygius*), salmon, herring, Pacific cod, rockfish, sculpins (Cottidae), flatfish (Pleuronectiformes), squid, and octopus (Sinclair and Zeppelin 2002, Trites et al. 2007). California sea lions feed on Pacific hake, walleye pollock, Pacific cod, and English sole (*Pleuronectes vetulus*) (Everitt et al. 1981).

Pacific harbour seal diet varies with area and season (Lance and Jeffries 2009). Generally, Pacific harbour seals feed mostly on Pacific hake, Pacific herring, Pacific tomcod (*Microgadus proximus*), salmon, starry flounder (*Platichthys stellatus*), English sole, lingcod, shiner perch, market squid, red octopus (*Octopus rubescens*), Pacific sandlance, plainfin midshipman (*Porichthys notatus*), staghorn sculpin (*Leptocottus armatus*), Northern anchovy (*Engraulis mordax*), three spine stickleback (*Gasteroseus aculeatus*), and rockfish (Olesiuk et al. 1990, Lance and Jeffries 2009).

A Q/B of 15.95 year^{-1} was estimated from Q/B values provided for seals in previous EwE models for the Strait of Georgia (Preikshot 2007, Li 2012, Preikshot et al. 2012).

2.5.4 Environmental Preferences

Harbour seals are the most common and widely distributed pinniped on the B.C. coast (Jeffries et al. 2000, Olesiuk 2009). They are considered non-migratory and are found in relatively high numbers throughout the year (Jeffries et al. 2000, Keple 2002). While no **haul-out sites** were identified within the study area, there are five nearby, in the Fraser River delta (i.e., on Sturgeon Bank) (Jeffries et al. 2000).

In the Strait of Georgia, male and female Steller sea lions occur year-round and peak from September to May (Calambokidis and Baird 1994, COSEWIC 2003*b*). Haul-out sites used year-round and winter sites used seasonally occur in the Strait of Georgia and within the study area (COSEWIC 2003*b*). Breeding however does not occur within or near the study area (Jeffries et al. 2000).

California sea lions are present along the B.C. and Washington coasts from fall until late spring. In spring, they return to their breeding rookeries off the coast of California and Mexico (Keple 2002). Male California sea lions, of all age classes, migrate into northern waters while females remain in southern rookeries off California (Jeffries et al. 2000). California sea lions are less common than Steller sea lions in B.C. A haul-out site at Sand Heads at the mouth of the Fraser River adjacent to the study area is used in spring (Jeffries et al. 2000).

No evidence was found that pinnipeds have any preference for any of the environmental parameters considered in this report; therefore, rankings were set to 1 (**Table 2-6**).

Table 2-6 Pinniped Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	0-1	Clay	1	Very low	1	Quiescent	1	Mud	1
Brackish	1	Shallow subtidal	1	Very fine sand	1	Low	1	Very low	1	Sand	1
Freshet	1	Moderate subtidal	1	Fine sand	1	Moderate	1	Low	1	Biofilm	1
Marine	1	Deep subtidal	1	Coarse sand	1	High	1	Moderate	1	Biomat	1
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	1
										Saltmarsh	1
										Grass	1
Source											
n/a		n/a		n/a		n/a		n/a		n/a	

Note: 0 indicates species do not occur in this habitat, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

2.6 SOUTHERN RESIDENT KILLER WHALES

2.6.1 Group Definition

Table 2-7 Species in the Southern Resident Killer Whales Functional Group

Common Name	Scientific Name
Southern resident killer whale	*Orcinus orca*

Southern resident killer whales (SRKW) live in a matriarchal society. Offspring stay with their mothers throughout their lives The SRKW community consists of 3 pods (J, K and L pods). As of September 2013, SRKW had a population of 81 (Center for Whale Research 2013).

Southern resident killer whales were selected as a marine mammal focal species for Roberts Bank by PC-TAG and formed its own functional group in the EwE model. SRKWs are provincially red-listed and also listed as Endangered under Schedule 1 of the *Species at Risk Act* (SARA) (DFO 2011*a*). They are an important species ecologically, economically, and culturally. Critical habitat identified in B.C. includes Roberts Bank. A recovery strategy has been published by Fisheries and Oceans Canada (DFO) (DFO 2011*a*).

2.6.2 Biomass and Production

SRKW presence at Roberts Bank peaks from mid-June to mid-September. Peak biomass was estimated to be 0.04 t/km^2 by multiplying a population size of 81 individuals with the average body weight of a female killer whale of 3.5 t, and dividing it by their summer range in the Strait of Georgia (equal to 7,000 km^2). Because killer whale females are smaller than males and larger than juveniles, the average weight of a female was used as a proxy for the average weight of the population. To account for the seasonal presence of SRKW in the study area, a quarter of the peak biomass or 0.01 t/km^2 was used as input into the EwE model. A P/B of 0.04 year^{-1} was used, based on previously published SRKW survival rates (Preikshot et al. 2012, Bain and Balcomb 2002).

2.6.3 Diet and Consumption

In the Strait of Georgia, Southern resident killer whales feed on adult salmon with preference for Chinook (*Oncorhynchus tshawytscha*) (Ford et al. 1998, Ford and Ellis 2006). Other prey items include Pacific herring, Pacific halibut (*Hippoglossus stenolepis*), yellow rockfish (*Sebastes ruberrimus*) and quillback rockfish (*Sebastes maliger*) (Ford et al. 1998, Ford and Ellis 2006). A Q/B of 14 year^{-1} was used, based on North Pacific killer whale metabolism, diet and food quality (Hunt et al. 2000, Preikshot et al. 2012).

2.6.4 Environmental Preferences

Southern resident killer whales are sighted regularly in the Strait of Georgia including Roberts Bank from May to October with sightings peaking in July and August (Hemmera 2014*a*). They are also found in low numbers in B.C. waters throughout the year (Keple 2002, COSEWIC 2008, Hemmera 2014*a*).

Southern resident killer whales can dive over 200 m but most are shallower than 30 m; they also only occasionally enter water less than 5 m (Baird et al. 2003, Wiles 2004). Rankings for environmental preferences are available (**Table 2-8**).

Table 2-8 Southern Resident Killer Whale Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	0	Clay	1	Very low	1	Quiescent	1	Mud	1
Brackish	1	Shallow subtidal	1	Very fine sand	1	Low	1	Very low	1	Sand	1
Freshet	1	Moderate subtidal	2	Fine sand	1	Moderate	1	Low	1	Biofilm	0
Marine	1	Deep subtidal	2	Coarse sand	1	High	1	Moderate	1	Biomat	0
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	1
										Saltmarsh	0
										Grass	0
Source											
n/a		Wiles 2004; Professional judgement		n/a		n/a		n/a		n/a	

Note: 0 indicates species do not occur in this habitat, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

2.7 TRANSIENT KILLER WHALES

2.7.1 Group Definition

Table 2-9 Species in the Transient Killer Whales Functional Group

Common Name	Scientific Name
Transient killer whales	*Orcinus orca*

Transient killer whale societies are based on a matriline structure similar to SRKW. However, offspring may disperse from their mother's group at maturity, especially females after having their own calves and transient killer whales are generally found in smaller groups. They rarely vocalise or **echolocate** while hunting, as their marine mammal prey would likely hear them underwater; instead, they follow the coastline, checking each cove for prey and use passive listening to locate seals and small cetaceans (Barrett-Lennard et al. 1996).

Transient killer whales were selected by the PC-TAG as a marine mammal focal species of ecological, economic, and cultural significance and modelled as a functional group in the EwE model. They are provincially red-listed and threatened under SARA (COSEWIC 2008).

2.7.2 Biomass and Production

Biomass of transient killer whales in the Strait of Georgia fluctuates depending on season. It was assumed that half (i.e., 119 individuals) of the B.C. and southeastern Alaska population of 243 individuals transit through the Strait of Georgia during their migration (DFO 2009, Wiles 2004). Therefore, peak biomass for the Strait of Georgia was estimated at 0.062 t/km^2 by multiplying a population size of 119 individuals by the average body weight of a female killer whale of 3.5 t and then dividing with an area in the Strait of Georgia (equal to 7,000 km^2). Because transient killer whale females are smaller than males and larger than juveniles, the average weight of a female was used as a proxy for the average weight of the population. Transient killer whales frequent waters of Haro Strait and the western part of the Strait of Georgia, and are rarely seen at Roberts Bank. To account for this, one third of the Strait of Georgia peak biomass was considered for the study area, which was further divided by four to reflect seasonal presence at Roberts Bank. Therefore, annual biomass of transient killer whales at Roberts Bank was estimated at 0.0052 t/km^2. The transient killer whale population is believed to have increased from about 50 in the early 1970s to approximately 240 in 2006 (DFO 2009). A P/B of 0.04 year^{-1}, equivalent to that of SRKW, was used for transient killer whales (Preikshot et al. 2012).

2.7.3 Diet and Consumption

In B.C., transient killer whales feed primarily on marine mammals, specifically seals, sea lions, porpoises, dolphins, and occasionally on calves or juveniles of larger species such as grey and humpback whales, and seabirds (Ford et al. 1998). Percent contribution (by weight) of prey items is: harbour seals 53%, harbour porpoise 11%, Dall's porpoise 12%, Steller sea lion 13%, with smaller contributions from California sea lion, Pacific white-sided dolphin, grey whales and minke whales, and seabirds (Ford et al. 1998).

The estimated Q/B of 10 year^{-1} was used and is lower than that of SRKW due to the higher energy content of their marine mammal prey (Hunt et al. 2000, Preikshot et al. 2012).

2.7.4 Environmental Preferences

Transient killer whales are generally present in the Strait of Georgia and around Roberts Bank in the summer and fall but may be present in low numbers the rest of the year (Keple 2002, COSEWIC 2008). The habitat requirements of transient killer whales are not well understood and there is no apparent seasonal pattern to their movements (Keple 2002, COSEWIC 2008).

Transient killer whales, like SRKW, can dive over 200 m but most of their dives are shallower (Baird et al. 2003). Some transient groups spend most of their time foraging close to shore in shallow waters (Wiles 2004). Rankings for their environmental preferences are available (**Table 2-10**).

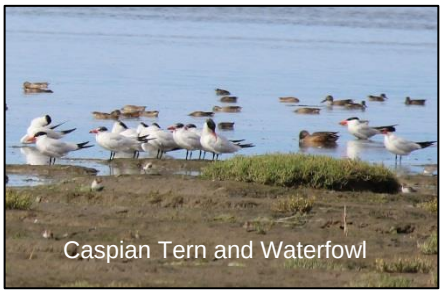
Table 2-10 Transient Killer Whale Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	0	Clay	1	Very low	1	Quiescent	1	Mud	1
Brackish	1	Shallow subtidal	1	Very fine sand	1	Low	1	Very low	1	Sand	1
Freshet	1	Moderate subtidal	2	Fine sand	1	Moderate	1	Low	1	Biofilm	0
Marine	1	Deep subtidal	2	Coarse sand	1	High	1	Moderate	1	Biomat	0
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	1
										Saltmarsh	0
										Grass	0
Source											
n/a		Wiles 2004; Professional judgement		n/a		n/a		n/a		n/a	

Note: 0 indicates species do not occur in this habitat, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

3.0 BIRDS


Dunlin and Western sandpiper


Caspian Tern and Waterfowl

Birds can occupy a range of trophic levels from herbivore to top predators. Waterfowl consume plant matter while raptors prey upon shorebirds, diving waterbirds, gulls, terns and waterfowl (Poole 2005). Peregrine falcons (*Falco peregrinus*) and merlins (*F. columbarius*) are the main predators of western sandpipers (*Calidris mauri*) in the Fraser River Delta (Dekker 1995, 1998, Butler 1999). Gulls can also be high trophic level predators in marine food webs (Furness and Camph 1997). The varied diets and mobility of birds enable them to have large influences on ecosystem functions such as preventing the overpopulation of any prey source.

3.1 FUNCTIONAL GROUPS

Bird species were divided into 11 functional groups. Five of the functional groups represent groups of species aggregated based on similar ecological niches. Many of these functional groups represented a diversity of species, many of which were present in low numbers, therefore, as a general rule, in order to be retained in a functional group a species had to account for >0.1% of all non-passerine bird observations at Roberts Bank. The other six functional groups were single species functional groups selected as focal species by the PC-TAG due to their ecological and social importance, their use as an **indicator species**, their ecological dependence on the study area, their traditional use in site monitoring (and therefore the availability of good historic data), and their consistent presence at Roberts Bank in relatively high numbers (Compass Resource Management Ltd. 2013). Functional groups used in this model are listed below.

1. Waterfowl
2. Shorebirds
3. Diving waterbirds
4. Raptors
5. Gulls and terns
6. Western sandpiper*
7. Great blue heron*
8. Dunlin*
9. Brant goose*
10. Bald eagle*
11. American wigeon*

3.2 METHODS

In general, estimation of EwE model parameters followed methodology described in Section 1.1 Study Area. However, additional analysis undertaken to estimate biomass, production, consumption, and environmental preferences specific to bird functional groups is described below.

3.2.1 Biomass and Production

Excluding shorebirds, biomass estimates were calculated by dividing the total annual abundance, from bird surveys conducted at Roberts Bank over a year, spanning 2012 and 2013, by the number of surveys performed within that year (Hemmera 2014*b*). Average abundance for shorebird species (i.e., dunlin, western sandpiper and black-bellied plover) was obtained from shorebird usage field surveys conducted over the majority of a year in 2012 and 2013 (Hemmera 2014*b*). In non-surveyed months an estimate of average abundance was calculated using a month-to-year abundance ratio derived from the general bird survey data.

Average annual abundances were multiplied by the species' average body weight, taken from the literature (BC MOE 1996). All species biomass estimates within a functional group were summed to yield a functional group biomass estimate. The total biomass for each functional group was divided by the study area of 54.68 km^2 to determine the biomass per square kilometre.

If available, taxa-specific P/B estimates were taken from other models with a similar geographical range. If taxa- and location-specific P/B estimates were not available, then P/B estimates were taken from models with similar functional groups. If P/B estimates were unavailable, the natural mortality rates from literature were considered equivalent to P/B. In many cases, the literature would list the natural mortality rate of both juveniles and adults, which were averaged to get natural mortality rate for the species. P/B for each functional group was calculated by taking the average of all the species' P/B values within each functional group.

3.2.2 Diet and Consumption

Diet information was extracted from the literature. When available, taxa specific Q/B estimates were taken from other models with a similar geographical range (elaborated upon case-by-case subsequently). If taxa- and location-specific Q/B estimates were not available, then Q/B estimates were taken from models with similar functional groups. If Q/B estimates were unavailable, the daily consumption rates were taken from published literature instead. In these cases, an estimation of Q/B was calculated by dividing the taxa-specific daily consumption rate by the average body weight of the species, and then multiplying it by 365 (annual rate). An average Q/B estimate for each functional group was calculated by taking the average of all the species' Q/B values.

3.2.3 Environmental Preferences

Data on environmental preferences for each functional group were gathered from field guide books, and electronic databases including the Birds of North America Online, E-Fauna BC: Electronic Atlas of the Wildlife of B.C., and the BC Species and Ecosystems Explorer (Stokes and Stokes 2010, Poole 2005, Klinkenberg 2013, (BC CDC 2013). A visual analysis of density was conducted using data obtained from field surveys in 2012 and 2013, overlaid by environmental parameter rasters, accounting for salinity, depth, sediment distribution, wave height, and habitat type (Hemmera 2014*b*). However, visual analysis of the field-derived density data alone was insufficient to determine environmental preferences for each functional group because several environmental parameters are highly correlated, e.g., salinity and depth. This makes it difficult to determine which environmental factor is driving bird distribution and abundance. For example, diving waterbirds exhibited preference for higher salinity water. This observation, however, may be an artefact of their actually seeking deeper waters where freshwater influence is not as strong, rendering depth the true determinant of diving waterbird distribution than salinity. Thus it was necessary to use a combination of literature-derived and field-derived information to inform the environmental trends and relationships of each bird functional group at Roberts Bank (elaborated upon case-by-case subsequently). It is important to note that freshwater and moderate wave height environments, as well as rock (cobble and boulders), gravel, and grass habitats do not occur to a great extent within the bird survey area. As a result, to draw conclusions regarding preference of a functional group for those particular habitat types, the literature was used as the primary source of information.

3.3 WATERFOWL

3.3.1 Group Definition

Table 3-1 Species in the Waterfowl Functional Group

Common Name	Scientific Name	Average Annual Abundance	Percent Contribution to Functional Group
Green-winged teal	*Anas carolinensis*	1119	44
Snow goose	*Chen caerulescens*	809	31.8
Northern pintail	*Anas acuta*	408	16
Mallard	*Anas platyrhynchos*	202	7.9
Canada goose	*Branta canadensis*	7	0.3
Eurasian wigeon	*Anas penelope*	1	0

The waterfowl functional group is made up of six species (**Table 3-1**), four of which contributed at least 0.1% of the total non-passerine avian abundance at Roberts Bank (Hemmera 2014*b*). Canada goose and Eurasian wigeon were also included. Waterfowl accounted for 26% of non-passerine abundance at Roberts Bank, while green-winged teal and snow geese represented about three quarters of the abundance of waterfowl.

Roberts Bank provides critical migration and/or wintering habitat along the Pacific Flyway for various species of waterfowl including each species included in this functional group as well as northern shovellers, trumpeter swans, and gadwalls (BirdLife Canada 2013). Waterfowl can be found at Roberts Bank year-round primarily using the area to forage and **roost** (Williams et al. 2009). The importance of Roberts Bank as waterfowl habitat comes from the unique combination of a vast mudflat with **intertidal** marshes and eelgrass (Vermeer and Butler 1989, Williams et al. 2009).

A large portion of the Roberts Bank wildlife area is open to recreational waterfowl hunting during prescribed 'general open seasons' (BC MFLNRO 2013). Open hunting season for ducks and snow geese occurs from October to January (BC MFLNRO 2013). Open hunting seasons for other geese vary; however, hunting generally takes place between fall and spring (Environment Canada 2013).

3.3.2 Biomass and Production

The mean annual biomass of waterfowl within the study area was estimated to be 0.3034 t/km^2, assuming that waterfowl are evenly distributed across Roberts Bank. A P/B of 0.20 year^{-1} was used (Bauer 2010), though this value is slightly lower than the 0.427 found in Harvey et al. (2010).

3.3.3 Diet and Consumption

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) (Poole 2005, Williams et al. 2009). Waterfowl also consume benthic invertebrates such as snails and insects (Poole 2005). A Q/B of 200 year^{-1} was used (Bauer 2010); models from Puget Sound (Harvey et al. 2010) have used a higher value (329) .

3.3.4 Environmental Preferences

Waterfowl use a range of marine and freshwater environments. In estuaries waterfowl can be found in intertidal marshes, grasslands, mudflats, sandflats, biofilm, biomat, *Ulva* and eelgrass patches (Poole 2005, Stokes and Stokes 2010, BC CDC 2013, Klinkenberg 2013). They feed and roost along the tide line during low tide or higher in the intertidal on the mudflats of Roberts Bank during high tide (Williams et al. 2009, Hemmera 2014*b*). Moderate use of the subtidal areas of Roberts Bank in the vicinity of the Deltaport terminal was also observed during the 2012-2013 bird surveys (Hemmera 2014*b*). Waterfowl prefer sheltered areas with limited exposure for roosting (Stokes and Stokes 2010, BC CDC 2013, Klinkenberg 2013). Environmental preferences for waterfowl in the study area are shown (**Table 3-2**).

Table 3-2 Waterfowl Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	2	Clay	2	Very low	n/a	Quiescent	2	Mud	2
Brackish	1	Shallow subtidal	1	Very fine sand	2	Low	n/a	Very low	2	Sand	2
Freshet	1	Moderate subtidal	0	Fine sand	2	Moderate	n/a	Low	1	Biofilm	2
Marine	1	Deep subtidal	0	Coarse sand	2	High	n/a	Moderate	1	Biomat	2
				Fine gravel	1					Rock	2
				Gravel	1					*Ulva*	1
				Cobbles/Boulder	1					Eelgrass	1
										Kelp	0
										Sea pens	0
										Saltmarsh	2
										Grass	2
Source											
(Poole 2005, Stokes and Stokes 2010, BC CDC 2013, Klinkenberg 2013, Hemmera 2014*b*)		(Poole 2005, BC CDC 2013, Klinkenberg 2013, Hemmera 2014*b*)		(Poole 2005, Hemmera 2014*b*)		n/a		(Stokes and Stokes 2010, BC CDC 2013, Klinkenberg 2013, Hemmera 2014*b*)		(Poole 2005, BC CDC 2013, Hemmera 2014*b*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

3.4 SHOREBIRDS

3.4.1 Group Definition

Table 3-3 Species in the Shorebirds Functional Group

Common Name	Scientific Name	Average Annual Abundance
Black-bellied plover	*Pluvialis squatarola*	145

During surveys at Roberts Bank, 16 species of shorebirds were encountered, though most of them in low numbers. Dunlin and Western sandpipers were treated individually in the model (see section 3.8 and 3.10), leaving black-bellied plovers to represent the other shorebird species. Black-bellied plovers were selected to represent the shorebird functional group because they comprised 88% of shorebird abundance once dunlin and Western sandpiper were removed (Hemmera 2014*b*).

The Fraser River estuary can have more than 500,000 shorebirds on a given day (Butler and Vermeer 1994) and as many as 1.4 million shorebirds over the course of a year (Butler and Campbell 1987). Roberts Bank intertidal mudflats, biofilm and marshes provide important shorebird feeding habitat (Williams et al. 2009). The reward of high food availability appears to offset the risk of predation by locally abundant birds of prey, making the area along the Pacific Flyway a very attractive stopover site (Pomeroy et al. 2008).

Black-bellied plovers use Roberts Bank to overwinter or as a stopover during migration. A small number of nonbreeding individuals are found in the area during the summer (Poole 2005).

3.4.2 Biomass and Production

The average annual biomass of shorebirds within the study area was estimated to be 0.00083 t/km^2. This estimate assumes that shorebird abundance is evenly distributed across sections of the study area that are greater than 0 m CD in elevation. A P/B 0.51 year^{-1} (Frisk et al. 2011) was used.

3.4.3 Diet and Consumption

The diet of black-bellied plover consists primarily of benthic invertebrates such as infaunal bivalves and polychaetes (Poole 2005). A Q/B of 92 year^{-1} was used (Dalsgaard et al. 1998).

3.4.4 Environmental Preferences

In marine environments, black-bellied plover are found in the intertidal zone, where their preferred sediment type includes sand, mud and occasionally rocky substrate (Poole 2005). The foraging rate of most shorebirds, including the black-bellied plover, increases rapidly during falling tide (Burger et al. 1977). Although black-bellied plovers are typically found foraging on sand or mud flats, they occasionally forage in salt marshes (Poole 2005, BC CDC 2013, Klinkenberg 2013). Shorebirds use eelgrass habitat less, because eelgrass physically obstructs their vision and feeding (Sutherland et al. 2013). Since shorebirds mostly use terrestrial and intertidal zones during low tide, wave exposure does not have a direct influence on shorebird distribution.

During the 2012-2013 bird surveys, high black-bellied plover densities were recorded in biofilm, biomat, and salt marsh habitats, and were moderately high in eelgrass and *Ulva* habitats (Hemmera 2014*b*). Areas with clay to fine sand sediment were also used by black-bellied plover. Environmental preferences for shorebirds at Roberts Bank are shown (**Table 3-4**).

Table 3-4 Shorebirds Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	2	Clay	2	Very low	n/a	Quiescent	1	Mud	2
Brackish	1	Shallow subtidal	0	Very fine sand	2	Low	n/a	Very low	0	Sand	2
Freshet	1	Moderate subtidal	0	Fine sand	2	Moderate	n/a	Low	0	Biofilm	2
Marine	1	Deep subtidal	0	Coarse sand	1	High	n/a	Moderate	0	Biomat	1
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/ Boulders	1					Eelgrass	1
										Kelp	0
										Sea pens	0
										Saltmarsh	1
										Grass	1
Source											
(Poole 2005, BC CDC 2013, Klinkenberg 2013, Hemmera 2014*b*)		(Poole 2005, BC CDC 2013, Klinkenberg 2013, Hemmera 2014*b*)		(Poole 2005, BC CDC 2013, Hemmera 2014*b*)		n/a		n/a		(Poole 2005, BC CDC 2013, Hemmera 2014*b*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

3.5 DIVING WATERBIRDS

3.5.1 Group Definition

Table 3-5 Species in the Diving Waterbirds Functional Group

Common Name	Scientific Name	Average Annual Abundance	Percent Contribution to Functional Group
Surf scoter	*Melanitta perspicillata*	90	41.3
Bufflehead	*Bucephala albeola*	34	15.7
Pelagic cormorant	*Phalacrocorax pelagicus*	28	12.8
Greater scaup	*Aythya marila*	23	10.5
Western grebe	*Aechmophorus occidentalis*	20	9
Common loon	*Gavia immer*	11	5
Horned grebe	*Podiceps auritus*	9	4
Double-crested cormorant	*Phalacrocorax auritus*	3	1.6
White-winged scoter	*Melanitta deglandi*	<1	0.1

The diving waterbirds functional group is made up of nine species (**Table 3-5**), six of which contributed at least 0.1% of the total non-passerine avian abundance at Roberts Bank (Hemmera 2014*b*). Horned grebe, double-crested cormorant, and white-winged scoter were also included. This functional group accounted for ~3% of total non-passerine bird observations. Surf scoters are the most abundant species in this group accounting for over 40% of the functional group (Hemmera 2014*b*).

Cormorants use the study area year-round whereas loons and grebes are generally found at Roberts Bank during fall, winter and spring (Poole 2005). Greater scaups, white-winged scoters and buffleheads are found in greatest numbers in fall through spring while surf scoters are most abundant in fall and winter (Williams et al. 2009).

3.5.2 Biomass and Production

The average annual biomass of diving waterbirds within the study area was estimated to be 0.0276 t/km^2. This estimate assumes that diving waterbird abundance is evenly distributed throughout the study area excluding the marsh. A P/B of 0.10 year^{-1} for double-crested and **pelagic** cormorant was used (Guénette 2005). For the remainder diving waterbird species, a P/B of 0.25 year^{-1} was used (Mackinson and Daskalov 2007). An average of the P/B values was calculated at 0.22 year^{-1}. The P/B value was increased slightly to 0.24 year^{-1} during model balancing (see Roberts Bank Ecosystem Model Development and Key Run Report (ESSA 2014*a*)).

3.5.3 Diet and Consumption

Diving waterbirds tend to be **carnivorous**, however, vegetative matter is equally important for the greater scaup (Vermeer and Levings 1977). Surf scoters, buffleheads, and white-winged scoters feed most heavily on benthic invertebrates while cormorants, loons and grebes feed more heavily on fish, such as juvenile flounders, pricklebacks, surf smelt, salmonids and sculpins (Poole 2005, Williams et al. 2009). Taxa-specific Q/B values were used and an average was calculated to get a Q/B of 92.63 year^{-1} for the functional group (Wada 1996), though this value is lower than 166 year^{-1}, suggested by Harvey et al. (2010).

3.5.4 Environmental Preferences

The birds included in the diving waterbirds functional group can tolerate the complete range of salinities found at Roberts Bank, and most do during their annual cycle (Poole 2005, Stokes and Stokes 2010, BC CDC 2013, Klinkenberg 2013). At Roberts Bank, diving waterbirds were found in deeper marine waters, and were seldom seen in intertidal areas (Hemmera 2014*b*). Common loons and Western grebes forage for fish further from shore at Roberts Bank (Vermeer et al. 1994). The rest of the diving waterbird species use a wider range of water depths, but tend to stick closer to shore (Hemmera 2014*b*). Preferred sediment types vary significantly depending on species (Hemmera 2014*b*). Pelagic cormorants prefer rocky areas whereas the greater scaup prefer finer sediment. Other diving waterbird species use various

sediment types with no apparent preference (Poole 2005, Stokes and Stokes 2010, BC CDC 2013, Klinkenberg 2013). At Roberts Banks, the highest diving waterbird densities occurred in sand, sea pen, kelp, *Ulva* and eelgrass habitats. Densities were moderately high in biofilm and biomat habitats, when these habitats were inundated with water during high tides (Hemmera 2014*b*). While most diving waterbird species prefer sheltered areas, others like the pelagic cormorant, are not deterred by rough water (Poole 2005, BC CDC 2013). Environmental preferences for diving waterbirds in the study area are shown (**Table 3-6**).

Table 3-6 Diving Waterbirds Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	1	Clay	1	Very low	n/a	Quiescent	1	Mud	2
Brackish	1	Shallow subtidal	2	Very fine sand	1	Low	n/a	Very low	1	Sand	2
Freshet	1	Moderate subtidal	2	Fine sand	2	Moderate	n/a	Low	2	Biofilm	1
Marine	2	Deep subtidal	2	Coarse sand	1	High	n/a	Moderate	2	Biomat	1
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	2
				Cobbles/Boulders	1					Eelgrass	2
										Kelp	2
										Sea pens	2
										Saltmarsh	1
										Grass	1
Source											
(Poole 2005, Stokes and Stokes 2010, Hemmera 2014*b*)		(Poole 2005, BC CDC 2013, Hemmera 2014*b*)		(Poole 2005, Hemmera 2014*b*)		n/a		(Poole 2005, Stokes and Stokes 2010, BC CDC 2013, Klinkenberg 2013, Hemmera 2014*b*)		(Poole 2005, Hemmera 2014*b*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

3.6 RAPTORS

3.6.1 Group Definition

Table 3-7 Species in the Raptors Functional Group

Common Name	Scientific Name	Average Annual Abundance	Percent Contribution to Functional Group
Northern harrier	*Circus cyaneus*	2	57.9
Peregrine falcon	*Falco peregrinus anatum*	<1	12.2
Snowy owl	*Bubo scandiacus*	<1	9.8
Red-tailed hawk	*Buteo jamaicensis*	<1	9.1
Short-eared owl	*Asio flammeus*	<1	4.9
Merlin	*Falco columbarius*	<1	4.9
Osprey	*Pandion haliaetus*	<1	1.2

Populations of raptors at Roberts Bank vary by species and season. Snowy owls overwinter at Roberts Bank on a fluctuating four year cycle that is likely linked to prey availability (Poole 2005). In contrast, peregrine falcons are present at Roberts Bank year-round, with populations increasing since the early 1980's, following the ban of DDT (Cade et al. 1988, Ydenberg et al. 2002). Other raptors use Roberts Bank as a stopover during migration (Poole 2005).

3.6.2 Biomass and Production

The average annual **biomass** of raptors within the study area was estimated at 0.00015 t/km^2, assuming even distribution at Roberts Bank, above -10 m CD elevation. Natural mortality of red-tailed hawk (0.41 year^{-1}) and peregrine falcon (0.4 year^{-1}) were averaged to get a P/B estimate of 0.41 year^{-1} for the functional group (Preston 2000, Craig and Enderson 2004). P/B was lowered slightly during the model balancing process to 0.35 year^{-1}.

3.6.3 Diet and Consumption

At Roberts Bank, the peregrine falcons feed mainly on passerines and waterfowl, the merlins on insects and passerines, the osprey on fish (Poole 2005), and the hawks, harriers and owls on small mammals. As passerines, insects, and small mammals were not part of this model, these elements of their diets were classified as import, meaning that they came from outside the study area. Daily consumption values of 70 g/d for peregrine falcons, 205 g/d for snowy owl, 135 g/d for red-tailed hawk and 300 g/d for osprey were used (Sindelar 1966, BC MOE 1996, Avianweb LLC. 2013, Peregrine Watch at Travelers Tower 2013). These daily consumption values were converted into Q/B estimates (Q/B = daily consumption * 365 / average mass) and then averaged to get a Q/B of 41.25 year^{-1} for the functional group.

3.6.4 Environmental Preferences

Most raptors can use both marine and freshwater habitats (Poole 2005, Stokes and Stokes 2010, BC CDC 2013). Raptors are highly mobile within estuarine ecosystems, connecting backshore habitats (e.g., vegetated woody areas, grassy areas, shrubs, agricultural areas) with intertidal estuarine habitats, such as mudflats and marsh. For example, backshore habitats provide nest and roost habitat for raptors, while intertidal areas provide foraging opportunities when they hunt for shorebirds and waterfowl (Williams et al. 2009).

At Roberts Bank, all members of the raptors functional group were primarily observed in the intertidal, and at low densities in the moderate and shallow subtidal zones bordering the Westshore Terminal. The density of raptors was greatest in brackish waters, however they were also observed in marine environments. The greatest raptor density was recorded in biomat, biofilm, *Ulva*, eelgrass, and salt marsh habitats where they were likely hunting for higher trophic levels (Hemmera 2014*b*). They use a wide range of sediments, however they may be more frequently associated with clay, since finer sediments are associated with biofilm distribution, which in turn influences distribution of raptor prey. Environmental preferences for raptors in the study area are shown (**Table 3-8**).

Table 3-8 Raptors Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	2	Intertidal	2	Clay	1	Very low	n/a	Quiescent	1	Mud	1
Brackish	2	Shallow subtidal	1	Very fine sand	1	Low	n/a	Very low	1	Sand	1
Freshet	1	Moderate subtidal	0	Fine sand	1	Moderate	n/a	Low	1	Biofilm	1
Marine	1	Deep subtidal	0	Coarse sand	1	High	n/a	Moderate	1	Biomat	1
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/Boulders	1					Eelgrass	1
										Kelp	0
										Sea pens	0
										Saltmarsh	1
										Grass	1
Source											
(Poole 2005, Stokes and Stokes 2010, Hemmera 2014*b*)		(Poole 2005, BC CDC 2013, Hemmera 2014*b*)		(Poole 2005, Hemmera 2014*b*)		n/a		n/a		(Poole 2005, Hemmera 2014*b*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

3.7 GULLS AND TERNS

3.7.1 Group Definition

Table 3-9 Species in the Gulls and Terns Functional Group

Common Name	Scientific Name	Average Annual Abundance	Percent Contribution to Functional Group
Ring-billed gull	*Larus delawarensis*	135	36.9
Mew gull	*Larus canus*	34	9.3
Glaucous-winged gull	*Larus glaucescens*	119	31.8
Caspian tern	*Hydroprogne caspia*	81	22.1

Each of the four gull species comprising the gull and tern functional group had a total cumulative abundance greater than 0.1% of the total cumulative abundance of all non-passerines observed at Roberts Bank during the 2012 – 2013 bird surveys. Glaucous-winged and ring-billed gulls each made up over 2% of the total non-passerine abundance at Roberts Bank, while each of the other two species amounted to less than 1% (Hemmera 2014*b*).

A small Caspian tern colony was confirmed near the study area at Vancouver International Airport in 2012 (Mike Boyd personal communication 2013), with counts at the site often reaching into the low hundreds. Glaucous-winged gulls are known to both nest and overwinter at Roberts Bank (Vermeer 1982). Some nonbreeding gulls and terns are present at Roberts Bank during the summer and migrate elsewhere for the winter (Poole 2005, Port Metro Vancouver 2005). Other gull species use Roberts Bank to forage during migration stopover or for overwintering. For example, mew gulls are present at Roberts Bank during the winter but numbers decline rapidly as the summer progresses (Hemmera 2014*b*).

3.7.2 Biomass and Production

The average annual biomass of gulls and terns within the study area was estimated to be 0.04836 t/km^2. This includes a large number of gulls not identified to species during bird surveys. This estimate assumes that abundance is evenly distributed across Roberts Bank. A P/B of 0.10 year^{-1} was used (Venier 1996); however this was determined to low. The P/B changed to 0.23 year^{-1} during model balancing to be more consistent with seabird values and account for predation by various raptor species.

3.7.3 Diet and Consumption

Gulls at Roberts Bank consume a broad variety of invertebrates and fish that they either catch or scavenge nearshore or in intertidal areas. Terns are more specialised predators. The diet of some species, such as Caspian tern, consists entirely of fish (Poole 2005). A Q/B of 75.6 year^{-1} for mew gull, and 65.9 year^{-1} for glaucous-winged gull were used (Guénette 2005). These values were then averaged to get a Q/B of 70.75 year^{-1}.

3.7.4 Environmental Preferences

Gulls and terns can use the whole range of salinities and depths at Roberts Bank (Hemmera 2014*b*). Gulls and terns show no particular preference to specific sediment or habitat types (Poole 2005, Stokes and Stokes 2010, Klinkenberg 2013). Gulls and terns were common over all sediment types identified at Roberts Bank (Hemmera 2014*b*).The highest densities of gulls and terns occurred in biofilm, biomat and eelgrass habitats and moderate densities occurred in *Ulva*, salt marsh, sand, sea pen and kelp habitats (Hemmera 2014*b*). They primarily used sheltered areas of quiescent and very low wave height, however, they were also seen in areas exposed to low wave height. Environmental preferences for gulls and terns in the study area are shown (**Table 3-10**).

Table 3-10 Gulls and Terns Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	2	Clay	1	Very low	n/a	Quiescent	2	Mud	1
Brackish	1	Shallow subtidal	1	Very fine sand	1	Low	n/a	Very low	2	Sand	1
Freshet	1	Moderate subtidal	1	Fine sand	1	Moderate	n/a	Low	1	Biofilm	2
Marine	1	Deep subtidal	1	Coarse sand	1	High	n/a	Moderate	1	Biomat	2
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/Boulders	1					Eelgrass	2
										Kelp	1
										Sea pens	1
										Saltmarsh	1
										Grass	1
Source											
(Poole 2005, Stokes and Stokes 2010, Hemmera 2014*b*)		(Poole 2005, Hemmera 2014*b*)		(Poole 2005, BC CDC 2013, Hemmera 2014*b*)		n/a		(Poole 2005, Stokes and Stokes 2010, BC CDC 2013, Klinkenberg 2013, Hemmera 2014*b*)		(Poole 2005, BC CDC 2013, Hemmera 2014*b*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

3.8 WESTERN SANDPIPER

3.8.1 Group Definition

Table 3-11 Species in the Western Sandpiper Functional Group

Common Name	Scientific Name
Western sandpiper	*Calidris mauri*

Western sandpipers use Roberts Bank as a key **staging area** during migration. Northward migration occurs between mid-April and mid-May encompassing approximately three to four weeks (Butler and Cannings 1989). Southward migration is more protracted. The majority of adults pass through the Fraser River estuary in July, followed by juveniles in August (Ydenberg et al. 2002). During migration, sandpipers use mud- and sandflats to forage and roost.

During the 2012-2013 bird surveys, western sandpipers were recorded at Roberts Bank during April, May, July, August, September and October (Hemmera 2014*b*). The highest abundance occurred in April and May (Hemmera 2014*b*).

3.8.2 Biomass and Production

The average annual biomass of western sandpipers within the study area was estimated to be 0.0010 t/km^2. This estimate assumes that abundance is evenly distributed across areas greater than 0 m CD in elevation. A P/B of 0.51 year^{-1} was used (Frisk et al. 2011).

3.8.3 Diet and Consumption

Western sandpiper's diet consists largely of macrofaunal and meiofaunal invertebrates (Wilson 1994, Pomeroy 2005, Fernández et al. 2010, Mathot et al. 2010). Western sandpipers also graze on biofilm by using keratinised spines on their tongues (Elner et al. 2005, Kuwae et al. 2008, 2012, Mathot et al. 2010). A Q/B of 92 year^{-1} was used (Dalsgaard et al. 1998).

3.8.4 Environmental Preferences

During the northward (spring) migration, western sandpipers use mud- and sandflat areas that occur between 150 – 500 m from the shoreline, but during the southward (fall) migration the range expands to areas between 100 – 600 m from the shoreline (Pomeroy 2005).

During migration, western sandpipers are known to use habitats with wide-ranging salinities, however, they prefer coastal intertidal habitats (Butler et al. 1996, BC CDC 2013, Hemmera 2014*b*). Foraging occurs along tidally-exposed mud- and sandflat areas characterised by clay and fine sand sediment, as well as biofilm and biomat patches (Poole 2005, BC CDC 2013). The highest sandpiper densities in the study area were observed in biofilm, biomat, and salt marsh, while moderate densities occurred in

eelgrass habitat (Hemmera 2014*b*). Roosting during night-time high tides occurs in agricultural fields and marshes (Poole 2005, BC CDC 2013). Since western sandpipers use intertidal zones during low tide, bottom current and wave exposure do not influence their distribution. Environmental preferences for western sandpiper at Roberts Bank are shown (**Table 3-12**).

Table 3-12 Western Sandpiper Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	2	Clay	2	Very low	n/a	Quiescent	n/a	Mud	2
Brackish	2	Shallow subtidal	0	Very fine sand	2	Low	n/a	Very low	n/a	Sand	2
Freshet	2	Moderate subtidal	0	Fine sand	2	Moderate	n/a	Low	n/a	Biofilm	2
Marine	2	Deep subtidal	0	Coarse sand	1	High	n/a	Moderate	n/a	Biomat	2
				Fine gravel	1					Rock	0
				Gravel	1					*Ulva*	1
				Cobbles/ Boulders	0					Eelgrass	1
										Kelp	0
										Sea pens	0
										Saltmarsh	2
										Grass	0
Source											
(BC CDC 2013, Hemmera 2014*b*)		(Poole 2005, Hemmera 2014*b*)		(BC CDC 2013, Hemmera 2014*b*)		n/a		n/a		(Butler et al. 2002, Mathot and Elner 2004, BC CDC 2013, Sutherland et al. 2013, Hemmera 2014*b*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

3.9 GREAT BLUE HERON

3.9.1 Group Definition

Table 3-13 Species in the Great Blue Heron Functional Group

Common Name	Scientific Name	Average Annual Abundance
Great blue heron (*fannini* ssp.)	*Ardea herodias fannini*	47

Great blue heron are found at Roberts Bank year-round with numbers peaking from May to July (Hemmera 2014*b*). The Fraser River delta is home to one of the largest wintering populations along the B.C. coast (Campbell et al. 1990). Roberts Bank is an important habitat for great blue heron because of its expansive intertidal flats and eelgrass beds which provide ample forage (Butler 1991).

3.9.2 Biomass and Production

The average biomass of great blue heron within the study area was estimated to be 0.0123 t/km^2. This estimate assumes that abundance is evenly distributed across areas greater than 0 m CD in elevation. A P/B of 0.49 year^{-1} was used (Owen 1959). This estimate represents an average of natural mortality rates of juveniles (<1 year) and adults (>1 year) (Owen 1959).

3.9.3 Diet and Consumption

Great blue herons prey on a large diversity of animals small enough to be swallowed whole. In many environments, including Roberts Bank, this generally means fish, but they will also take small mammals, amphibians, and reptiles in nearby terrestrial habitats. Gunnel, sculpins and shiner perch were the majority of their diet measured on the mudflats of the Fraser River and off Sydney on Vancouver Island (Butler 1995). A Q/B of 82 year^{-1} was used based on Wada (1996).

3.9.4 Environmental Preferences

Great blue herons breed and roost in forested **riparian** habitat in close proximity to wetland feeding areas. A large breeding colony is known to exist along the Tsawwassen bluff overlooking Roberts Banks. Great blue herons use habitats with wide-ranging salinities. They often feed in the intertidal zone by slowly wading or standing in wait for their prey. Foraging also occurs in eelgrass beds and estuarine marshes (Gebauer and Moul 2001). At Roberts Bank, heron densities were relatively evenly distributed over clay to coarse sand, as well as salt marsh, biofilm, biomat, eelgrass and *Ulva* habitats (Hemmera 2014*b*). Environmental preferences for great blue heron in the study area are shown (**Table 3-14**).

Table 3-14 Great Blue Heron Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	2	Clay	2	Very low	n/a	Quiescent	1	Mud	2
Brackish	1	Shallow subtidal	0	Very fine sand	2	Low	n/a	Very low	1	Sand	2
Freshet	1	Mid subtidal	0	Fine sand	2	Moderate	n/a	Low	1	Biofilm	2
Marine	1	Deep subtidal	0	Coarse sand	2	High	n/a	Moderate	1	Biomat	2
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	2
				Cobbles/Boulders	1					Eelgrass	2
										Kelp	0
										Sea pens	0
										Saltmarsh	2
										Grass	2
Source											
(BC CDC 2013, Hemmera 2014*b*)		(BC CDC 2013, Hemmera 2014*b*)		(Poole 2005, Hemmera 2014*b*)		n/a		n/a		(Poole 2005, Hemmera 2014*b*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

3.10 DUNLIN

3.10.1 Group Definition

Table 3-15 Species in the Dunlin Functional Group

Common Name	Scientific Name
Dunlin	*Calidris alpina*

The dunlin is a migratory sandpiper with a circumpolar distribution divided amongst several populations (often described as subspecies) that are characterised by distinct breeding sites and/or migratory pathways. Most Pacific dunlins breed in western Alaska and migrate through B.C. to winter residence sites in Mexico (Warnock and Gill 1996). While the fall migration from Alaska is mostly trans-oceanic, the northward spring migration follows a coastal route that brings much of the population through the Fraser River estuary (Butler and Campbell 1987, Warnock and Gill 1996). During the winter residence period, approximately 25,000 to 60,000 dunlin remain in the Fraser River estuary (Butler and Vermeer 1994, Shepherd and Lank 2004). Dunlin were observed at Roberts Bank every month except July; numbers greater than 99,000 birds were recorded in April 2013 (Hemmera 2014*b*).

3.10.2 Biomass and Production

The average annual biomass of dunlin within the study area was estimated to be 0.00863 t/km^2, assuming that it is evenly distributed across areas greater than 0 m CD. A P/B of 0.51 year^{-1} was used (Frisk et al. 2011).

3.10.3 Diet and Consumption

Macrofaunal and meiofaunal invertebrates comprise a large portion of a dunlin's diet (Wilson 1994, Pomeroy 2005, Fernández et al. 2010, Mathot et al. 2010). Like the western sandpiper, dunlin also graze on biofilm though not as extensively (Elner et al. 2005, Mathot et al. 2010). A Q/B of 92 year^{-1} was used (Dalsgaard et al. 1998).

3.10.4 Environmental Preferences

Dunlin primarily use marine and brackish habitats but are also found in freshwater. They are often observed grazing on biofilm and biomat along the tide line, especially during the ebb tide (Brennan et al. 1985, Elner et al. 2005, Poole 2005). They often use finer grain sediment but can also be found in gravelly sediment (BC CDC 2013). At Roberts Bank, densities were greatest over clay, but smaller numbers were observed over very fine sand to coarse gravel (Hemmera 2014*b*). Highest dunlin densities occurred in biofilm, biomat and salt marsh habitats, and moderate densities in *Ulva* and eelgrass (Hemmera 2014*b*). During high tides, Dunlin will roost in agricultural land (Sheppard and Lank 2004). Environmental preferences for dunlin in the study area are shown (**Table 3-16**).

Table 3-16 Dunlin Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	2	Intertidal	2	Clay	2	Very low	n/a	Quiescent	n/a	Mud	2
Brackish	2	Shallow subtidal	0	Very fine sand	1	Low	n/a	Very low	n/a	Sand	2
Freshet	2	Moderate subtidal	0	Fine sand	1	Moderate	n/a	Low	n/a	Biofilm	2
Marine	2	Deep subtidal	0	Coarse sand	1	High	n/a	Moderate	n/a	Biomat	2
				Fine gravel	1					Rock	0
				Gravel	1					*Ulva*	1
				Cobbles/Boulders	0					Eelgrass	1
										Kelp	0
										Sea pens	0
										Saltmarsh	2
										Grass	2
Source											
(BC CDC 2013, Hemmera 2014*b*)		(BC CDC 2013, Hemmera 2014*b*)		(BC CDC 2013, Hemmera 2014*b*)		n/a		n/a		(BC CDC 2013, Hemmera 2014*b*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

3.11 BRANT GOOSE

3.11.1 Group Definition

Table 3-17 Species in the Brant Goose Functional Group

Common Name	Scientific Name	Average Annual Abundance
Brant goose	*Branta bernicla*	9

Brant geese are migratory birds that breed in the Arctic and then migrate to wintering areas such as Roberts Bank (Poole 2005). Brant were seen in the study area in January, March, April, November and December with highest numbers in April (Hemmera 2014*b*). Roberts Bank is an important wintering site due to the abundance of seagrass (Williams et al. 2009). Brant geese can be harvested at Roberts Bank by licenced recreational hunters. The daily bag limit is low with a narrow open season. In 2014, harvesting occurred from March 1 to March 10 with a daily bag limit of 2 birds (BC MFLNRO 2013).

3.11.2 Biomass and Production

The average annual biomass of brant within the study area was estimated to be 0.0199 t/km^2, assuming even areal distribution. A P/B of 0.2 year^{-1} was used (Bauer 2010), though this value is lower than the 0.427 found in Harvey et al. (2010).

3.11.3 Diet and Consumption

Brant feed exclusively on marine plants. Diet at Roberts Bank consists primarily of eelgrass (*Zostera marina,* 52%; *Z. japonica,* 12.4%), but also *Ulva lactuca* (0.65%) and 35% import from outside the study area (Baldwin and Lovvorn 1994*a*, *b*). Native eelgrass is more important to brant than to any other waterfowl species considered in this study. A Q/B value of 200 year^{-1} was used (Bauer 2010), though this value is lower than the 329 year^{-1} found in Harvey et al. (2010).

3.11.4 Environmental Preferences

Outside of the breeding season, brant use intertidal coastal habitat. They are typically found in muddy or sandy substrate where eelgrass and/or green algae is abundant. At Roberts Bank, brant occur primarily in intertidal and shallow subtidal zones over muddy/sandy substrate and less frequently in moderate and deep subtidal zones (Hemmera 2014*b*). This distribution likely coincides with their foraging on native eelgrass in the mid to lower intertidal flats and on Japanese eelgrass in the high intertidal. In addition to eelgrass and green algae patches, they occasionally make use of grassy areas (Klinkenberg 2013). Brant are typically found in sheltered areas and on occasion in areas more exposed to waves (Klinkenberg 2013). They are also known to tolerate a wide range of salinities (Klinkenberg 2013). Environmental preferences for brant geese in the study area are shown (**Table 3-18**).

Table 3-18 Brant Goose Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0	Intertidal	2	Clay	1	Very low	n/a	Quiescent	1	Mud	2
Brackish	1	Shallow subtidal	2	Very fine sand	1	Low	n/a	Very low	1	Sand	2
Freshet	1	Moderate subtidal	1	Fine sand	1	Moderate	n/a	Low	2	Biofilm	0
Marine	2	Deep subtidal	1	Coarse sand	1	High	n/a	Moderate	1	Biomat	0
				Fine gravel	1					Rock	0
				Gravel	0.75					*Ulva*	2
				Cobbles/ Boulders	0.5					Eelgrass	2
										Kelp	1
										Sea pens	1
										Saltmarsh	0
										Grass	1
Source											
(Klinkenberg 2013, Hemmera 2014*b*)		(Klinkenberg 2013, Hemmera 2014*b*)		(Klinkenberg 2013, Hemmera 2014*b*)		n/a		(Klinkenberg 2013, Hemmera 2014*b*)		(Baldwin and Lovvorn 1994*b*, Ganter 2000, Klinkenberg 2013, Hemmera 2014*b*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

3.12 BALD EAGLE

3.12.1 Group Definition

Table 3-19 Species in the Bald Eagle Functional Group

Common Name	Scientific Name	Average Annual Abundance
Bald eagle	*Haliaeetus leucocephalus*	4

Bald eagles can be found year-round along the B.C. coast, though numbers can fluctuate seasonally in response to shifts in food availability. Most bald eagles leave the south coast of BC in late summer, likely driven by salmon spawning runs in Alaska and the BC interior. Bald eagles begin to return to the southern B.C. coast in late October (Blood and Anweiler 1994). Bald eagles abundance is highest in May and June and they are absent during August and September (Hemmera 2014*b*).

3.12.2 Biomass and Production

The average annual biomass of bald eagles at the study area was estimated to be 0.0022 t/km^2, assuming that abundance is even along intertidal and shallow subtidal areas. A P/B of 0.25 year^{-1} was

used (Blood and Anweiler 1994). This value is an average of natural mortality rates reported for juveniles (<1 year) and adults (>1 year) (Blood and Anweiler 1994).

3.12.3 Diet and Consumption

Bald eagles are carnivorous and prey on a range of organisms. They usually live near water and get the bulk of their diet from fish and waterfowl (as is the case at Roberts Bank). They will, however, also hunt mammals and marine invertebrates and will scavenge **carrion** and anthropogenic wastes (Blood and Anweiler 1994, Poole 2005). Q/B of 41 year^{-1} was calculated from daily consumption rate information for bald eagles in western Washington (Stalmaster and Gessaman 1984).

3.12.4 Environmental Preferences

Bald eagles use marine and freshwater environments and can be found up to 500 m offshore (Poole 2005). Bald eagles use large trees in riparian woodland to nest, perch and roost (Blood and Anweiler 1994). At Roberts Bank the highest densities of bald eagles were observed in biofilm, biomat, and salt marsh habitats where prey was likely abundant (Hemmera 2014*b*). Large numbers of bald eagles also occurred over clay, with fewer found in very fine to coarse sand (Hemmera 2014*b*). Sediment type likely influences bald eagle distribution indirectly by determining distribution and availability of their prey. Environmental preferences for bald eagle in the study area are shown (**Table 3-20**).

Table 3-20 Bald Eagle Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	2	Clay	1	Very low	n/a	Quiescent	1	Mud	1
Brackish	1	Shallow subtidal	1	Very fine sand	1	Low	n/a	Very low	1	Sand	1
Freshet	1	Moderate subtidal	0	Fine sand	1	Moderate	n/a	Low	1	Biofilm	1
Marine	1	Deep subtidal	0	Coarse sand	1	High	n/a	Moderate	1	Biomat	1
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/Boulders	1					Eelgrass	1
										Kelp	0
										Sea pens	0
										Saltmarsh	1
										Grass	1
Source											
(Poole 2005, Hemmera 2014*b*)		(Poole 2005, Hemmera 2014*b*)		(Hemmera 2014*b*)		n/a		n/a		(Hemmera 2014*b*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

3.13 AMERICAN WIGEON

3.13.1 Group Definition

Table 3-21 Species in the American Wigeon Functional Group

Common Name	Scientific Name	Average Annual Abundance
American wigeon	*Anas americana*	878

American wigeon are most abundant in the study area during the fall, using Roberts Bank as a staging site during their migration from breeding to wintering grounds. Most individuals continue south, but some winter at Roberts Bank. During the northward spring migration, large numbers of American wigeon also occur at Roberts Bank until May (Hemmera 2014*b*). Nesting has not been observed in the Lower Mainland (Leach 1972). American wigeons can be hunted at Roberts Bank (BC MFLNRO 2013).

3.13.2 Biomass and Production

The mean annual biomass of American wigeon at the study area was estimated to be 0.0873 t/km^2, assuming biomass is evenly distributed throughout the intertidal and shallow subtidal areas. A P/B of 0.2 year^{-1} was used (Bauer 2010), though this value is lower than the 0.427 found in Harvey et al. (2010).

3.13.3 Diet and Consumption

While at Roberts Bank, the diet of the American wigeon is mainly intertidal vegetation (e.g. *Zostera japonica, Ulva lactuca*, *Ruppia maritima* and *Z. marina*). American wigeon also consume seeds of salt marsh plants (*Salicornia* spp.*),* and algae (Baldwin and Lovvorn 1994*a*, *b*). During the winter, American wigeon also feed a lot on grasses in nearby agricultural fields (Poole 2005). A Q/B of 200 year^{-1} was used (Bauer 2010), though this value is lower than the 0.427 found in Harvey et al. (2010).

3.13.4 Environmental Preferences

American wigeon use marine and freshwater habitats throughout the year. While at Roberts Bank they are most abundant in intertidal mudflats, where they feed on Japanese eelgrass below the mean water level during low tide (Baldwin and Lovvorn 1994*a*, *b*). Alternatively, at high tide, estuarine channel edges and salt marshes are also used for foraging, and American wigeon were observed at Roberts Bank only in sheltered intertidal areas (Hemmera 2014*b*). Highest densities occurred in biomat, biofilm, eelgrass, *Ulva spp.* and salt marsh habitats, characterised by clay to fine sand sediments. Environmental preferences for American wigeon in the study area are shown (**Table 3-22**).

Table 3-22 American Wigeon Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	2	Clay	1	Very low	n/a	Quiescent	2	Mud	2
Brackish	1	Shallow subtidal	0	Very fine sand	1	Low	n/a	Very low	1	Sand	1
Freshet	1	Moderate subtidal	0	Fine sand	1	Moderate	n/a	Low	1	Biofilm	2
Marine	1	Deep subtidal	0	Coarse sand	1	High	n/a	Moderate	1	Biomat	2
				Fine gravel	1					Rock	0
				Gravel	0.75					*Ulva*	2
				Cobbles/Boulders	0.5					Eelgrass	2
										Kelp	0
										Sea pens	0
										Saltmarsh	2
										Grass	2
Source											
(Poole 2005, Hemmera 2014*b*)		(Poole 2005, Hemmera 2014*b*)		(Hemmera 2014*b*)		n/a		(Stokes and Stokes 2010, Hemmera 2014*b*)		(Baldwin and Lovvorn 1994*b*, Poole 2005, Hemmera 2014*b*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

4.0 FISH


Rockfish


Lingcod


Starry Flounder
Photo credit: Archipelago

Roberts Bank's estuarine habitats also support a diverse fish community, with inter- and subtidal habitats including eelgrass beds, sand- and mudflats, riprap artificial reefs and saltmarsh. Eelgrass (*Zostera marina*) beds are a refuge and nursery for many fish species. Recent surveys have documented a variety of adult and juvenile fish species utilizing eelgrass beds at Roberts Bank (Archipelago Marine Research Ltd. 2014*a*). Sand- and mudflat habitats are also used by fish and recent surveys of Roberts Bank have documented extensive use of these areas, particularly by flatfish and Pacific sandlance (Archipelago Marine Research Ltd. 2014b). Rocky reefs and associated macroalgae also create unique three-dimensional habitat that serves as refuge. Surveys of the ten artificial riprap reefs (created from 1994 to 2009) at Roberts Bank indicate that they are inhabited by lingcod (*Ophiodon elongatus*) and rockfish (*Sebastes* spp.), including the quillback rockfish (*S. maliger*), which is designated as endangered by the Committee on the Status of Endangered Wildlife in Canada (Archipelago Marine Research Ltd. 201*4c,* COSEWIC 2009). Additionally, recent surveys have documented the occurrence of juvenile salmon, particularly chum (*Oncorhynchus keta*) and Chinook (*O. tshawytscha*), across all inter- and subtidal habitats at Roberts Bank (Archipelago Marine Research Ltd. 2014d).

4.1 FUNCTIONAL GROUPS

Fish divided into 18 functional groups, based on similarity in diet and habitat preferences. These include nine focal species of fish identified by the PC-TAG including adult and juvenile Chinook and chum, lingcod, rockfish, Pacific sandlance, starry flounder and shiner perch (Compass Resource Management Ltd. 2013). Salmonids are ecologically, economically and socially important at Roberts Bank and have complex life history patterns, and were, therefore, divided into adult and juvenile groups to capture their ecological ontogeny in the EwE model.

1 Chinook salmon (adult)*
2 Chinook salmon (juvenile)*
3 Chum salmon (adult)*
4 Chum salmon (juvenile)*
5 Salmon (adult)

6 Salmon (juvenile)
7 Dogfish
8 Flatfish
9 Forage fish
10 Herring
11 Large demersal fish
12 Lingcod*
13 Rockfish*
14 Sandlance*
15 Shiner perch*
16 Skate
17 Small demersal fish
18 Starry flounder*

4.2 METHODS

In general, estimation of EwE model parameters followed methodology described in Section 1.1 Study Area. However, additional analysis undertaken to estimate biomass specifically for the fish functional groups is described below.

4.2.1 Biomass

Biomass estimates were derived from data collected during a field program in 2012 and 2013 at Roberts Bank (Archipelago Marine Research Ltd. 2014*a*, *b*, *c*, *d*). Fish communities were sampled in four surveys: a benthic fish trawl, eelgrass fish community, reef fish (including lingcod), and juvenile salmon (Archipelago Marine Research Ltd. 2014*a*, *b*, *c*, *d*). Fish surveys were completed at multiple locations within the study area from 2012 to 2013. Benthic fish sampling was conducted with an otter trawl at different depth ranges, inside and out of the proposed RBT2 footprint, seasonally from summer 2012 to spring 2013. Eelgrass fish sampling was conducted with a beach seine net (3mm and 6mm) in intertidal sandflat and eelgrass habitat, seasonally from spring 2012 to winter 2013. Reef fish sampling was conducted by dive surveying by visual transects at existing artificial reefs, seasonally from summer 2012 to spring 2013. Juvenile Salmon Surveys were conducted by beach seine (6mm) and deep purse seine (6mm) in nearshore and offshore habitats, seasonally from spring 2012 to summer 2013. Each survey location was mapped and the underlying habitat deciles from the habitat map were used to calculate the proportion of each survey's representative habitat (Section 1.5.3 Ecopath Habitat and Substrate Map). Abundance data recorded during each survey was weighted to the proportion of habitat types sampled at each survey location. These habitat proportions were multiplied against the total area of each habitat present within the entire study area. This number was then divided by the total study area to calculate the total percent habitat at Roberts Bank. This approach provides a habitat-corrected sampling estimate for a variety of survey types that target different species.

For the reef and lingcod surveys, habitat proportions, based on GPS and the sampling plan, were seen to be unrealistic as several sampling points occurred next to kelp and rock habitat but contained only sand. To determine reef habitat, therefore, a post-survey definition of habitat was used. For both reef and lingcod egg mass surveys, habitat proportions were defined by dive survey characteristics recorded by the divers and known life history characteristics of the species counted. All habitat-weighted numbers were used to estimate annual biomass for Roberts Bank.

Fish biomass for Roberts Bank was calculated for each survey and fish species, and was then summed by functional group. For each survey, fish biomass was calculated by multiplying abundance with mean body weight of fish species that was 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 t/km^2) specific to each sampling event. When no body weight measurements were available, body weights from the literature were used. Annual average biomass by survey type and fish species was equal to the sum of seasonal average biomass calculated from data sampled seasonally during the period of a year. These survey and species-specific biomass estimates were then summed to generate fish biomass by functional group for Roberts Bank. Biomass values for fish species not targeted by field studies (i.e., forage fish, including Pacific herring, adult salmon, and cartilaginous fish, such as dogfish and skate) were extracted from existing literature and previous EwE models for the Strait of Georgia (Beattie 2001, Preikshot 2007, Li 2012, Preikshot et al. 2012).

4.3 CHINOOK SALMON (ADULT AND JUVENILE)

4.3.1 Group Definition

Table 4-1 Life History Phases in the Chinook Salmon Functional Group

Common Name	Scientific Name
Chinook salmon, juvenile (0-18 months)	*Oncorhynchus tshawytscha*
Chinook salmon, adult (18 months +)	*Oncorhynchus tshawytscha*

Chinook salmon is an ecologically, economically and socially important species within B.C. and was selected as a focal species at Roberts Bank by the PC-TAG. The Fraser is the largest Chinook-bearing river in Canada (DFO 1999). Adult Chinook are present at Roberts Bank prior to returning to spawn up the Fraser River. They return as three-, four-, and five-year old fish over an extended period from February to November, with dominant return age and return timing being stock-dependent (DFO 2011*b*). Juvenile Chinook often rear in estuarine environments near their natal stream. In the Fraser River outmigration occurs between January and October, with individual residency time varying but thought to be one to six weeks. Use of Roberts Bank habitats by juvenile Chinook extends from March to at least August (Levings 1985), with peak abundances in mid-May to mid-June (MacDonald 1984), and in July (Conlin et al. 1982, Gordon and Levings 1984). Recent surveys have documented the presence of juvenile Chinook salmon at Roberts Bank in summer and spring and in the summer, juvenile Chinook is the most abundant salmon species at Roberts Bank (Archipelago Marine Research Ltd. 2014d).

4.3.2 Biomass and Production

An average biomass of 0.0120 t/km^2 for juvenile Chinook was estimated for the study area using data collected during field surveys conducted in 2012 and 2013 (Archipelago Marine Research Ltd. 2014*a*, *c*, d). No adult Chinook were sampled during the field surveys. Therefore, adult Chinook biomass was estimated to be 3.428 t/km^2 based upon information from field programs, guidance from third party reviewers, and comparisons with Harvey et al. (2012). This calculation assumes a juvenile biomass of 2.1 g per individual based on field sampling, a 5% juvenile-to-adult return (survival) (Dave Preikshot pers. comm, DFO) and an adult return biomass of adult bimass of 12 kg (Madrone Environmental Services Ltd. 2014).

A P/B of 0.19 year^{-1} for adult Chinook was initially proposed based upon Froese and Pauly (2011); however was adjusted higher to 0.31 year^{-1} for adult Chinook based calculations from third party review (Madrone Environmental Services Ltd. 2014). A P/B of 0.80 year^{-1} was used for juvenile Chinook (Froese and Pauly 2011).

4.3.3 Diet and Consumption

Juvenile Chinook salmon mainly consume macrofauna and a variety of small forage fish species (Brodeur 1990, Harvey et al. 2012). In the Strait of Georgia, herring is the dominant food of sub-adult and adult Chinook salmon (Healey 1980). Other important prey items include euphausiids, amphipods, copepods, shrimp, and larvae (Brodeur 1990, Levings et al. 1991, Weitkamp and Sturdevant 2008). A Q/B of 2.0 year^{-1} for adult Chinook was taken from Fishbase (Froese and Pauly 2011). A Q/B for juvenile Chinook was not found in the literature and was calculated to be 2.667 by the model by setting P/Q to 0.3.

4.3.4 Environmental Preferences

Juvenile Chinook salmon may rear in freshwater for one year (stream type) or migrate to the ocean at less than six months (ocean type) to rear in estuaries (DFO 1999, Levings 2004). Juvenile Chinook from the Harrison River tend to leave their natal stream within one to two weeks after hatching and rear in the Fraser River estuary over the summer months (Levings 2004). Juvenile Chinook salmon use the near shore area of Roberts Bank both within the proposed RBT2 footprint and immediate vicinity (west to Canoe Passage and east including the Inter-causeway Area), during spring and summer (Archipelago Marine Research Ltd. 2014d). In estuarine environments, juvenile Chinook occupy a range of depths and sediment types (Heard et al. 1998, Peterson et al. 2010). They are known to forage in sand- and mudflats as well as in vegetated habitats. Juvenile Chinook are often found in areas with complex substrates and within marine vegetation such as marsh and eelgrass beds (Healey 1980, Levings et al. 1991, Archipelago Marine Research Ltd. 2013*a*, *c*, d). Environmental preferences for juvenile Chinook salmon in the study area are shown (**Table 4-2**).

Table 4-2 Juvenile Chinook Salmon Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	1	Clay	1	Very low	1	Quiescent	1	Mud	1
Brackish	1	Shallow subtidal	1	Very fine sand	1	Low	1	Very low	1	Sand	1
Freshet	1	Moderate subtidal	1	Fine sand	1	Moderate	1	Low	1	Biofilm	0
Marine	1	Deep subtidal	1	Coarse sand	1	High	1	Moderate	1	Biomat	0
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/ Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	0
										Saltmarsh	1
										Grass	0
Source											
(Froese and Pauly 2011)		(Peterson et al. 2010)		(Heard et al. 1998)		n/a		n/a		(Healey 1980, Levings et al. 1991, Archipelago Marine Research Ltd. 2014*a*, *c*, d)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

Chinook are oceanic during most of their adult life but swim through estuarine waters on their way to spawn upriver. Adult Chinook salmon return to the Fraser River between April and November, with different stocks migrating during spring, summer or fall. Generally, the earlier the run, the farther up the Fraser River the individuals spawn (Levings and Lauzier 1991). The Harrison River population enters the lower Fraser River from September to November (DFO 1999). Because adult Chinook occur at Roberts Bank only for a short time period during their spawning migration, it has been assumed that they do not exhibit strong environmental and habitat preferences within this ecosystem. Environmental preferences for adult Chinook salmon at Roberts Bank are shown (**Table 4-3**).

Table 4-3 Adult Chinook Salmon Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	1	Clay	1	Very low	1	Quiescent	1	Mud	1
Brackish	1	Shallow subtidal	2	Very fine sand	1	Low	1	Very low	1	Sand	1
Freshet	1	Moderate subtidal	2	Fine sand	1	Moderate	1	Low	1	Biofilm	1
Marine	1	Deep subtidal	2	Coarse sand	1	High	1	Moderate	1	Biomat	1
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	1
										Saltmarsh	1
										Grass	0
Source											
(Froese and Pauly 2011)		(Candy and Quinn 1999)		(Heard et al. 1998)		n/a		n/a		n/a	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

4.4 CHUM SALMON (ADULT AND JUVENILE)

4.4.1 Group Definition

Table 4-4 Life History Phases in the Chum Salmon Functional Group

Common Name	Scientific Name
Chum Salmon, juvenile (0-12 months)	*Oncorhynchus keta*
Chum Salmon, adult (12 months +)	*Oncorhynchus keta*

Chum salmon are an ecologically, economically and socially important species within B.C. and were selected as a focal species for Roberts Bank by the PC-TAG. The Fraser is the largest chum salmon bearing river in B.C. (Grant and Pestal 2009). Adult chum salmon occur at Roberts Bank prior to their spawning migration up the Fraser River, and as juveniles they rear in the estuary (Levings 2004). Chum migrate to spawn from September to December, but peak spawning migration occurs in October (Grant and Pestal 2009). In the Fraser River, juvenile chum downstream migration takes place from February to June, peaking in mid-March and late April (Beacham and Starr 1982, Salo 1991).

4.4.2 Biomass and Production

An average biomass of 0.009 t/km^2 for juvenile chum was estimated for the study area using data collected during surveys conducted in 2012 and 2013 (Archipelago Marine Research Ltd. 2014*a*, *c*, d). No adult chum were sampled during the field surveys. Therefore, adult chum biomass was estimated to be 2.046 t/km^2 based upon information from field programs, guidance from third party reviewers, comparisons with Harvey et al. (2012). This calculation assumes a juvenile biomass of 1.1 g per individual based on field sampling, a 5% juvenile-to-adult return (survival) (Dave Preikshot pers. comm, (DFO 2010*c*)) and an adult return biomass of adult bimass of 5 kg (DFO 2014*a*). A P/B value of 0.43 year^{-1} for adult chum and 0.9 year^{-1} for juvenile chum were used (Froese and Pauly 2011).

4.4.3 Diet and Consumption

Juvenile chum salmon prey selection is size dependent and diet will shift with growth. Chum salmon will move offshore as they reach a size that allows them to feed on larger pelagic species, and as inshore prey resources decline (Brodeur 1990). Juvenile chum salmon are **piscivorous** but also consume copepods, euphausiids, hyperiid amphipods, larvae (predominately crab and fish) and chaetognaths (Brodeur 1990).

Adult chum salmon feed on small fish species as well as euphausiids, amphipods, zooplankton (mostly crustacean), and squid (Scott and Crossman 1973). A Q/B of 1.4 year^{-1} (for adult chum salmon) was used (Froese and Pauly 2011). A Q/B value was not available for juvenile chum and was calculated to be 3.0 by the EwE model, by setting P/Q to 0.3.

4.4.4 Environmental Preferences

Compared to other species of Pacific salmon, juvenile Chinook and chum salmon are the species that reside the longest in the Fraser River estuary; residencies of up to 6 weeks are common (Beamish et al. 2003, Levings 2004). In the estuary, juvenile chum occupy the shallow waters up to 20 m, and a variety of sediments (Salo 1991). They are found in both unvegetated and vegetated habitats (Heard et al. 1998, Walker et al. 2007). Chum fry primarily consume benthic organisms and occupy shallower waters with low current velocities (Mason 1974). During field surveys at Roberts Bank, they were often found in shallow water depths, above 0 datum CD (Archipelago Marine Research Ltd. 2014d). As body size increases and swimming ability is enhanced, juveniles adopt a pelagic lifestyle and move to deeper and more swiftly moving waters (Salo 1991). Movement offshore coincides with the decline of inshore prey resources and is normally at the time when the fish have grown to a size that allows them to feed upon larger **neritic** organisms and avoid predators (Salo 1991). Recent field surveys of inter- and subtidal habitats at Roberts Bank document a high abundance of juvenile chum salmon in spring across habitats including saltmarsh, artificial reef, eelgrass, and sand- and mudflats (Archipelago Marine Research Ltd. 2014d). Environmental preferences for juvenile chum salmon in the study area are shown (**Table 4-5**).

Table 4-5 Juvenile Chum Salmon Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	2	Clay	1	Very low	1	Quiescent	1	Mud	1
Brackish	1	Shallow subtidal	2	Very fine sand	1	Low	1	Very low	1	Sand	1
Freshet	1	Moderate subtidal	1	Fine sand	1	Moderate	1	Low	1	Biofilm	0
Marine	1	Deep subtidal	0	Coarse sand	1	High	1	Moderate	1	Biomat	0
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/ Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	0
										Saltmarsh	1
										Grass	0
Source											
(Froese and Pauly 2011)		(Salo 1991, Walker et al. 2007)		(Heard et al. 1998)		n/a		n/a		(Archipelago Marine Research Ltd. 2014*a*, *c*, d)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

Adult chum salmon likely occur in the Fraser River estuary including Roberts Bank from September to December during their spawning migration up the Fraser River and do not exhibit strong environmental preferences (Grant and Pestal 2009). Environmental preferences for adult chum salmon in the study area are shown (**Table 4-6**).

Table 4-6 Adult Chum Salmon Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	1	Clay	1	Very low	1	Quiescent	1	Mud	1
Brackish	1	Shallow subtidal	1	Very fine sand	1	Low	1	Very low	1	Sand	1
Freshet	1	Mid subtidal	1	Fine sand	1	Moderate	1	Low	1	Biofilm	1
Marine	1	Deep subtidal	1	Coarse sand	1	High	1	Moderate	1	Biomat	1
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	1
										Saltmarsh	1
										Grass	0
Source											
(Froese and Pauly 2011)		(Froese and Pauly 2011)		n/a		n/a		n/a		n/a	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

4.5 SALMON (ADULT AND JUVENILE)

4.5.1 Group Definition

Table 4-7 Species in the Salmon Functional Group

Common Name	Scientific Name
Steelhead Salmon, adult (36 months+)	*Oncorhynchus mykiss*
Steelhead Salmon, juvenile (0-36 months)	*Oncorhynchus mykiss*
Sockeye Salmon, adult (18 month+)	*Oncorhynchus nerka*
Sockeye Salmon, juvenile (0-18 months)	*Oncorhynchus nerka*
Pink Salmon, adult (6 months+)	*Oncorhynchus gorbuscha*
Pink Salmon, juvenile (0-6 months)	*Oncorhynchus gorbuscha*
Coho Salmon, adult (18 months+)	*Oncorhynchus kisutch*
Coho Salmon, juvenile (0-18 months)	*Oncorhynchus kisutch*

Salmon are an ecologically, economically and social important species in B.C. Chinook and chum salmon were selected as focal species at Roberts Bank by the PC-TAG and are modelled as separate functional groups. The remaining salmonids that comprise this functional group pass through Roberts Bank as adults, on their way to the Fraser River to spawn. Pink salmon, for example, which operate on a two-year cycle, mostly spawn in odd numbered years, with juveniles utilizing the Fraser River estuary and entering the Strait of Georgia in even numbered years, such as 2012 and 2014 (Neave 1966, Beamish et al. 1994).

4.5.2 Biomass and Production

An average biomass of 0.0017 t/km^2 for juvenile salmon was estimated for Roberts Bank using data collected during field surveys conducted at Roberts Bank in 2012 and 2013 (Archipelago Marine Research Ltd. 2014d). A P/B of 0.43 year^{-1} for adult salmon and 0.85 year^{-1} for juvenile salmon were used, which are averages of the P/B ratios of adults and juveniles, respectively, of each species within this functional group (Froese and Pauly 2011). Biomass of adult salmon was calculated by the EwE model by setting EE to 0.5.

4.5.3 Diet and Consumption

Juvenile salmon consume small fish species (including smaller salmon), as well as invertebrates like euphausiids, decapod larvae, hyperiid amphipods, pteropods, insects, and copepods (Godin 1981, Brodeur 1990). Ontogenetic diet shifts occur with increase in body size (Salo 1991). Adult salmon are primarily piscivorous but also consume squid, octopus and benthic and pelagic invertebrate species.

A Q/B of 1.4 year^{-1} was used for adult salmon, which is an average of the Q/B ratios for each (adult) species within this functional group (Froese and Pauly 2011). A Q/B value was not available for juvenile salmon and was calculated to be 2.833 by the EwE model, by setting P/Q to 0.3.

4.5.4 Environmental Preferences

Juvenile salmon prefer shallow waters and a range of habitat types, depending on species and life stage. Estuarine and coastal areas provide juvenile salmon with invertebrate food sources, protection from predators and act as transition zones to adjust to saline conditions (Healey 1982, Levy and Northcote 1982, Aitkin 1998). The Fraser River estuary is highly utilized by chinook and chum salmon and to a lesser extent pink salmon, which use the estuary just to reach shallow coastal rearing grounds (Waldichuk 1987, Aitkin 1998). Coho, sockeye salmon and steelhead trout have multiple life history types but are thought to be less reliant on estuaries. Juvenile pink salmon were present in low numbers in artificial reef, saltmarsh and sand- and mudflat habitat at Roberts Bank during spring and summer, while juvenile coho were rarely caught and sockeye salmon and steelhead trout were absent (Archipelago Marine Research Ltd. 2014d).

Juvenile pink salmon commonly appear in the nearshore area of Roberts Bank both within the proposed RBT2 footprint and immediate vicinity (west to Canoe Passage and east including the Inter-causeway Area) during spring and summer, although individual resident time is believed to be very short (Levings 2004, Archipelago Marine Research Ltd. 2014d). Environmental preferences for juvenile salmon at Roberts Bank are shown (**Table 4-8**).

Table 4-8 Juvenile Salmon Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	2	Clay	1	Very low	1	Quiescent	1	Mud	1
Brackish	1	Shallow subtidal	2	Very fine sand	1	Low	1	Very low	1	Sand	1
Freshet	1	Moderate subtidal	1	Fine sand	1	Moderate	1	Low	1	Biofilm	0
Marine	1	Deep subtidal	1	Coarse sand	1	High	1	Moderate	1	Biomat	0
				Fine gravel	1					Rock	0
				Gravel	1					*Ulva*	1
				Cobbles/ Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	0
										Saltmarsh	1
										Grass	0

Salinity	Depth	Sediment	Bottom Current	Exposure	Habitat
Source					
(Froese and Pauly 2011)	(Levy and Northcote 1982, Walker et al. 2007, Peterson et al. 2010)	(Richardson et al. 2000)	(Godin 1981, Aitkin 1998)	n/a	(Levy and Northcote 1982, Murphy et al. 2000, Richardson et al. 2000, Archipelago Marine Research Ltd. 2014d)

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

Adult salmon are **anadromous** and move through Roberts Banks during their spawning migrations to the Fraser River. Residency in the estuary is short, therefore, they are not expected to have strong environmental preferences within this ecosystem. Environmental preferences for adult salmon at Roberts Bank are shown (**Table 4-9**).

Table 4-9 Adult Salmon Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	1	Clay	1	Very low	1	Quiescent	n/a	Mud	1
Brackish	1	Shallow subtidal	1	Very fine sand	1	Low	1	Very low	n/a	Sand	1
Freshet	1	Moderate subtidal	1	Fine sand	1	Moderate	1	Low	n/a	Biofilm	0
Marine	1	Deep subtidal	1	Coarse sand	1	High	1	Moderate	n/a	Biomat	0
				Fine gravel	1					Rock	0
				Gravel	1					*Ulva*	1
				Cobbles/Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	0
										Saltmarsh	0
										Grass	0
Source											
(Froese and Pauly 2011)		(Ruggerone et al. 1990, Walker et al. 2007, Froese and Pauly 2011)		(Friesen 2005)		(Heard et al. 1998)				(Murphy et al. 2000, Archipelago Marine Research Ltd. 2014d)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

4.6 DOGFISH

4.6.1 Group Definition

Table 4-10 Species in the Dogfish Functional Group

Common Name	Scientific Name
North Pacific Spiny Dogfish	*Squalus suckleyi*

North Pacific spiny dogfish was selected as a focal species at Roberts Bank by the PC-TAG. Juvenile spiny dogfish are found in or above scattering layers in the Strait of Georgia at depths of 100 – 170 m (Beamish et al. 1982). Adults become more closely associated with the **continental shelf** with schools occasionally found in shallow or surface waters (Ketchen et al. 1983). At age 15-20 years (approximately 60 cm in length) it is common for dogfish to switch from a pelagic to demersal lifestyle (Beamish and Sweeting 2009). North Pacific spiny dogfish are long-lived and residents to the Strait of Georgia, as most of the local population remains in this area throughout their life period (Beamish and Sweeting 2009).

4.6.2 Biomass and Production

A biomass value of 0.6587 t/km^2 for spiny dogfish was extracted from the literature, as recent field surveys conducted in 2012 and 2013 did not specifically target this species. A P/B of 0.12 year^{-1} was used (Froese and Pauly 2011).

4.6.3 Diet and Consumption

The spiny dogfish are opportunistic and highly active feeders (Jones and Geen 1977). The spiny dogfish is an opportunistic feeder, with adult diet predominantly consisting of fish and large invertebrates, such as crabs, jellyfish, amphipods, squid and octopus (Jones and Geen 1977). A Q/B value of 2.77 year^{-1} was used (Maretll 2002; Harvey et al. 2010; Preikshot et al. 2012).

4.6.4 Environmental Preferences

North Pacific spiny dogfish inhabit temperate waters of the North Pacific Ocean. They can be found from Japan, through eastern Russia, the Bering Sea and Aleutian Islands and along the western coast of North America from the Gulf of Alaska to the southern Baja peninsula. They are extremely common off the coast of B.C. (Ebert 2003). Spiny dogfish tend to form large schools, often segregate by size, sex, or reproductive state (Compagno 1984). Although predominantly bottom-dwelling, spiny dogfish are often observed in large foraging schools that consume prey across pelagic and benthic habitats (Jones and Geen 1977). Spiny dogfish is not likely to exhibit strong environmental and habitat preferences at Roberts Bank. Dogfish have recently been spotted within the artificial reef structures at Roberts Bank (Archipelago Marine Research Ltd 2014c). They have also been seen over sand- and mudflat habitat during remotely operated vehicle (ROV) video surveying of the proposed RBT2 footprint. Environmental preferences for dogfish in the study area are shown (**Table 4-11**).

Table 4-11 Dogfish Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0	Intertidal	1	Clay	1	Very low	1	Quiescent	1	Mud	1
Brackish	1	Shallow subtidal	1	Very fine sand	1	Low	1	Very low	1	Sand	1
Freshet	1	Mid subtidal	2	Fine sand	1	Moderate	1	Low	1	Biofilm	1
Marine	1	Deep subtidal	2	Coarse sand	1	High	1	Moderate	1	Biomat	1
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	1
										Saltmarsh	1
										Grass	0
Source											
(Froese and Pauly 2011)		(Froese and Pauly 2011)		(Perry et al. 1994, Archipelago Marine Research Ltd. 2014b)		n/a		n/a		(Triton 2004, Archipelago Marine Research Ltd 2013b, Archipelago Marine Research Ltd. 2013*c*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

4.7 FLATFISH

4.7.1 Group Definition

Table 4-12 Species in the Flatfish Functional Group

Common Name	Scientific Name
Sand sole	*Pegusa lascaris*
Rock sole	*Lepidopsetta bilineata*
Sanddab	*Citharichthys* sp.
Flathead sole	*Hippoglossoides elassodon*
English sole	*Parophrys vetulus*
Dover sole	*Microstomus pacificus*
Butter sole	*Isopsetta isolepis*

Flatfish species in the Strait of Georgia spawn within a depth range of 20 - 90 m in winter (Levings and Ong 2003). Flatfish generally produce highly buoyant eggs that rise to the sea surface (Ketchen et al. 1983). Larvae are carried to sandy intertidal zones, such as Roberts Bank, where they **metamorphose** and settle to the bottom until late summer. Juvenile flatfish are important benthic prey for other fish. Flatfish of 2+ and 3+ years progress to depths occupied by adults (Ketchen et al. 1983). They take three to four years to reach sexual maturity and marketable size. The historical record of flatfish landings in the Strait of Georgia shows unstable fishing yields (Ketchen et al. 1983). For many flatfish species there is little or no recent data (within the last 30 years) available to determine whether changes in the fishery are due to environmental or anthropomorphic effects.

4.7.2 Biomass and Production

An average biomass of 0.3745 t/km^2 was estimated for the study area using data collected during field surveys conducted in 2012 and 2013 (Archipelago Marine Research Ltd. 2014*a*, *b*). A P/B of 0.37 year^{-1} was used, which is an average of the P/B ratios for each species within this functional group (Froese and Pauly 2011).

4.7.3 Diet and Consumption

The fish species in this functional group are mostly bottom-dwellers and feed primarily on invertebrates. Where no specific reference is given, diet information was obtained from Fishbase (Froese and Pauly 2011). Sand sole diet consists of fish, worms, crustaceans and mollusks (Quéro et al. 1986). Rock sole diet consists of mollusks, polychaete worms, crustaceans, brittle stars, and fish (Hart 1973). Pacific sanddab diet consists of crustaceans, smaller fish, squid, and octopus (Pearcy and Hancock 1978). Flathead sole diet consists of clams, worms and crustaceans (Hart 1973). English sole diet consists of polychaetes, bivalve mollusks, foraminifera, amphipods, and unidentified crustaceans (Levings and Ong 2003). Dover sole diet consists of small crustaceans, bottom dwelling organisms like worms, clams, and crabs (Hagerman 1952). Butter sole diet consists of crabs, shrimps, chaetopod marine worms and sand dollars, as well as young herring (Hart 1973). A Q/B of 3.53 year^{-1} was used, which is an average of the Q/B ratios for each species within this functional group (Froese and Pauly 2011).

4.7.4 Environmental Preferences

Pacific flatfish use nearshore areas as nurseries with juvenile flatfish abundant in estuaries, and associated areas, like Roberts Bank. Adults typically reside in deeper waters and return to estuaries to spawn (Levings and Ong 2003). Flatfish prefer finer grain sediment such as mud, sand, or a mixture of both depending on species and life history stage (Moles and Norcross 1995). For example, in Auke Bay, Alaska, juvenile rock sole (body size: 50 – 80 mm) prefer sand and mixed sand substrata while juvenile English sole (body size: 50 – 80 mm) prefer mud and mixed mud (Moles and Norcross 1995). Flatfish primarily rest on the seafloor and prefer areas with low current, as they are not strong swimmers (Gibson

2005). Sand sole, rock sole, Pacific sanddab, flathead sole, English sole, Dover sole, and butter sole have all been recently documented across eelgrass and sand- and mudflat habitat at Roberts Bank (Archipelago Marine Research Ltd. 2014*a*, *b*). During recent summer and fall benthic trawls, juvenile flatfish were the most abundant fish present across shallow (0 – -25 m CD) sand- and mudflat habitat at Roberts Bank (Archipelago Marine Research Ltd. 2014b). The most abundant juvenile flatfish species was English sole, while Pacific sanddab and rock sole were also common (Archipelago Marine Research Ltd. 2014b). Environmental preferences for flatfish in the study area are shown (**Table 4-13**).

Table 4-13 Flatfish Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0.5	Intertidal	1	Clay	1	Very low	1	Quiescent	1	Mud	2
Brackish	0.5	Shallow subtidal	1	Very fine sand	1	Low	1	Very low	1	Sand	2
Freshet	0.5	Moderate subtidal	1	Fine sand	1	Moderate	1	Low	1	Biofilm	0
Marine	1	Deep subtidal	1	Coarse sand	1	High	0	Moderate	1	Biomat	0
				Fine gravel	1					Rock	0
				Gravel	0.5					*Ulva*	0
				Cobbles/ Boulders	0					Eelgrass	1
										Kelp	0
										Sea pens	0
										Saltmarsh	0
										Grass	0
Source											
(Froese and Pauly 2011)		(Levings and Ong 2003, Froese and Pauly 2011)		(Becker 1988, Perry et al. 1994, Moles and Norcross 1995, Abookire and Norcross 1998, McConnaughey and Smith 2000, Anchor Environmental, L.L.C. 2001, Yoklavich et al. 2002, Martinho et al. 2010, Froese and Pauly 2011)		(Marchand 1991, Nichol and Somerton 2009)		n/a		(Perry et al. 1994, Murphy et al. 2000, Johnson et al. 2003, Froese and Pauly 2011, Archipelago Marine Research Ltd. 2014*a*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 0.5 indicates species does not prefer habitat but does not actively avoid it, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

4.8 FORAGE FISH

4.8.1 Group Definition

Table 4-14 Species in the Forage Fish Functional Group

Common Name	Scientific Name
Surf smelt	*Hypomesus pretiosus*
Northern anchovy	*Engraulis mordax*
Long fin smelt	*Spirinchus thaleichthys*
Eulachon	*Thaleichthys pacificus*

Forage fish are small, pelagic, schooling fish. This group transfers energy from plankton to larger predatory fish and marine mammals (Alder et al. 2008). Eulachon is a culturally significant fish species to coastal B.C. First Nations who historically extracted its oil for consumption and trade (Moody 2008). Eulachon is provincially blue-listed (BC CDC 2013). The Fraser River eulachon population was designated as endangered in 2011 by COSEWIC and is under consideration for listing as endangered under SARA by Fisheries and Oceans Canada (DFO 2014*b*). Other forage fish, such as northern anchovy, surf and long fin smelt, have been recorded from Roberts Bank (Archipelago Marine Research Ltd. 2013*a*, *b*, *c*, *d*).

4.8.2 Biomass and Production

Forage fish biomass estimates were derived upon literature and not data collected during field surveys. Forage fish catch in the field was incidental, as field surveys did not target pelagic species. As a result, forage fish are likely under-represented in the field catch data. An estimated biomass of 15 t/km^2 was used from a published EwE model weighted by the available habitat for forage fish across Roberts Bank (Beattie 2001) and small pelagics (Preikshot 2012). Biomass was lowered to 5.0 t/km^2 during model balancing as this was thought to be high for the condition at Roberts Bank; however this was to low for the model to balance. A final biomass of 10.5 t/km^2 was used to balance the model. A P/B of 0.95 year^{-1} was used, which is an average of P/B ratios for each species within this functional group (Froese and Pauly 2011).

4.8.3 Diet and Consumption

The diet composition matrix for this functional group was compiled from forage fish diet information extracted from literature (Wilson et al. 2009, Froese and Pauly 2011). Eulachon feed primarily on euphausiids (Wilson et al. 2009). Surf smelt have a mixed diet including jellyfish, insects, euphausiids, fish larvae, and other planktonic crustaceans (Froese and Pauly 2011). The diet of long fin smelt consists of insects, euphausiids, mysids, copepods, and other planktonic crustaceans (Froese and Pauly 2011). Northern anchovy feed on phytoplankton, mysids, euphausiids, copepods, fish larvae, and other planktonic zooplankton (Froese and Pauly 2011). A Q/B of 6.4 year^{-1} was used, which is an average of the Q/B ratios for each species within this functional group (Froese and Pauly 2011).

4.8.4 Environmental Preferences

Forage fish operate as a mid-trophic level group that depends heavily for food on small planktonic organisms. The availability of planktonic food for forage fish has been linked to environmental fluctuations. Given their short life span, forage fish distribution and biomass are also influenced by changes in ocean climate and associated production regime shift events, more strongly than other commercial fish species (Cury et al. 2000, Alder et al. 2008). Spawning intensity and location of spawning grounds are generally associated with areas of relatively high production (e.g., riverine outflows, upwelling areas and fronts). For anchovy and sardines, temperature, length of day, and wind-driven mixing effects determine the depth of the upper mixed layer and suitability of spawning habitat (Palomera et al. 2007). In contrast, surf smelt spawn on intertidal beaches that exhibit specific sediment grain-size distributions (Quinn et al. 2012, Parks et al. 2013).

At Roberts Bank, forage fish abundance is ephemeral and seasonal. For example, adult eulachon can be abundant in April when they migrate upstream to spawn on gravel beds (Levings 2004). Northern anchovy were the most abundant fish species incidentally documented in fall eelgrass habitat surveys (not found in spring or summer). Surf smelt was the most abundant fish species incidentally documented in spring eelgrass habitat surveys, as well as summer and fall benthic trawl surveys (Archipelago Marine Research Ltd. 2013*a*, *b*). Environmental preferences for forage fish in the study area are shown (**Table 4-15**).

Table 4-15 Forage Fish Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	0-1	Clay	1	Very low	1	Quiescent	1	Mud	1
Brackish	1	Shallow subtidal	1	Very fine sand	1	Low	1	Very low	1	Sand	2
Freshet	1	Moderate subtidal	1	Fine sand	1	Moderate	1	Low	1	Biofilm	0
Marine	1	Deep subtidal	1	Coarse sand	1	High	1	Moderate	1	Biomat	0
				Fine gravel	1					Rock	0
				Gravel	0.75					*Ulva*	1
				Cobbles/ Boulders	0.5					Eelgrass	1
										Kelp	1
										Sea pens	0
										Saltmarsh	1
										Grass	0
Source											
(Froese and Pauly 2011)		(Levings and Ong 2003, Penttila 2007, Froese and Pauly 2011)		(Lassuy 1989, Stables et al. 2005, Parks et al. 2013)		n/a		n/a		(Seliskar and Gallagher 1983, Johnson et al. 2003, Cambria Gordon Ltd. 2006, Archipelago Marine Research Ltd. 2014*a*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

4.9 HERRING

4.9.1 Group Definition

Table 4-16 Species in the Herring Functional Group

Common Name	Scientific Name
Pacific herring	*Clupea pallasii*

Pacific herring was chosen as a focal species by the PC-TAG because of their presence at Roberts Bank and significant contribution to the diet of higher trophic level organisms such as salmon, seabirds and marine mammals. Pacific herring stocks in the Strait of Georgia sustain an important commercial fishery

(Beamish et al. 1994). There is a small resident population and a larger migratory population that moves into the Strait of Georgia in the fall and spawns the following winter (Hourston and Haegele 1980). Mature Pacific herring lay their adhesive eggs on eelgrass and rockweed algae in or immediately below the intertidal zone (Hourston and Haegele 1980). Spawning in the Strait of Georgia takes place during March and incubation takes about two weeks. Larvae are distributed by tides and wind-driven currents. As swimming ability improves with increasing body size, Pacific herring congregate in increasingly larger schools. With the approach of autumn, the schools move gradually seaward to wintering grounds on the continental shelf off the southwest coast of Vancouver Island. With the onset of maturity, usually at three to four years of age, these Pacific herring migrate in late winter from the continental shelf to the enclosed waters of the Strait of Georgia to spawn in shallow areas (Hourston and Haegele 1980).

4.9.2 Biomass and Production

Herring biomass estimates were derived from the literature and not data collected during field surveys. Herring catch in the field was incidental, as field surveys did not target pelagic species. As a result, herring is likely under-represented in the field catch data. Biomass of 4.4469 t/km^2 was estimated by weighting biomass estimate from a published Strait of Georgia EwE model with the available habitat across Roberts Bank (Preikshot et al. 2012). A P/B of 0.80 year^{-1} was used (Froese and Pauly 2011).

4.9.3 Diet and Consumption

Pacific herring feeds primarily on zooplankton and macrofauna (Foy and Norcross 1999). A Q/B value of 5.5 year^{-1} was used (Froese and Pauly 2011).

4.9.4 Environmental Preferences

There are both resident and migratory Pacific herring in the Strait of Georgia stock. Pacific herring are found at various depths, with varying substrate types. Herring return to coastal waters in large numbers to spawn on marine vegetation, such as eelgrass, as well as on hard substrates (Penttila 2007). Herring mature and recruit to the spawning stock between ages three and five. However, age-at-recruitment tends to increase with latitude. Adult males and females migrate from the open ocean to sheltered bays around November or December. Recent research indicates that the interplay of food supply and predation impacts on herring survival and production is complex and not readily predictable (Schweigert et al. 2010). Spawning occurs regularly at Point Roberts and Boundary Bay, with little actually occurring in eelgrass beds (Hay and McCarter 2013). Juvenile herring have been observed in abundance at Roberts Bank (Levings 2004). Summer field surveys at Roberts Bank found that Pacific herring were present in eelgrass habitat (Archipelago Marine Research Ltd. 2014a). Environmental preferences for Pacific herring at Roberts Bank are shown (**Table 4-17**).

Table 4-17 Herring Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0	Intertidal	1	Clay	1	Very low	1	Quiescent	n/a	Mud	1
Brackish	1	Shallow subtidal	1	Very fine sand	1	Low	1	Very low	1	Sand	0
Freshet	1	Moderate subtidal	1	Fine sand	1	Moderate	1	Low	1	Biofilm	0
Marine	1	Deep subtidal	1	Coarse sand	1	High	1	Moderate	1	Biomat	0
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/ Boulders	1					Eelgrass	2
										Kelp	2
										Sea pens	0
										Saltmarsh	0
										Grass	0
Source											
(Froese and Pauly 2011)		(Levings and Ong 2003, Penttila 2007, Hay et al. 2008)		(Lassuy 1989)		n/a		(Hoshikawa et al. 2004)		(Penttila 2007)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

4.10 LARGE DEMERSAL FISH

4.10.1 Group Definition

Table 4-18 Species in the Large Demersal Fish Functional Group

Common Name	Scientific Name
White spotted greenling	*Hexagrammos stelleri*
Walleye pollock	*Theragra chalcogramma*
Sturgeon poacher	*Podothecus accipenserinus*
Striped perch	*Embiotoca lateralis*
Plainfin midshipman	*Porichthys notatus*
Kelp greenling	*Hexagrammos decagrammus*
Great sculpin	*Myoxocephalus polyacanthocephalus*
Bay pipefish	*Syngnathus leptorhyncus*

The large **demersal** fish functional group consists of fish species at Roberts Bank greater than ten centimetres in length (adult) and are benthic or **benthopelagic** feeders. These fish species are known to occur at Roberts Bank, with individual species showing preferences for distinct habitats.

4.10.2 Biomass and Production

An average biomass of 0.1536 t/km^2 was estimated for the study area using data collected during field surveys conducted at Roberts Bank in 2012 and 2013 (Archipelago Marine Research Ltd. 2014*a*, *b*, *c*). A P/B of 0.51 year^{-1} was used, which is an average of the P/B ratios for each species within this functional group (Froese and Pauly 2011).

4.10.3 Diet and Consumption

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. A Q/B of 4.78 year^{-1} was used, which is an average of the Q/B ratios for each species within this functional group (Froese and Pauly 2011).

4.10.4 Environmental Preferences

While individual species within the group are affiliated with particular habitats, the group as a whole does not have any strong preferences for any one substrate or marine vegetation. For example, kelp greenling are associated with kelp beds, whereas bay pipefish are rarely found outside of eelgrass habitats (Murphy et al. 2000). Walleye pollock are opportunistic and will occupy a diversity of habitats, ranging from eelgrass beds in Puget Sound to the open oceanic waters of the Aleutian basin (Bailey et al. 2005).This functional group occurs in a variety of depths, salinities, and current velocities at Roberts Bank. Field surveys at Roberts Bank found bay pipefish and plainfin midshipman in eelgrass habitat; bay pipefish, great sculpin, plainfin midshipman, walleye pollock, and white spotted greenling in mud- and sandflat habitat; and kelp greenling and striped perch in artificial rocky reef habitat (Archipelago Marine Research Ltd. 2014*a*, *b*, *c*). While the plainfin midshipman was most commonly encountered, kelp greenling had the largest biomass within this functional group. Environmental preferences for large demersal fish at Roberts Bank are shown (**Table 4-19**).

Table 4-19 Large Demersal Fish Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	1	Clay	1	Very low	1	Quiescent	n/a	Mud	1
Brackish	1	Shallow subtidal	1	Very fine sand	1	Low	1	Very low	n/a	Sand	1
Freshet	1	Moderate subtidal	1	Fine sand	1	Moderate	1	Low	n/a	Biofilm	0
Marine	1	Deep subtidal	1	Coarse sand	1	High	1	Moderate	n/a	Biomat	0
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	0
				Cobbles/ Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	0
										Saltmarsh	0
										Grass	0
Source											
(Froese and Pauly 2011)		(Hixon 1980, Levings and Ong 2003, Haggarty and King 2006, Froese and Pauly 2011)		(Lassuy 1989, Pearcy et al. 1989, Bulthuis 1996, Abookire et al. 2001, Yoklavich et al. 2002, Johnson et al. 2008, Kelly et al. 2008, Huff et al. 2011)		(Babcock Hollowed et al. 2007, Kelly and Klimley 2012)				(Dean et al. 2000, Murphy et al. 2000, Bailey et al. 2005, Froese and Pauly 2011, Archipelago Marine Research Ltd. 2014*a*, *b*, *c*, *d*,)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

4.11 LINGCOD

4.11.1 Group Definition

Table 4-20 Species in the Lingcod Functional Group

Common Name	Scientific Name
Lingcod	*Ophiodon elongatus*

Lingcod were overfished in the Strait of Georgia through much of the 20th Century and their population has been depressed for several decades (Surry and King 2007). Lingcod live on reefs and reach maturity at four to five years. Spawning occurs primarily during December to March, some of it in shallow water close to the intertidal zone where eggs are laid in large adhesive masses under rocks or in crevices. Survival of eggs appears to be greatest in localities of high tidal velocity (Giorgi and Congleton 1984). Lingcod adults lead a rather sedentary existence. Lingcod is also a hard substrate favouring species Lingcod were selected as a focal species at Roberts Bank by the PC-TAG.

4.11.2 Biomass and Production

An average biomass of 0.5868 t/km^2 was estimated for the study area using data collected during field surveys conducted in 2012 and 2013 at Roberts Bank (Archipelago Marine Research Ltd. 2014c). A P/B of 0.31 year^{-1} was used (Froese and Pauly 2011).

4.11.3 Diet and Consumption

Lingcod are generalist piscivorous predators that also consume octopus and benthic invertebrates such as crab and shrimp (Miller 2007, Tinus 2009). A Q/B of 1.7 year^{-1} was used (Froese and Pauly 2011).

4.11.4 Environmental Preferences

Lingcod inhabit shallow rocky reefs and exhibit site fidelity (Tinus 2009). As an ambush predator, adult lingcod seek out hiding locations within crevices of larger-sized substrata or in complex habitat created by marine vegetation like kelp (Johnson et al. 2003). Lingcod prefer marine waters with a moderate to low bottom current (Froese and Pauly 2011). Juveniles reside on the seafloor in shallow waters with finer sediment types and weak bottom currents (Froese and Pauly 2011). Recent surveys indicate that lingcod are common in ten artificial reefs that were constructed between 1994 and 2009 off the southwest side of the existing terminal (Archipelago Marine Research Ltd. 2014c). Environmental preferences for lingcod at Roberts Bank are shown (**Table 4-21**).

Table 4-21 Lingcod Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0	Intertidal	0-1	Clay	0	Very low	1	Quiescent	1	Mud	1
Brackish	1	Shallow subtidal	1	Very fine sand	0	Low	1	Very low	1	Sand	1
Freshet	1	Moderate subtidal	1	Fine sand	1	Moderate	1	Low	1	Biofilm	0
Marine	1	Deep subtidal	1	Coarse sand	1	High	0	Moderate	1	Biomat	0
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	0
				Cobbles/ Boulders	0					Eelgrass	1
										Kelp	1
										Sea pens	0
										Saltmarsh	0
										Grass	0
Source											
(Froese and Pauly 2011)		(Froese and Pauly 2011)		(Perry et al. 1994)		n/a				(Johnson et al. 2003, Triton 2004, Froese and Pauly 2011, Archipelago Marine Research Ltd. 2014c)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

4.12 ROCKFISH

4.12.1 Group Definition

Table 4-22 Species in the Rockfish Functional Group

Common Name	Scientific Name
Quillback rockfish	*Sebastes maliger*
Copper rockfish	*Sebastes caurinus*

Rockfish have been a commercially important fish species in B.C., and were also identified as focal species at Roberts Bank by the PC-TAG. Recently there have been concerns about management of rockfish populations; a Rockfish Conservation Strategy was developed by DFO and Rockfish Conservation Areas have been established within the province (Yamanaka and Logan 2010). Additionally, quillback rockfish were designated as threatened by (COSEWIC 2009).

4.12.2 Biomass and Production

An average biomass of 0.3385 t/km^2 was estimated for the study area using data collected during field surveys conducted in 2012 and 2013 at Roberts Bank (Archipelago Marine Research Ltd. 2014c). A P/B of 0.22 year^{-1} was used, which is an average of the P/B ratios for each species within this functional group (Froese and Pauly 2011).

4.12.3 Diet and Consumption

Copper rockfish primarily consume pelagic (mainly Pacific herring) and demersal fish, as well as benthic crustaceans such as decapods (Murie 1995). Quillback rockfish are opportunistic predators and their diet shifts in response to local availability. During the herring run these fish may constitute up to 90% of prey mass (Murie 1995). They feed on demersal and pelagic fish, predominantly Pacific herring, as well as benthic crustaceans such as benthic decapods (Murie 1995). A Q/B of 2.85 year^{-1} was used, which is an average of the Q/B ratios for each species within this functional group (Froese and Pauly 2011).

4.12.4 Environmental Preferences

Copper and quillback rockfish are benthic species, and hide among rocks and kelp beds with the former found at shallower depths. Rockfish prefer moderate to deep subtidal marine environments (Richards 1986). They are typically found in areas with a low to moderate bottom current and large-sized sediment (Richards 1986, Pacunski and Palsson 2002). Both are present at Roberts Bank, within the artificial rocky reef habitat. Copper rockfish is abundant at a few artificial reef sites in both summer and fall, while quillback rockfish are rare (Archipelago Marine Research Ltd. 2014c). Rockfish are a hard substrate favouring species. Environmental preferences for rockfish at Roberts Bank are shown (**Table 4-23**).

Table 4-23 Rockfish Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0	Intertidal	0-1	Clay	0	Very low	1	Quiescent	1	Mud	0
Brackish	0	Shallow subtidal	1	Very fine sand	0	Low	1	Very low	1	Sand	0
Freshet	0	Moderate subtidal	1	Fine sand	0	Moderate	1	Low	1	Biofilm	0
Marine	1	Deep subtidal	1	Coarse sand	0.5	High	1	Moderate	1	Biomat	0
				Fine gravel	1					Rock	2
				Gravel	1					*Ulva*	0
				Cobbles/ Boulders	1					Eelgrass	0
										Kelp	2
										Sea pens	0
										Saltmarsh	0
										Grass	0
Source											
(Johnson et al. 2003)		(Richards 1986, 1987, Froese and Pauly 2011)		(Richards 1987, Stein and Hassler 1989)		(Johnson et al. 2003)				(Richards 1987, Yamanaka and Logan 2010, Archipelago Marine Research Ltd. 2014c)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

4.13 SANDLANCE

4.13.1 Group Definition

Table 4-24 Species in the Sandlance Functional Group

Common Name	Scientific Name
Pacific sandlance	*Ammodytes hexapterus*

Pacific sandlance were selected as a focal species by the PC-TAG. They are ecologically important as prey for many species of fish, seabirds, and marine mammals at Roberts Banks. When not foraging in the water column, Pacific sandlance bury in the intertidal or subtidal sand because they lack a swim bladder. They leave their subtidal habitat for short periods in late winter to lay eggs in intertidal sand. The largest Pacific sandlance burrowing habitats are in the southern Strait of Georgia, from Haro Strait and Boundary Pass in the southern Gulf Islands eastward to Roberts and Sturgeon Banks (Robinson et al. 2013). Dynamic processes that concentrate sand on the seafloor and transport sediment also influence this habitat. Subaqueous dunes at Roberts and Sturgeon Banks are produced by currents acting upon sediment. Large numbers of Pacific sandlance use the extensive shallow areas of suitable sand on the banks to bury, and then moving to the adjacent well-mixed water column along the edges of the bank to forage (Robinson et al. 2013).

4.13.2 Biomass and Production

An average biomass of 0.2075 t/km^2 was estimated using data collected during field surveys conducted at Roberts Bank in 2012 and 2013 (Archipelago Marine Research Ltd. 2014*a*, *c*). A P/B of 0.47 year^{-1} was used (Froese and Pauly 2011).

4.13.3 Diet and Consumption

Pacific sandlance diet consists primarily of zooplankton including calanoid and cyclopoid copepods with lower proportions of crustacean **zoeae** and **nauplii**, gammarid amphipods, larvaceans, and epibenthic invertebrates (Simenstad et al. 1979, Ciannelli 1997). Adults will also feed on herring larvae and eggs. Pacific sandlance often associate with juvenile Pacific herring when feeding (Ciannelli 1997). A Q/B of 4.2 year^{-1} was used (Froese and Pauly 2011).

4.13.4 Environmental Preferences

Pacific sandlance rely on sand substrates to bury in, especially overnight and during the winter. Habitat modelling has determined that shallow (<80 m) areas around Roberts Bank contain suitable burying habitat characterised by strong bottom currents (25 – 63 cm/s), and coarse sediment (0.25 – 2.00 mm grain diameter) (Robinson et al. 2013). Pacific sandlance were present in relatively large numbers in eelgrass habitat and were observed schooling at artificial reefs at Roberts Bank (Archipelago Marine Research Ltd. 2014a, c). Environmental preferences for Pacific sandlance at Roberts Bank are shown (**Table 4-25**).

Table 4-25 Sandlance Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0	Intertidal	0-1	Clay	1	Very low	0	Quiescent	1	Mud	1
Brackish	1	Shallow subtidal	1	Very fine sand	1	Low	0	Very low	1	Sand	2
Freshet	1	Moderate subtidal	1	Fine sand	1	Moderate	1	Low	1	Biofilm	0
Marine	1	Deep subtidal	1	Coarse sand	1	High	1	Moderate	1	Biomat	0
				Fine gravel	0.75					Rock	0
				Gravel	0.5					*Ulva*	1
				Cobbles/Boulders	0.5					Eelgrass	1
										Kelp	1
										Sea pens	0
										Saltmarsh	0
										Grass	0
Source											
(Froese and Pauly 2011)		(Froese and Pauly 2011, Robinson et al. 2013)		(Haynes et al. 2007)		(Robinson et al. 2013)				(Archipelago Marine Research Ltd. 2014*a*, *c*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

4.14 SHINER PERCH

4.14.1 Group Definition

Table 4-26 Species in the Shiner Perch Functional Group

Common Name	Scientific Name
Shiner perch	*Cymatogaster aggregata*

Shiner perch have a wide distribution in the northeast Pacific Ocean and can be found in brackish or even freshwater environments. Adult shiner perch occur at Roberts Bank during the summer months when they bear young; they are rare during the rest of the year (Archipelago Marine Research Ltd. 2014*a*, *b*, *c*, *d*). Young are born between May and August. Shiner perch are important prey to many fish, birds, and marine mammals. Shiner perch were identified as focal species at Roberts Bank by the PC-TAG. Shiner perch are a hard substrate favouring species.

4.14.2 Biomass and Production

An average biomass of 0.1635 t/km^2 was estimated using data collected during field surveys conducted at Roberts Bank in 2012 and 2013 (Archipelago Marine Research Ltd. 2014*a*, *b*, *c*, *d*). A P/B of 1.27 year^{-1} was used (Froese and Pauly 2011).

4.14.3 Diet and Consumption

Shiner perch exhibit seasonal shifts in diet, and will alter feeding depending on prey availability (Woods 2010). They are opportunistic feeders and diet varies across regions (Woods 2010). Prey items include copepods, diatoms, barnacles, as well as large crustaceans (Gordon 1965). A Q/B of 9.4 year^{-1} was used (Froese and Pauly 2011).

4.14.4 Environmental Preferences

Shiner perch are found in shallow waters in estuaries during the spring and summer to bear young (Woods 2007). In estuaries, they form loose schools or small aggregations in sheltered areas such as bays and they congregate around eelgrass beds or man-made structures such as piers and pilings (Woods 2007). After **parturition**, adult males and females, as well as young-of the-year with noticeable secondary sexual characteristics move into open waters during fall and winter (Woods 2007).

Shiner perch tolerate a wide range of salinities. While they prefer to have shelter nearby, they may also be found over unvegetated sand- and mudflat habitat (Day and Pearcy 1968). In recent surveys at Roberts Bank, shiner perch were noted to be abundant in eelgrass, sand- and mudflat habitat, however they were rare in artificial reef habitat (Archipelago Marine Research Ltd. 2014*a*, *b*, *c*, *d*). Shiner perch have complex seasonal and **diurnal** movements which vary with the age and sex of the fish (Gordon 1965). Environmental preferences for shiner perch at Roberts Bank are shown (**Table 4-27**).

Table 4-27 Shiner Perch Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	0-1	Clay	0.5	Very low	1	Quiescent	1	Mud	1
Brackish	1	Shallow subtidal	1	Very fine sand	0.5	Low	1	Very low	1	Sand	1
Freshet	1	Moderate subtidal	1	Fine sand	0.5	Moderate	1	Low	1	Biofilm	0
Marine	1	Deep subtidal	1	Coarse sand	0.5	High	1	Moderate	1	Biomat	0
				Fine gravel	0.75					Rock	0
				Gravel	1					*Ulva*	0
				Cobbles/Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	0
										Saltmarsh	0
										Grass	0
Source											
(Froese and Pauly 2011)		(Levings and Ong 2003, Froese and Pauly 2011)		(Day and Pearcy 1968)		n/a				(Archipelago Marine Research Ltd. 2014*a*, *b*, *c*, *d*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 0.5 indicates species does not prefer habitat but does not actively avoid it, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

4.15 SKATE

4.15.1 Group Definition

Table 4-28 Species in the Skate Functional Group

Common Name	Scientific Name
Big skate	*Raja binoculata*

The big skate is the largest species of skate in the waters off North America. It is found along the coast from Baja California and to the eastern Bering Sea in the eastern Pacific Ocean (Mecklenburg et al. 2002, Ebert 2003). Since it is the only skate species likely to be found at Roberts Bank, the big skate was modelled as a single species functional group. Big skate have been recorded at Roberts Bank (Triton 2004).

4.15.2 Biomass and Production

A biomass estimate of 0.2305 t/km^2 was calculated by weighting the biomass estimate from a published Strait of Georgia EwE model with the available habitat at Roberts Bank (Preikshot et al. 2012). Literature-derived biomass values were used because this group was not specifically targeted and no big skate were spotted during field surveys at Roberts Bank. A P/B of 0.09 year^{-1} was used (Froese and Pauly 2011).

4.15.3 Diet and Consumption

Big skate feed primarily on flatfish and crustaceans, including crabs and shrimp (Yang 2007). A Q/B of 1.2 year^{-1} was used (Froese and Pauly 2011).

4.15.4 Environmental Preferences

Big skate are from the low intertidal to 800 m depth (Mecklenburg et al. 2002). They prefer sand substrates and low bottom current velocities (Perry et al. 1994). At Roberts Bank they have been found within the mud of the shallow dredge basin as well as in the sand/mudflat west of the terminal at depths between 3 - 25 m. Big skate egg cases have been seen off the western corner of the terminal, in the sand at depths of less than 5 m (Triton 2004). Big skate at Roberts Bank are likely resident as there is no evidence that they migrate seasonally in B.C. waters (King and McFarlane 2010). Environmental preferences for skate at Roberts Bank are shown (**Table 4-29**).

Big skate are landed in a commercial fishery in waters off B.C. The majority of landings are made by trawl tow however long line gear is used as well. A rapidly expanding fishery has resulted in the implementation of catch limits within some areas of the B.C. coast (King and McFarlane 2010). To date there are no size limits or seasonal closures and no full detailed pacific stock assessment has ever been made (DFO 2013).

Table 4-29 Skate Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0	Intertidal	0	Clay	1	Very low	2	Quiescent	1	Mud	1
Brackish	0	Shallow subtidal	1	Very fine sand	1	Low	2	Very low	1	Sand	1
Freshet	0	Moderate subtidal	1	Fine sand	1	Moderate	1	Low	1	Biofilm	0
Marine	1	Deep subtidal	1	Coarse sand	1	High	0	Moderate	1	Biomat	0
				Fine gravel	0.5					Rock	0
				Gravel	0					*Ulva*	0
				Cobbles/Boulders	0					Eelgrass	0
										Kelp	0
										Sea pens	0
										Saltmarsh	0
										Grass	0
Source											
(Froese and Pauly 2011)		(Mecklenburg et al. 2002, Froese and Pauly 2011)		(Perry et al. 1994)		n/a		n/a		(Perry et al. 1994)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

4.16 SMALL DEMERSAL FISH

4.16.1 Group Definition

Species in the small demersal fish functional group at Roberts Bank are typically less than 10 centimetres long at maturity and are benthic or benthopelagic feeders. Fish in this group are likely to occur throughout Roberts Bank, but individual species will show preferences for distinct habitats.

Table 4-30 Species in the Small Demersal Fish Functional Group

Common Name	Scientific Name
Tubesnout	*Aulorhynchus flavidus*
Tidepool sculpin	*Oligocottus maculosus*
Three spine stickleback	*Gasterosteus aculeatus*
Tadpole sculpin	*Psychrolutes paradoxus*
Snake prickleback	*Lumpenus sagitta*
Smooth alligatorfish	*Anoplagonus inermis*
Sailfin sculpin	*Nautichthys oculofasciatus*
Saddleback gunnel	*Pholis ornata*
Ribbed sculpin	*Triglops pingelii*

Common Name	Scientific Name
Pygmy poacher	*Odontopyxis trispinosa*
Padded sculpin	*Artedius fenestralis*
Pacific staghorn sculpin	*Leptocottus armatus*
Northern spearnose poacher	*Agonopsis vulsa*
Northern sculpin	*Icelinus borealis*
Manacled sculpin	*Synchirus gilli*
Grunt sculpin	*Rhamphocottus richardsonii*
Crescent gunnel	*Pholis laeta*
Buffalo sculpin	*Enophrys bison*
Blackeye goby	*Rhinogobiops nicholsii*
Arrow goby	*Clevelandia ios*

4.16.2 Biomass and Production

An average biomass of 0.0723 t/km^2 was estimated using data collected during field surveys conducted at Roberts Bank in 2012 and 2013 (Archipelago Marine Research Ltd. 2014*a*, *b*, *c*, *d*). A P/B of 1.00 year^{-1} was used, which is an average of the P/B ratios for each species within this functional group (Froese and Pauly 2011).

4.16.3 Diet and Consumption

Small demersal fish feed on small invertebrates that occur as zooplankton or macrofauna (Froese and Pauly 2011). Many small demersal fish are **scavengers**. A Q/B of 7.96 year^{-1} was used, which is an average of the Q/B ratios for adults in this functional group (Froese and Pauly 2011).

4.16.4 Environmental Preferences

The small demersal fish functional group contains species with diverse habitat preferences, though most species in this group prefer shallow waters with weak currents (Green 1970, Dean et al. 2000). Some of the species, such as the saddleback gunnel, use cover offered by rocks and boulders. Others, such as the tadpole sculpin, prefer muddy/sandy substrates (Bulthuis 1996, MacDougall et al. 1999). Crescent gunnel, saddleback gunnel, Pacific staghorn sculpin, and three-spine stickleback are found in eelgrass habitat. Crescent and saddleback gunnel, buffalo, manacled, Pacific staghorn, padded, ribbed, and tidepool sculpin, northern spearnose, pygmy poacher, smooth alligatorfish, snake prickleback, and tubesnout are found in mud- and sandflat habitat. Three-spine stickleback and Pacific staghorn sculpin are found in salt marsh habitat (Archipelago Marine Research Ltd. 2014*a*, *b*, *c*). Environmental preferences for small demersal fish at Roberts Bank are shown (**Table 4-31**).

Table 4-31 Small Demersal Fish Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	2	Clay	1	Very low	2	Quiescent	1	Mud	1
Brackish	1	Shallow subtidal	2	Very fine sand	1	Low	2	Very low	1	Sand	1
Freshet	1	Moderate subtidal	1	Fine sand	1	Moderate	1	Low	1	Biofilm	0
Marine	1	Deep subtidal	1	Coarse sand	1	High	0	Moderate	1	Biomat	0
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	0
										Saltmarsh	1
										Grass	0
Source											
(Froese and Pauly 2011)		(Green 1970, Dean et al. 2000, Levings and Ong 2003, Froese and Pauly 2011)		(Limbaugh 1962, Nakamura 1970, Bulthuis 1996, MacDougall et al. 1999, Williams and Zedler 1999, Murphy et al. 2000, Richardson et al. 2000, Yoklavich et al. 2002, Johnson et al. 2008)		n/a		n/a		(Wingert and Miller 1979, Seliskar and Gallagher 1983, Dean et al. 2000, Murphy et al. 2000, Romanuk and Levings 2006, Archipelago Marine Research Ltd. 2014*a*, *b*, *c*, *d*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

4.17 STARRY FLOUNDER

4.17.1 Group Definition

Table 4-32 Species in the Starry Flounder Functional Group

Common Name	Scientific Name
Starry flounder	*Platichthys stellatus*

The starry flounder is a common flatfish widely distributed across the North Pacific which inhabits coastal waters to depths up to 90 m (Birtwell et al. 1993). Starry flounder migrate to very shallow water during the spawning season, which spans from mid-February to mid-April with a peak in March (Birtwell et al. 1993). In B.C., over 90% of the commercial catch of starry flounder is taken from the Strait of Georgia (Birtwell et al. 1993). In a review of marine food webs in California, starry flounder was stated to be an important prey item for seabirds and marine mammals (Leet et al. 2001). Starry flounder were selected as a focal species at Roberts Bank by the PC-TAG.

4.17.2 Biomass and Production

An average biomass of 0.2098 t/km^2 was estimated using data collected during field surveys conducted at Roberts Bank in 2012 and 2013 (Archipelago Marine Research Ltd. 2013*a*, *b*, *c*, *d*). A P/B of 0.40 year^{-1} was used (Froese and Pauly 2011).

4.17.3 Diet and Consumption

Juvenile starry flounder feed almost exclusively on harpacticoid copepods (McCall 1992). Adults feed on benthic and **infaunal** species such as bivalves (particularly clam siphons), worms, crabs, molluscs, echinoderms, and fish (Miller 1967, Leet et al. 2001). A Q/B value of 4.6 year^{-1} was used (Froese and Pauly 2011).

4.17.4 Environmental Preferences

Starry flounder reside in mud- and sandflats of shallow watered bays and estuaries (Leet et al. 2001). Starry flounder are also freshwater tolerant and are known to be present in freshwater sloughs of the lower Fraser River (Birtwell et al. 1993). Starry flounder prefer moderate to low water current velocities (Froese and Pauly 2011). This is especially true for juveniles, which are common at Roberts Bank. Starry flounder are abundant year-round in the shallow subtidal (0 - 25 m CD) sand- and mudflat habitat of Roberts Bank and have also been documented within eelgrass beds (Archipelago Marine Research Ltd. 2014*a*, *b*). Environmental preferences for starry flounder at Roberts Bank are shown (**Table 4-33**).

Table 4-33 Starry Flounder Environmental Preferences

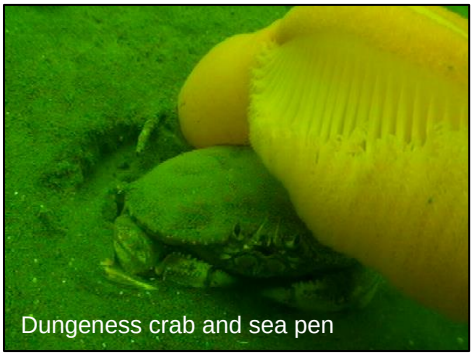
Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	1	Intertidal	1	Clay	1	Very low	1	Quiescent	1	Mud	2
Brackish	1	Shallow subtidal	1	Very fine sand	1	Low	1	Very low	1	Sand	2
Freshet	1	Moderate subtidal	1	Fine sand	1	Moderate	1	Low	1	Biofilm	0
Marine	1	Deep subtidal	1	Coarse sand	0	High	0	Moderate	1	Biomat	0
				Fine gravel	0					Rock	0
				Gravel	0					*Ulva*	0
				Cobbles/Boulders	0					Eelgrass	1
										Kelp	0
										Sea pens	0
										Saltmarsh	1
										Grass	0
Source											
(Birtwell et al. 1993, Froese and Pauly 2011)		(Froese and Pauly 2011)		(Moles and Norcross 1995)		n/a		n/a		(Seliskar and Gallagher 1983, Moles and Norcross 1995, Archipelago Marine Research Ltd. 2014*a, d*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

5.0 INVERTEBRATES

Roberts Bank supports a diverse community of invertebrates. Field studies at Roberts Bank for invertebrates included: juvenile Dungeness crab (*Metacarcinus magister*) surveys, ROV transects for subtidal invertebrates, intertidal shellfish sampling, and infaunal grab samples. Limited data was collected on **epifaunal grazers**, epifaunal omnivores, or epifaunal sessile **suspension feeders**. Dungeness crab population estimates were taken from a Roberts Bank population model (Hemmera 2014*c*). Biomass estimates where there was no survey data were collected from primary literature or models of the entire Strait of Georgia were used to develop parameter estimates.


Dungeness crab


Dungeness crab and sea pen


Infaunal bivalve


Polychaete

5.1 FUNCTIONAL GROUPS

The 13 functional groups of marine invertebrates were determined by their similarity in diet and life history. Bivalves, polychaetes, Dungeness crab and macrofauna were identified as focal groups by the PC-TAG, while sea pens were identified as a species of local importance during field surveys by Hemmera due to their habitat location.

1. Carnivorous zooplankton
2. Omnivorous and herbivorous zooplankton
3. Dungeness crab (adult)*
4. Epifaunal grazer
5. Epifaunal omnivore
6. Epifaunal sessile suspension feeder
7. Infaunal bivalve*
8. Jellyfish
9. Macrofauna*
10. Meiofauna
11. Polychaetes*
12. Orange sea pen
13. Shrimp

5.2 METHODS

In general, estimation of EwE model parameters followed methodology described in Section 1.1 Study Area. In addition, productivity of invertebrates functional groups was calculated using **Brey's algorithm** (Brey et al. 2010, Brey 2012). Brey's algorithm uses phylogenetically based self-learning to model the relationships between P/B and twenty easy-to-measure abiotic and biotic parameters in 1252 data sets of population production for macrobenthic populations in marine and freshwater habitats (Brey 2012). Body mass and water temperature provide the majority of explanatory power of the model. Using log-transformed data, the final predictive model estimates log(P/B) with reasonable accuracy and precision (r^2 = 0.801; residual mean square RMS = 0.083).

5.3 CARNIVOROUS ZOOPLANKTON

5.3.1 Group Definition

Table 5-1 Species in the Carnivorous Zooplankton Functional Group

Common Name	Scientific Name
Euphausiids	Euphausiidae
Other zooplankton species	

This group includes euphausiids (e.g., *Euphausia pacifica* and *Thysanoessa spp*.) and other large carnivorous zooplankton species (such as gammarid amphipods, hyperiid amphipods and chaetognaths).

5.3.2 Biomass and Production

No zooplankton samples were collected during field surveys conducted at Roberts Bank. A biomass of 29.7468 t/km^2 was estimated from a 20-year database on zooplankton sampling in the Strait of Georgia corrected for habitat availability (Mackas et al. 2013). A P/B of 7 year^{-1} was used (Preikshot 2007).

5.3.3 Diet and Consumption

Carnivorous zooplankton diet primarily consists of other carnivorous zooplankton, as well as **herbivorous** and **omnivorous** zooplankton (Hu 1978, Kearney et al. 2012). A Q/B of 20 year^{-1} was used (Beamish et al. 2001).

5.3.4 Environmental Preferences

There is a high degree of seasonality in the abundance and timing for zooplankton (Mackas et al. 2013). Average zooplankton dry weight biomass in the Strait of Georgia is high (9 t/km^2) and varies seasonally between a winter minimum (4 t/km^2) and a broad late-spring to autumn maximum (10 – 11 t/km^2) (Mackas et al. 2013). Slightly higher marine salinity (~32 psu) and nutrient load from increased upwelling events are associated with increases in zooplankton productivity. Winter wind mixing with moderate wave height is linked to increased zooplankton productivity (Mackas et al. 2013). Environmental preferences for carnivorous zooplankton at Roberts Bank are shown (**Table 5-2**).

Table 5-2 Carnivorous Zooplankton Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0	Intertidal	0-0.5	Clay	1	Very low	1	Quiescent	1	Mud	1
Brackish	0-0.5	Shallow subtidal	0.5-0.75	Very fine sand	1	Low	1	Very low	1	Sand	1
Freshet	1	Moderate subtidal	0.75-1	Fine sand	1	Moderate	1	Low	2	Biofilm	1
Marine	2	Deep subtidal	1	Coarse sand	1	High	1	Moderate	1	Biomat	1
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	1
										Saltmarsh	1
										Grass	0
Source											
(Dethier 2006, Mackas et al. 2013)		n/a		n/a		n/a		n/a		(Mackas et al. 2013)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 0.5 indicates species does not prefer habitat but does not actively avoid it, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

5.4 OMNIVOROUS AND HERBIVOROUS ZOOPLANKTON

5.4.1 Group Definition

Table 5-3 Species in the Omnivorous and Herbivorous Zooplankton Functional Group

Common Name	Scientific Name
Omnivorous/herbivorous zooplankton	*Neocalanus* spp., Pseudo *Calanus* spp., Calanus spp., etc.

This group is defined by pelagic zooplankton which primarily feed on phytoplankton.

5.4.2 Biomass and Production

A biomass estimate of 54.436t/km^2 was estimated using a 20-year retrospective of zooplankton sampling in the Strait of Georgia (Mackas et al. 2013). A P/B value of 24 year^{-1} was used based on estimated mortality of herbivorous zooplankton (Mackas et al. 2013).

5.4.3 Diet and Consumption

Diet information was gathered from primary literature (Ainsworth et al. 2008, Li 2012, Mackas et al. 2013). A Q/B of 70 year^{-1} was also used based upon Mackas et al. (2013).

5.4.4 Environmental Preferences

Herbivorous zooplankton are an ephemeral group driven by large scale environmental conditions and food availability with a strong seasonal component (Li 2012, Mackas et al. 2013). Zooplankton show a narrow preference for marine salinity and moderate wave exposure (Mackas et al. 2013). Environmental preferences for omnivorous and herbivorous zooplankton at Roberts Bank are shown (**Table 5-4**).

Table 5-4 Omnivorous and Herbivorous Zooplankton Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0	Intertidal	0-0.25	Clay	1	Very low	1	Quiescent	2	Mud	1
Brackish	0	Shallow subtidal	0.25-0.5	Very fine sand	1	Low	1	Very low	2	Sand	1
Freshet	0	Moderate subtidal	0.5-0.75	Fine sand	1	Moderate	1	Low	2	Biofilm	1
Marine	2	Deep subtidal	0.75-1	Coarse sand	1	High	1	Moderate	1	Biomat	1
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/ Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	1
										Saltmarsh	1
										Grass	0
Source											
(Mackas et al. 2013)		n/a		n/a		n/a		(Mackas et al. 2013)		(Kozloff and Price 1987)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 0.5 indicates species does not prefer habitat but does not actively avoid it, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

5.5 DUNGENESS CRAB

5.5.1 Group Definition

Table 5-5 Species in the Dungeness Crab Functional Group

Common Name	Scientific Name
Dungeness crab	*Cancer magister*

5.5.2 Biomass and Production

Adult male Dungeness crab biomass was estimated to be 2.2591 t/km^2. This estimate was derived from the mean legal crab biomass from prior and post commercial fishing estimates for fisheries management areas overlapping with the study area (Hemmera 2014*c*). The amount of crabs estimated in Area 29 (Lower Mainland and Sunshine Coast) ranged from a low of 272 t in 1991 to a high of 1,865 t in 2007. Sub-areas 29-6 and 29-7 (the area which contains Roberts Bank) ranged from 93 to 797 t and 20 to 105 t, respectively. These estimates were adjusted for percentage area of harvest for each sub-area and summed for a single mean adult male Dungeness biomass estimate for Roberts Bank. To estimate the the total adult biomass including females the biomass of fished males was doubled, increased by five percent to account for males not caught, and doubled to include an estimate for adult females. This results in an adult Dungeness crab biomass estimate of 4.631 t/km^2. P/B of 2.5 year^{-1} was used (Zhang et al. 2004).

5.5.3 Diet and Consumption

Adult Dungeness crabs are often found in sandy/silty substrates in bays and estuaries where they prey on bivalves, crustaceans, worms, and fish (Stevens et al. 1982, Dudas et al. 2005, Dunham et al. 2011). Juvenile crabs actively forage in **littoral** habitats where they consume bivalves (clams and mussels), small fish, molluscs, shrimp, and other crabs (Jensen and Asplen 1998, Holsman et al. 2003). A Q/B of 5 year^{-1} was used (Ainsworth 2006).

5.5.4 Environmental Preferences

Dungeness crabs are weak osmoregulators so it is energetically costly for them to stay in environments with rapid changes in salinity (Dunham et al. 2011). Adult Dungeness crabs inhabit substrates comprised of sand, mud or silt, and eelgrass beds. They occur from the low intertidal to depths of 230 m (Dunham et al. 2011). Females are relatively inactive during the winter; they seldom feed and remain buried in the bottom sediment much of the time. When incubating their eggs, females prefer sandy substrate where there is moderate current (Dunham et al. 2011). Crabs usually live five to eight years, but in intensive fisheries nearly all legal width crabs are removed during a fishing season. Males rarely grow larger than 215 mm, and females 170 mm **carapace** width (Butler 1960, 1961).

In B.C., Dungeness crab eggs hatch in late winter/early spring depending on the area and water temperature. They emerge first as pre-zoeae but moult within an hour to the first zoea stage (Dunham et al. 2011). Predation is a key mechanism controlling juvenile populations. The population density of many crustaceans is correlated with three-dimensional structures that provide refuge (Heck and Wilson 1987, Doty et al. 1990, Dumbauld et al. 1993). Shell middens and vegetation such as *Ulva* mounds and eelgrass harbour greater densities of juvenile crabs than less complex habitats (Dinnel et al. 1986). Studies have shown that a minimum or threshold density of vegetation is required to reduce predation (Stevens and Armstrong 1985, Heck and Thoman 1991, Dumbauld et al. 1993). 0+ age crabs are nearly absent in spring when eelgrass cover is less than 40% (McMillan et al. 1995).

Sub-adults require littoral habitats for foraging. In estuaries, juveniles inhabit bivalve and eelgrass habitat (Dumbauld et al. 1993, Fernandez et al. 1993). Growth of **instars** is rapid throughout the spring/summer but is slower for the remainder of the year. Generally, juvenile crabs less than 70 mm carapace width remain in lower intertidal or shallow subtidal waters, and overwinter in these habitats (Dunham et al. 2011). Environmental preferences for Dungeness crab at Roberts Bank are shown (**Table 5-6**).

Table 5-6 Dungeness Crab Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0	Intertidal	1	Clay	1	Very low	1	Quiescent	2	Mud	1
Brackish	0	Shallow subtidal	2	Very fine sand	1	Low	1	Very low	2	Sand	1
Freshet	0.5	Moderate subtidal	2	Fine sand	1	Moderate	2	Low	1	Biofilm	1
Marine	2	Deep subtidal	2	Coarse sand	1	High	0	Moderate	0.5	Biomat	1
				Fine gravel	0.5					Rock	0
				Gravel	0.5					*Ulva*	1
				Cobbles/ Boulders	0					Eelgrass	1
										Kelp	0.5
										Sea pens	1
										Saltmarsh	0
										Grass	0
Source											
(Curtis and McGaw 2008)		(Stone and O'Clair 2001, Holsman et al. 2006, Dunham et al. 2011)		(Dethier 2006)		(Dethier 2006)		(Dethier 2006)		(Dinnel et al. 1986)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 0.5 indicates species does not prefer habitat but does not actively avoid it, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

5.6 EPIFAUNAL GRAZER

5.6.1 Group Definition

Table 5-7 Species in the Epifaunal Grazer Functional Group

Common Name	Scientific Name
Kelp isopod	*Idotea wosnesenskii*
Sea urchin	*Strongylocentrotus* spp.
Limpet	*Tectura* spp.
Battilaria spp.	*Battilaria* spp.
Black chiton	*Katharina tunicata*
Brittle stars	*Ophiuroididae* spp.
Cancellate gairysnail	*Trichotropis cancellata*
Giant sea cucumber	*Parastichopus californicus*
Japanese false cerith	*Batillaria attramentaria*
Lined chiton	*Tonicella lineata*
Orange sea cucumber	*Cucamaria* sp.
Pacific wingfoot snail	*Gastropteron pacificum*
Periwinkle	*Littorina scutulata*
Sand dollar	*Dendraster exentricus*
Top snail	Trochidae

The epifaunal grazer group is a broad taxonomic group of benthic organisms that are generally secondary consumers and/or **detritivores**.

5.6.2 Biomass and Production

The biomass estimate of 15.3111 t/km^2 was based on the epibenthic invertebrate group in the Hecate Strait model (Beattie 2001). A P/B of 1.448 year^{-1} was used from the estimate for the benthic invertebrate group in the Hecate Strait model (Beattie 2001).

5.6.3 Diet and Consumption

The majority of epifaunal grazers consume benthic algae and biofilm, with the exception of the sea cucumbers and sand dollars (Kozloff and Price 1987). These are both echinoderms and have a different feeding mechanism. Sea cucumbers are **deposit feeders** that consume **detritus**, from the seafloor and water column with ciliated tentacles. The sand dollar is a filter feeding organism that feeds on detritus and phytoplankton at the benthic water column interface (Kozloff and Price 1987). A P/Q value of 0.2 year^{-1} was used (Ainsworth 2006).

5.6.4 Environmental Preferences

This group includes species that are both subtidal and intertidal and does not have any significant seasonal trends (Kozloff and Price 1987). Intertidal organisms live in a dynamic and stressful environment, and are subject to large changes in temperature, waves, and food availability. Environmental preferences for epifaunal grazers at Roberts Bank are shown (**Table 5-8**).

Table 5-8 Epifaunal Grazer Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0	Intertidal	2	Clay	0	Very low	2	Quiescent	1	Mud	0
Brackish	0	Shallow subtidal	2	Very fine sand	0	Low	2	Very low	1	Sand	0
Freshet	1	Moderate subtidal	1	Fine sand	0	Moderate	1	Low	1	Biofilm	1
Marine	2	Deep subtidal	1	Coarse sand	0	High	0	Moderate	1	Biomat	1
				Fine gravel	1					Rock	1
				Gravel	2					*Ulva*	1
				Cobbles/Boulders	2					Eelgrass	1
										Kelp	1
										Sea pens	0
										Saltmarsh	1
										Grass	0
Source											
(Kozloff and Price 1987)		(Kozloff and Price 1987)		(Kozloff and Price 1987)		(Kozloff and Price 1987)		(Kozloff and Price 1987)		(Kozloff and Price 1987)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 0.5 indicates species does not prefer habitat but does not actively avoid it, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

5.7 EPIFAUNAL OMNIVORE

5.7.1 Group Definition

Table 5-9 Species in the Epifaunal Omnivore Functional Group

Common Name	Scientific Name
Barnacle nudibranch	*Onchidoris bilamellata*
Blood star	*Henricia leviuscula*
Brown horned dorid	*Acanthodoris brunnea*
Channeled dogwinkle	*Nucella canaliculata*
Frilled dogwinkle	*Nucella lamellose*
Frosted nudibranch	*Dirona albolineata*
Furrowed rock crab	*Romaleon branneri*
Giant Pacific octopus	*Enteroctopus dofleini*
Giant pink starfish	*Pisaster brevispinus*
Golden dirona	*Dirona pellucida*
Graceful crab	*Metacarcinus gracilis*
Graceful decorator crab	*Oregonia gracilis*
Green shore crab	*Hemigrapsus oregonensis*
Helmut crab	*Telmessus cheiragonus*
Hermit crab	*Pagurus* spp.
Kelp crab	*Pugettia product*
Leather star	*Dermasterias imbricate*
Mottled star	*Evasterias troschelii*
Mud star	*Luidia foliolata*
Ochre star	*Pisaster ochraceus*
Opalescent nudibranch	*Hermissenda crassicornis*
Pacific lyre crab	*Hyas lyratus*
Purple shore crab	*Hemigrapsus nudas*
Red gilled nudibranch	*Flabellina verrucosa*
Red rock crab	*Cancer productus*
Setose hermit crab	*Pagurus setosus*
Shaggy dovesnail	*Astyris gausapata*
Stubby squid	*Rossia pacifica*
Sun star	*Crossaster papposus*
Sunflower seastar	*Pycnopodia helianthoides*
Umbrella crab (syn. Sitka crab)	*Cryptolithodes sitchensis*
Whelk	Gastropoda
Yellow tip dorid	*Acanthodoris nanaimoensis*

The epifaunal omnivore functional group contains mobile invertebrates larger than 0.05 m that live on or near the seafloor, such as small crabs, sea stars, and nudibranchs.

5.7.2 Biomass and Production

The marine vegetation surveys, which took place along the rip-rap of the causeway in Roberts Bank, counted snails, barnacles, mussels, and shore crabs but did not include subtidal sampling. The estimated biomass of 1.929 t/km^2 and P/B of 3.5 year^{-1} were both based on estimates for the small crabs in the Hecate Strait model (Beattie 2001).

5.7.3 Diet and Consumption

Sea stars are generalist predators and 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 (Kozloff and Price 1987). Nudibranchs are predatory and feed on hydroids, cnidarians, and other nudibranchs (Kozloff and Price 1987). Whelks are a specialist predator that feed primarily on barnacles. A Q/B of 14 year^{-1} was used in the model based on the small crab group estimated in the Hecate Strait model (Ainsworth 2006).

5.7.4 Environmental Preferences

There is no significant seasonality with most of these subtidal invertebrates. Environmental preferences for epifaunal omnivores at Roberts Bank are shown (**Table 5-10**).

Table 5-10 Epifaunal Omnivore Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0	Intertidal	1	Clay	0	Very low	2	Quiescent	2	Mud	0.5
Brackish	0	Shallow subtidal	1	Very fine sand	0	Low	2	Very low	1	Sand	0.5
Freshet	1	Moderate subtidal	1	Fine sand	1	Moderate	1	Low	1.5	Biofilm	1
Marine	2	Deep subtidal	1	Coarse sand	1	High	1	Moderate	1.5	Biomat	1
				Fine gravel	2					Rock	1
				Gravel	2					*Ulva*	1
				Cobbles/ Boulders	2					Eelgra ss	1
										Kelp	1
										Sea pens	1
										Saltma rsh	0
										Grass	0
Source											
(Kozloff and Price 1987)		(Kozloff and Price 1987)		(Kozloff and Price 1987)		(Kozloff and Price 1987)		(Kozloff and Price 1987)		(Kozloff and Price 1987)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 0.5 indicates species does not prefer habitat but does not actively avoid it, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

5.8 EPIFAUNAL SESSILE SUSPENSION FEEDER

5.8.1 Group Definition

Table 5-11 Species in the Epifaunal Sessile Suspension Feeder Functional Group

Common Name	Scientific Name
Acorn barnacle	*Balanus glandula*
Blue mussel	*Mytilus spp*.
Breadcrumb sponge	*Halichondria panicea*
Broad-base tunicate	*Cnemidocarpa finmarkiensis*
Bryozoan	Bryozoa
Calcareous tubeworm	Serpulidae
Small acorn barnacle	*Chthamalus dalli*
Hairy tunicate	*Boltenia villosa*
Hydroids	Hydrozoa
Jingle shell	*Anomia simplex*

Common Name	Scientific Name
Other tubeworms	Polychaeta
Pacific oyster	*Crassostrea gigas*
Painted anemone	*Urticina crassicornis*
Giant plumose anemone	*Metridium farcimen*
Short plumose anemone	*Metridium senile*

The epifaunal sessile suspension feeder functional group is a mix of subtidal and intertidal, colonial and non-colonial organisms.

5.8.2 Biomass and Production

A biomass estimate of 0.8955 t/km^2 was calculated from marine vegetation surveys that collected abundance data on intertidal invertebrates (Hemmera 2014*d*). Abundance data were converted to biomass estimates using literature and field values for mean weights of each species (Marchinko and Palmer 2003, Hemmera 2014*e*). Species-specific biomass estimates were summed for the functional group and weighted by availability of rocky habitats across the study area. Epifaunal sessile prefer hard substrate. A P/B of 1.71 year^{-1} was calculated using Brey's productivity **phylogenetically**-based algorithm assuming 23 joules/mg as a mass input (Brey et al. 2010).

5.8.3 Diet and Consumption

Epifaunal sessile suspension feeder diet was compiled from published literature and web-based resources (Kozloff and Price 1987, Marchinko and Palmer 2003, Lidgard 2008). Phytoplankton, zooplankton, and detritus dominate filter feeder diet. A Q/B of 22.2 year^{-1} was used (Ainsworth 2006).

5.8.4 Environmental Preferences

There is no seasonal migration or trends though reproduction. Recruitment is seasonal (Kozloff and Price 1987). Environmental preferences for epifaunal sessile suspension feeders at Roberts Bank are shown (**Table 5-12**).

Table 5-12 Epifaunal Sessile Suspension Feeder Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0	Intertidal	2	Clay	0	Very low	1	Quiescent	1	Mud	1
Brackish	0.5	Shallow subtidal	2	Very fine sand	0	Low	1	Very low	1	Sand	1
Freshet	0.5	Moderate subtidal	1	Fine sand	0	Moderate	1	Low	2	Biofilm	0
Marine	2	Deep subtidal	1	Coarse sand	1	High	1	Moderate	2	Biomat	0
				Fine gravel	1					Rock	1
				Gravel	2					*Ulva*	0
				Cobbles/ Boulders	2					Eelgrass	1
										Kelp	1
										Sea pens	0
										Saltmarsh	0
										Grass	0
Source											
(Pauley et al. 1989, Dethier 2006)		(Kozloff and Price 1987)		(Kozloff and Price 1987)		(Pauley et al. 1989, Dethier 2006)		(Kozloff and Price 1987)		(Kozloff and Price 1987)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 0.5 indicates species does not prefer habitat but does not actively avoid it, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

5.9 INFAUNAL BIVALVE

5.9.1 Group Definition

Table 5-13 Species in the Infaunal Bivalve Functional Group

Common Name	Scientific Name
Butter clam	*Saxidomus gigantean*
Cockles	*Clinocardia* spp.
Horse clam	*Tresus capax*
Horse clam	*Tresus nuttallii*
Littleneck clam	*Protothaca staminea*
Macoma clam	*Macoma* sp.
Manila clam	*Venerupis philippinarum*
Swimming scallop	*Chlamys hastata*
Venus clam	*Nutricola tantilla*

The infaunal bivalve functional group was identified as a focal group by the PC-TAG and includes the most common ecologically and culturally significant bivalves. Bivalves include clams, cockles, mussels, and scallops. They are characterised by: (i) a calcium carbonate shell consisting of two hinged valves attached by a ligament; (ii) a laterally compressed body (enclosed within the shell); and (iii) modified gills called ctenidia (used for feeding and breathing). Most bivalves are filter feeders, sieving suspended food particles out of the water by passing the water over their gills (Kozloff and Price 1987, Dethier 2006).

5.9.2 Biomass and Production

Biomass estimates for the infaunal bivalve group was calculated using field survey estimates of mean abundance per area multiplied by the average wet weight of an individual and extrapolated to available habitat at Roberts Bank. A weighted mean biomass of 120.7443 t/km^2 was estimated for the study area by habitat type for all bivalves in this group. A P/B of 2.059 year^{-1} was used (Harvey et al. 2011).

5.9.3 Diet and Consumption

This functional group is primarily filter feeders though the bivalve *Macoma* sp. is a deposit feeder (Kozloff and Price 1987, Ward et al. 2003, Dethier 2006). These species feed primarily on phytoplankton and detritus from the water column and seafloor interface. A Q/B of 6.863 year^{-1} was estimated by Harvey et al. (2010).

5.9.4 Environmental Preferences

The Infaunal bivalves functional group has broad environmental tolerance due to its diversity, though there is a general preference for soft to mixed sediment with some gravel content (Dethier 2006). Infaunal bivalve species are primarily found in the intertidal and shallow subtidal, and most species show optimal growth where there is moderate to high bottom current (Dethier 2006). Adult littleneck clams can tolerate low salinities, but prefer marine conditions of 24 to 31 psu (Dethier 2006). There is no significant seasonality for this group at Roberts Bank. Environmental preferences for infaunal bivalves at Roberts Bank are shown (**Table 5-14**).

Table 5-14 Infaunal Bivalve Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0	Intertidal	2	Clay	1	Very low	0	Quiescent	1	Mud	1
Brackish	0.5	Shallow subtidal	2	Very fine sand	1	Low	1	Very low	1	Sand	1
Freshet	1	Moderate subtidal	1	Fine sand	1	Moderate	1	Low	2	Biofilm	1
Marine	2	Deep Subtidal	1	Coarse sand	1	High	2	Moderate	2	Biomat	1
				Fine gravel	0.5					Rock	0
				Gravel	0.5					*Ulva*	0
				Cobbles/ Boulders	0					Eelgrass	1
										Kelp	0
										Sea pens	0
										Saltmarsh	0
										Grass	0
Source											
(Kozloff and Price 1987, Dethier 2006)		(Kozloff and Price 1987, Dethier 2006)		(Rodnick and Li 1983, Kozloff and Price 1987)		(Rodnick and Li 1983, Kozloff and Price 1987)		(Kozloff and Price 1987, Dethier 2006)		(Kozloff and Price 1987, Dethier 2006)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 0.5 indicates species does not prefer habitat but does not actively avoid it, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

5.10 JELLYFISH

5.10.1 Group Definition

Table 5-15 Species in the Jellyfish Functional Group

Common Name	*Species Name*
Gelatinous zooplankton	Cnidaria, Ctenophora, Appendicularia, etc.
Jellyfish	Scyphozoa
Sea gooseberry	*Pleurobrachia bachei*

The jellyfish group includes all cnidarian medusa, ctenophores, salps or other larvaceans.

5.10.2 Biomass and Production

The biomass of jellyfish was estimated to be 10.9885 t/km^2 based on data reported for jellyfishes in the Strait of Georgia (Mackas et al. 2013). Their dry weight estimates were converted to biomass by assuming dry weight is 4.2% of wet weight (Larson 1986). Total biomass value was weighted to available shallow subtidal and subtidal habitat at Roberts Bank. A P/B of 9.6 year^{-1} was derived from growth rates of moon jellies (*Aurelia aurita*) of 0.053 to 0.15 day^{-1} at 5 to 16.5°C (Hansson 1997).

5.10.3 Diet and Consumption

Gelatinous zooplankton diet is composed primarily of phytoplankton (81%), herbivorous zooplankton, and macrofauna (Mackas et al. 2013). A Q/B of 13 year^{-1} was used from the model of Preikshot et al. (2012) which was derived from reported energetics of medusa in the Black Sea by Matishov and Denisov (1999).

5.10.4 Environmental Preferences

In general, the best single indicator of the larger zooplankton community change is the spring extratropical-based Southern Oscillation Index, with an one-year lag (Li 2012). At Roberts Bank, peak flow of the Fraser River is a good local indicator of zooplankton change (Li 2012). Jellyfish presence and abundance is ephemeral and related to seasonally dynamic environmental conditions and food availability. Temperature and salinity changes driven by El Niño Southern and Pacific Decadal Oscillations play important roles in the appearance and intensity of plankton blooms (Mackas et al. 2013). Environmental preferences for jellyfish at Roberts Bank are shown (**Table 5-16**).

Table 5-16 Jellyfish Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0	Intertidal	0-0.25	Clay	1	Very low	1	Quiescent	1	Mud	1
Brackish	0	Shallow subtidal	0.25-0.5	Very fine sand	1	Low	1	Very low	2	Sand	1
Freshet	0.5	Mid subtidal	0.5-0.75	Fine sand	1	Moderate	1	Low	1	Biofilm	1
Marine	2	Deep subtidal	0.75-1	Coarse sand	1	High	1	Moderate	1	Biomat	1
				Fine gravel	1					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/ Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	1
										Saltmarsh	1
										Grass	1
Source											
(Mills 1984, Mackas et al. 2013)		n/a		n/a		n/a		(Li 2012, Mackas et al. 2013)		n/a	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 0.5 indicates species does not prefer habitat but does not actively avoid it, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

5.11 MACROFAUNA

5.11.1 Group Definition

Table 5-17 Species in the Macrofauna Functional Group

Common Name	Scientific Name
Mites and ticks - no wings	Acari
Amphipod (Caprellid)	Caprellidae
Amphipod (Gammarid)	Gammaridae
Biting midges - wings	Diptera - Ceratopogonidae
Non-biting midges - wings	Chironomidae
Cladocerans	Cladocera
Cyclopoid copepod	Cyclopoida
Collembola (no wings)	Collembola
Harpacticoid copepod	Harpacticoida
Cumaceans	Cumacea
Flatworms	Platyhelminthes
Gnathostomulids	Gnathostomulida
Leeches	Hirudinea
Kinorhynchs	Kinorhynchia
Insects (Megaloptera - wings)	Megaloptera (has wings)
Mysids	Mysidacea
Nematodes	Nematoda
Ribbon worms	Nemertea
Oligochaetes	Oligochaeta
Ostracods	Ostracoda
Phronoids	Phronoid
Insects (Plecoptera - stoneflies)	Plecoptera
Pycnogonids	Pycnogonida
Sipunculids	Sipuncula
Tanaids	Tanaidacea
Tardigrades	Tardigrada

The macrofauna functional group was identified by the PC-TAG as a focal group. For this study, macrofauna was defined as being infaunal organisms that are greater than 500 µm and less than 1 mm. These organisms are important in the diets of migratory and overwintering shorebirds and juvenile salmonids.

5.11.2 Biomass and Production

A biomass of 50.2645 t/km^2 was estimated using data collected during field surveys at Roberts Bank (Hemmera 2014*f*). A P/B of 4 year^{-1} was used (Ainsworth 2006).

5.11.3 Diet and Consumption

Diets of the group was primarily determined to be primary producers, herbivorous zooplankton, and detritus based on the group as a whole (Snelgrove 1998, Ferraro and Cole 2007) subcomponent species gammerid and caprellid amphipods (Cruz-Rivera and Hay 2000, Alarcón-Ortega et al. 2012) and tanaids (Stoner 1983:83). Diet composition information is mainly specific to only a few of the taxa comprising this functional group (e.g., amphipods). Diets are predominately made up of detritus, phytoplankton, and meiofauna (81%). A Q/B of 13.333 year^{-1} was calculated by the model assuming a P/Q value of 0.3 year^{-1}(Ainsworth 2006).

5.11.4 Environmental Preferences

Environmental preferences for this functional group are broad and were extrapolated from site-specific data collected in 2012 and 2013 (Hemmera 2014*f*). Macrofauna community structure is influenced by the structure of the sediment though the group will be found in a wide range of sediment types (Somerfield et al. 1995, Ferraro and Cole 2007). While there is a difference in species assemblages between muddy and sandy habitats, there are no consistent differences in diversity (Somerfield et al. 1995). Sediment size is strongly correlated with bottom current velocities and wave energy. Macrofauna habitat preferences are broadly driven by sediment size and total organic carbon. Macrofauna have a similar broad tolerance for water movement parameters (Ferraro and Cole 2007). Literature-derived environmental preferences for macrofauna at Roberts Bank are shown (**Table 5-18**). Project area derived preferences curves are presented in Roberts Bank Ecosystem Model Development and Key Run Report (ESSA 2014*a*).

Table 5-18 Macrofauna Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0.5	Intertidal	2	Clay	1	Very low	1	Quiescent	1	Mud	1
Brackish	0.5	Shallow subtidal	2	Very fine sand	1	Low	2	Very low	0.5	Sand	1
Freshet	1	Moderate subtidal	1	Fine sand	1	Moderate	1	Low	2	Biofilm	1
Marine	2	Deep subtidal	1	Coarse sand	2	High	0	Moderate	0.5	Biomat	1
				Fine gravel	2					Rock	0.5
				Gravel	1					*Ulva*	1
				Cobbles/ Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	1
										Saltmarsh	0.5
										Grass	0
Source											
(Fenchel 1978)		(Fenchel 1978, Hemmera 2014*f*)		(Fenchel 1978, Somerfield et al. 1995, Hemmera 2014*f*)		(Kozloff and Price 1987, Hemmera 2014*f*)		(Hemmera 2014*f*)		(Kozloff and Price 1987, Hemmera 2014*f*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 0.5 indicates species does not prefer habitat but does not actively avoid it, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

5.12 MEIOFAUNA

5.12.1 Group Definition

Table 5-19 Species in the Meiofauna Functional Group

Common Name	Scientific Name
Mites and ticks - no wings	Acari
Amphipod (Caprellid)	Caprellidae
Amphipod (Gammarid)	Gammaridae
Biting midges - wings	Diptera - Ceratopogonidae
Non-biting midges - wings	Chironomidae
Cladocerans	Cladocera
Copepod	Clyclopoida
Collembola (no wings)	Collembola (no wings)
Harpacticoid copepods	Harpacticoida
Cumaceans	Cumacea
Flatworms	Platyhelminthes
Gnathostomulids	Gnathostomulida
Leeches	Hirudinea
Kinorhynchs	Kinorhynchia
Insects (Megaloptera - wings)	Megaloptera (has wings)
Mysids	Mysidacea
Nematodes	Nematoda
Ribbon worms	Nemertea
Oligochaetes	Oligochaeta
Ostracods	Ostracoda
Phronoids	Phronoidae
Insects (Plecoptera - stoneflies)	Plecoptera
Pycnogonids	Pycnogonida
Sipunculids	Sipuncula
Tanaids	Tanaidacea
Tardigrades	Tardigrada

Meiofauna is defined as infaunal organisms that are greater than 63 µm and less than 500 µm. This functional group was determined through field surveys conducted at Roberts Bank.

5.12.2 Biomass and Production

A biomass estimate of 29.1069 t/km^2 was based on field samples from Roberts Bank (Hemmera 2014*f*). Estimates of biomass per area were weighted by the available habitat across the study area. A P/B of 8 year^{-1} was used (Ainsworth 2006).

5.12.3 Diet and Consumption

This functional group is made up of large phylogenetic groupings. Diets of the group was primarily determined to be primary producers and detritus based on the group in general (Fenchel 1978) and copepods more specifically (Kleppel 1993, Buffan-Dubau et al. 1996, Gasparini and Castelt 1997, De Troch et al. 2005) Diets are predominately (90%) made up of detritus and phytoplankton, with some meiofauna eating other meiofauna (~10%). A Q/B of 14.9 year^{-1} was calculated by the model using a P/Q value of 0.2 from Ainsworth (2006).

5.12.4 Environmental Preferences

Meiofauna is a broad group of species. Environmental preferences for this functional group were extrapolated from site-specific data collected in 2012 and 2013 (Hemmera 2014*f*). Meiofauna are found in well sorted sediments with median grain sizes above 100 microns at the coarser end of very fine sand (Fenchel 1978). Meiofauna community structure is influenced by sediment structure, though the group is found in a wide range of sediment types (Somerfield et al. 1995, Ferraro and Cole 2007). While there is a difference in species assemblages between muddy and sandy habitats, there is no consistent differences in diversity (Somerfield et al. 1995). Sediment size is strongly correlated with bottom current velocities and wave energy, and macrofauna preferences are broadly driven by sediment size and total organic carbon. As a result, macrofauna have a similar broad tolerance for water movement parameters (Ferraro and Cole 2007). Literature based environmental preferences for meiofauna at Roberts Bank are shown (**Table 5-20**); while Project area derived preferences curves are presented in Roberts Bank Ecosystem Model Development and Key Run Report (ESSA 2014*a*).

Table 5-20 Meiofauna Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0	Intertidal	1	Clay	1	Very low	2	Quiescent	1	Mud	1
Brackish	0	Shallow subtidal	1	Very fine sand	1	Low	2	Very low	1	Sand	1
Freshet	1	Moderate subtidal	1	Fine sand	1	Moderate	1	Low	1	Biofilm	1
Marine	2	Deep subtidal	1	Coarse sand	1	High	0	Moderate	1	Biomat	1
				Fine gravel	0.75					Rock	0.5
				Gravel	0.5					*Ulva*	1
				Cobbles/ Boulders	0.5					Eelgrass	1
										Kelp	1
										Sea pens	1
										Saltmarsh	0.5
										Grass	0
Source											
(Kozloff and Price 1987, Hemmera 2014*f*)		(Hemmera 2014*f*)		n/a				(Hemmera 2014*f*)		(Kozloff and Price 1987, Hemmera 2014*f*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 0.5 indicates species does not prefer habitat but does not actively avoid it, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

5.13 POLYCHAETES

5.13.1 Group Definition

Table 5-21 Species in the Polychaetes Functional Group

Common Name	Scientific Name
Polychaetes	Polychaeta

Polychaetes were identified as a focal group by the PC-TAG as an important environmental indicator species (Wilson et al. 1994). They contribute significantly to the diets of larger invertebrates, fish and birds at Roberts Bank.

5.13.2 Biomass and Production

A biomass of 20.15 t/km^2 was estimated from field data from Roberts Bank (Hemmera 2014*f*). A P/B of 5 year^{-1} (Holsman et al. 2003) was used based on data reported for the polychaete *Pectinaria californiensis* in Puget Sound (Nichols 1975).

5.13.3 Diet and Consumption

The polychaete group is broad, which is reflected in the diet matrix (**Appendix A**). The diet estimate references for this group were only broadly representative of the variety of species in this group (Fauchald and Jumars 1979, Braeckman et al. 2012). A Q/B of 25 year^{-1} was calculated by the model assuming a P/Q of 0.2 year^{-1}**,** equivalent to that of epifauna.

5.13.4 Environmental Preferences

The polychaetes group has broad environmental preferences. They are one of most common infaunal groups and while they are primarily found in soft sediment habitats, they can also be found throughout the marine environment (Bertness and Hay 2001). They have a relatively high tolerance for fluctuations of salinity allowing them to be successful in marine, brackish, and freshwater environments (Bertness and Hay 2001). A number of different feeding strategies such as deposit feeding, filter feeding, as well as primary and secondary consumption allow this group to exploit numerous habitats with varying current and wave exposure regimes (Bertness and Hay 2001). Literature based environmental preferences for polychaetes at Roberts Bank are shown (**Table 5-22**); while Project area derived preferences curves are presented in Roberts Bank Ecosystem Model Development and Key Run Report (ESSA 2014*a*).

Table 5-22 Polychaetes Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0	Intertidal	2	Clay	1	Very low	1	Quiescent	2	Mud	1
Brackish	1	Shallow subtidal	2	Very fine sand	1	Low	2	Very low	2	Sand	1
Freshet	2	Moderate subtidal	1	Fine sand	2	Moderate	1	Low	1	Biofilm	1
Marine	2	Deep subtidal	1	Coarse sand	2	High	0	Moderate	1	Biomat	1
				Fine gravel	1					Rock	0
				Gravel	1					*Ulva*	1
				Cobbles/Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	1
										Saltmarsh	1
										Grass	0
Source											
(Hemmera 2014*f*)		(Fenchel 1978)		(Moreira et al. 2006, Hemmera 2014*f*)		(Hemmera 2014*f*)		(Hemmera 2014*f*)		(Hemmera 2014*f*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

5.14 ORANGE SEA PEN

5.14.1 Group Definition

Table 5-23 Species in the Orange Sea Pen Functional Group

Common Name	Scientific Name
Orange sea pen	*Ptilosarcus gurneyi*

The current sea pen distribution overlaps with the proposed RBT2 footprint. Sea pens are often found in areas dominated by vigorous tidal flows and offshore currents (Kozloff and Price 1987, Best 1988).

5.14.2 Biomass and Production

Sea pen biomass was estimated at 0.1409 t/km^2 by using polygon maps of sea pen densities created from ROV surveys at Roberts Bank with estimated densities for sparse and dense sea pen areas (**Figure 1**). Biomass was generated by converting abundance per square metre to total abundance per area for each of sparse and dense areas, then by an estimated mean individual dry weight (Batie 1971). The mean dry weight was converted to wet weight using the conversion factor of 19.3 for sea cucumbers (Ricciardi and Bourget 1999). A P/B of 1.2 year^{-1} was estimated using Brey's productivity algorithm where sea pens were assumed to have 23 kJ/mg with a mean dry weight of 0.5 g per individual (Brey et al. 2010, Brey 2012).

5.14.3 Diet and Consumption

Sea pens are filter feeders and consume both phytoplankton and zooplankton (Best 1988). Water current flow is likely important in regulating food availability (Best 1988). A Q/B of 6 year^{-1} was calculated by the model assuming P/Q of 0.2 year^{-1} equivalent to that of epifauna.

5.14.4 Environmental Preferences

This functional group is dependent on specific substrate requirements for habitat, and water current flow for feeding efficiencies. Sea pens show a preference for coarse sand to fine gravel, but can be found in sediment that is at the extreme end of these two grain size classifications (Hemmera and Archipelago 2014). Sea pens are filter feeders that require moderate to strong current and wave mixing of the water column to feed efficiently (Best 1988). Environmental preferences for orange sea pens at Roberts Bank are shown (

Table 5-24). The sea pen mapping polygons were also used to derive Project area environmental preferences as frequency histograms.

Table 5-24 Orange Sea Pen Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0	Intertidal	0	Clay	0	Very low	0	Quiescent	0	Mud	0
Brackish	0	Shallow subtidal	1	Very fine sand	0	Low	2	Very low	0	Sand	1
Freshet	0	Moderate subtidal	2	Fine sand	1	Moderate	2	Low	1	Biofilm	0
Marine	2	Deep subtidal	2	Coarse sand	2	High	1	Moderate	1	Biomat	0
				Fine gravel	2					Rock	0
				Gravel	0					*Ulva*	0
				Cobbles/ Boulders	0					Eelgrass	0
										Kelp	0
										Sea pens	1
										Saltmarsh	0
										Grass	0
Source											
(Hemmera and Archipelago 2014)		(Shimek 2011, Hemmera and Archipelago 2014)		(Best 1988, Shimek 2011, Hemmera and Archipelago 2014)		(Best 1988, Hemmera and Archipelago 2014)		(Hemmera and Archipelago 2014)		(Hemmera and Archipelago 2014)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

5.15 SHRIMP

5.15.1 Group Definition

Table 5-25 Species in the Shrimp Functional Group

Common Name	Scientific Name
Dana's blade shrimp	*Spirontocaris lamellicornis*
Dock shrimp	*Pandalus danae*
Ghost shrimp	*Neotrypaea califoriensis*
Herdman coastal shrimp	*Heptacarpus herdmani*
Horned shrimp	*Paracragnon echinata*
Shrimp	Decapoda
Slender coastal shrimp	*Heptacarpus tenuissimus*
Spot prawn	*Pandalus platyceros*
Stout coastal shrimp	*Heptacarpus brevirostris*

This group is made up of a number of coastal small shrimp and larger commercially and recreationally important prawn (Pandalidae) species.

5.15.2 Biomass and Production

There are no direct abundance estimates for shrimp from the field program so proxy species were used to estimate biomass. The shrimp biomass estimate of 0.5 t/km^2 was taken from a Strait of Georgia model based on penaeid shrimp species (Preikshot et al. 2012), which have been scaled to the study area. A P/B of 2.4 year^{-1} was calculated based on data from southwestern Vancouver Island (Beattie 2001). Species in this functional group, such as the spot prawn, sustain commercial, recreational and Aboriginal fisheries.

5.15.3 Diet and Consumption

Diet for this group is dominated by detritus, macrofauna, and herbivorous zooplankton (Dunham and Boutillier 2001). A Q/B of 9.67 year^{-1} was estimated by the model, assuming a P/Q value of 0.25 (Ainsworth 2006).

5.15.4 Environmental Preferences

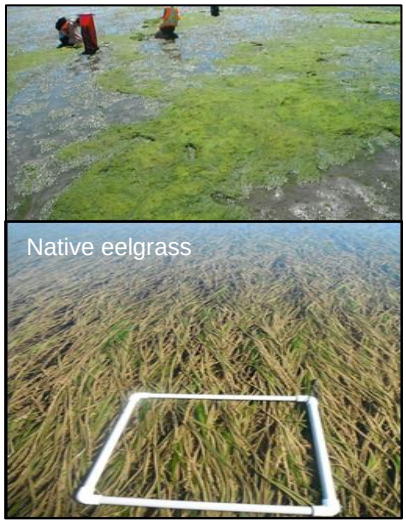
There is no significant seasonality or migration with this functional group. Shrimp have a preference for soft sediments with low to moderate current velocities (Dunham and Boutillier 2001). They can be found at a range of depths but are more abundant from the moderate subtidal to the deeper subtidal areas which is dominated by marine salinities (Dunham and Boutillier 2001). Environmental preferences for shrimp at Roberts Bank are shown (**Table 5-26**).

Table 5-26 Shrimp Environmental Preferences

Salinity		Depth		Sediment		Bottom Current		Exposure		Habitat	
Freshwater	0	Intertidal	0-1	Clay	1	Very low	0	Quiescent	1	Mud	1
Brackish	0	Shallow subtidal	1	Very fine sand	2	Low	2	Very low	1	Sand	1
Freshet	0.5	Moderate subtidal	2	Fine sand	2	Moderate	0.5	Low	1	Biofilm	1
Marine	2	Deep subtidal	2	Coarse sand	2	High	0	Moderate	1	Biomat	1
				Fine gravel	2					Rock	1
				Gravel	1					*Ulva*	1
				Cobbles/ Boulders	1					Eelgrass	1
										Kelp	1
										Sea pens	1
										Saltmarsh	0
										Grass	0
Source											
(Dunham and Boutillier 2001)		(Dunham and Boutillier 2001)		(Dunham and Boutillier 2001)						(Hemmera 2014*g*)	

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 0.5 indicates species does not prefer habitat but does not actively avoid it, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

6.0 PRIMARY PRODUCERS



The Roberts Bank ecosystem supports a rich assembly of primary producers. The diverse nature of Roberts Bank arises from its variety of habitats ranging from terrestrial upland, to intertidal soft and hard substrates and shallow and deep subtidal habitats supplemented by man-made rock reefs. The upland and intertidal zones support brackish tidal marshes near Canoe Passage and salt marshes along the Roberts Bank causeway. The intertidal mudflats have highly productive native and non-native eelgrass meadows and biofilm and biomat assemblages in the less exposed upper intertidal. The hard substrates associated with the causeway provide a stable attachment for brown, red and green algal species, which add structure for invertebrates and fish communities and provide food for higher trophic levels. The subtidal area is mainly sand and free of marine vegetation except where man-made reefs were created allowing kelp forests to develop and house demersal fish and invertebrate species. There were over 70 taxa of primary producers observed during the field programs at Roberts Bank divided into ten functional groups for the EwE model.

6.1 FUNCTIONAL GROUPS

The ten functional groups of Primary Producers were determined to be essential to assessing the productivity of Roberts Bank based upon life history traits, ecological function and social importance. Within these ten functional groups, seven were selected as focal species by the PC-TAG including freshwater and marine biofilm, sea lettuce (*Ulva*), kelp and rockweed (*Fucus distichus)*, native eelgrass (*Zostera. marina*), non-native eelgrass (*Z. japonica*), and tidal marsh vegetation including pickleweed (*Sarcocornia pacifica)*, seashore saltgrass (*Distichlis spicata)*, sea clubrush (*Bulboschoenus* spp.), bulrush (*Schoenoplectus* spp.), and Lyngbye's sedge (*Carex lyngbyei)*. For the purposes of modelling, some of the focal species were combined into higher phylogenetic classes, e.g., including kelp and rockweed into Brown Algae, sea lettuce as Green Algae, and numerous salt and brackish marsh species into the Tidal Marsh vegetation group. The marine vegetation functional groups modelled include:

1 Freshwater Biofilm*

2 Marine Biofilm*

3 Biomat

4 Brown Algae*

5 Native Eelgrass*

6 Green Algae*

7 Non-native Eelgrass*

8 Red Algae

9 Phytoplankton

10 Tidal Marsh*

6.2 METHODS

In general, estimation of EwE model parameters followed methodology described in Section 1.1 Study Area. Estimates for basic inputs and environmental preferences in the EwE model were based on field studies of marine vegetation in the intertidal, subtidal and salt marsh areas of Roberts Bank conducted in 2012 and 2013 (Hemmera 2014*d*). Data was collected on percent cover of marine vegetation, slope of substrate, substrate type, and geo-referenced for each sample location. Hyperspectral imagery was also collected for the intertidal portions of Roberts Bank, and in combination with field data, was used to estimate vegetated cover and biomass (see Section 1.5.3 Ecopath Habitat and Substrate Map). Cover of marine vegetation is presented in **Figure 1**. Where estimates could not be determined through field studies, literature values from the region were used. Diet and consumption information does not apply to primary producers. All environmental preferences were determined through Roberts Bank specific sampling using ArcGIS as outlined in Section 1.1.5.3. The range of and most common frequencies for both the summer/freshet (May – July) and winter/non-freshet (October – December) seasons are presented here.

6.3 BIOFILM (FRESHWATER AND MARINE)

6.3.1 Group Definition

Table 6-1 Taxa in the Biofilm Functional Group

Common Name	Scientific Name
Diatoms	Bacillariophyta
Blue-green algae	Cyanobacteria
Dinoflagellates	Pyrrophycophyta

Biofilm at Roberts Bank is the thin (0.01 – 2.00 mm), but dense layer of microbes, organic detritus and sediment. This layer occurs in a mucilaginous matrix of extracellular polymeric substances together with non-carbohydrate components secreted by microphytobenthos and benthic bacteria (Kuwae et al. 2008). Microphytobenthos are photosynthetic and are constrained by light penetration to the top 2.0 mm of sediments (Herlory et al. 2004). These organisms can be attached to sediment particles, but are known to

exhibit passive vertical migrations within sediments spurred by changing conditions in the physical environment, namely light levels and water immersion/emersion (Underwood and Smith 1998, Guarini et al. 2000).

Biofilm was initially modelled as one functional group; however with increasing knowledge gained through field studies at Roberts Bank it was determined that two distinct and important communities exist: those associated with freshwater conditions and those associated with brackish-marine conditions. In order to assess how each community may be affected by the Project, they were modelled as separate groups.

6.3.2 Biomass and Production

Biomass of all biofilm at Roberts Bank was estimated using abundance of chlorophyll *α* data identified by the hyperspectral imagery. The abundance of chlorophyll *α* was converted to biofilm biomass through a series of steps identified in the literature (Kuwae et al. 2008, 2012). The total mass of chlorophyll *α* for the study area (0.3410 t) was converted to carbon content of microphytobenthos using a factor of 40 (13.6400 t). This is estimated to be approximately 7% of carbon content of biofilm resulting in a total carbon content of biofilm of 194.8494 t. To convert to dry mass, multiplied total carbon content by 50, as C accounts for approximately 2% of mass (9742.4715 t). Water content of biofilm is estimated to be approximately 48% at Roberts Bank (Kuwae et al. 2012), so dry mass was multiplied by 2 to obtain a total wet biomass of 19486 t. Dividing this by the local study area (54.6805 km^2) and correcting for the growing season (0.3 or 30% of the year, WorleyParsons. 2015b), the final wet biomass was estimated to be 106.9000 $t/km^2/yr$.

To estimate biomass of the freshwater and marine groups present at Roberts Bank, mean values for each were estimated in mg of chlorophyll *α* per square meter based off the 2012 hyperspectral data by the biofilm discipline lead. The freshwater density was determined to be 93.62 mg/m^2 resulting in a biomass of 30.10 t/km^2. The marine density was determined to be 115.38 mg/m^2 resulting in a biomass of 33.34 t/km^2. Freshwater and marine biomass are adjusted to individual group areas.

A P/B of 36 $year^{-1}$ was used for each group based on an estimated biomass turnover rate of once every 10-days for biofilm at Roberts Bank (WorleyParsons 2015a).

6.3.3 Environmental Preferences

Microphytobenthos can be limited by: light, temperature, salinity, nitrogen and dissolved organic nitrogen levels, sediment size, and immersion/emersion cycles (Pinckney and Zingmark 1991, Hillebrand and Sommer 1997, Underwood and Kromkamp 1999, Underwood and Paterson 2003, Underwood et al. 2005). Robert Bank environmental preferences for freshwater and marine biofilm are summarised in **Table 6-2**. Environmental preference curves for depth, salinity, currents and waves were generated by ArcGis by relating the distribution of each biofilm group with its corresponding environmental conditions. These environmental curves were not smoothed (see Roberts Bank Ecosystem Model Sensitivity Analyses report for additional information smoothing).

Table 6-2 Biofilm Environmental Preferences

Salinity	Depth (CD)	Sediment	Bottom Current	Exposure
Roberts Bank Specific Range – freshwater group				
Range: 0–12, peaks: 6 and 9	Range 3.5- 0	Range: 0-0.250 Peak: 0.008-0.220	Common: 0.1 – 0.4 0.2 peak: 0.2	Common: 0.0 – 1.6
Roberts Bank Specific Range – marine group				
Range: 8 – 32 peaks: 14 and 19	Range 4.0- 0	Range: 0-0.250 Peak: 0.008-0.220	Common: 0.0 – 0.2	Common: 0.0 – 1.6

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 0.5 indicates species does not prefer habitat but does not actively avoid it, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

6.4 BIOMAT

6.4.1 Group Definition

Table 6-3 Taxa in the Biomat Functional Group

Common Name	Scientific Name
Blue-green algae	Cyanobacteria

The biomat layer is associated with a raised ridge, from approximately 3.0 to 3.5 m CD, with tidal channels running perpendicular to shore (NHC 2013). This ridge may be an area of accretion due to the trapping of sediment and detritus by the cyanobacteria or a result of erosion of the high shoreline resulting in the formation of a pioneering marsh. The biologically active layer occurs on the ridges of this feature and is primarily comprised of cyanobacteria and blue-green algae that trap detritus and sediment (NHC 2013).

6.4.2 Biomass and Production

Biomat biomass, within the mapped polygons at Roberts Bank, was estimated to be 22.3000 t/km^2. Biomat was estimated to cover 40% of the ridge based upon hyperspectral reflection of chlorophyll *α*. The average production of biomat at Roberts Bank has been recorded as approximately 8 mm for a one-month period during peak growing conditions observed in July and August (NHC 2013). Biomass of biomat was estimated as four times that of what the dense biofilm biomass would be for the same area, proportional to the depth sampled.

The P/B ratio was not determined during the study however, it is estimated to be rapid since the main constituents are microbes and **microalgae**. An estimated P/B of 83 year^{-1} was used based on the average of 36 for biofilm at Roberts Bank (WorleyParsons 2015a) and 130 for bacteria, assuming the biomat is approximately 50% microalgae and 50% bacteria.

6.4.3 Environmental Preferences

Robert Bank-specific environmental preferences are summarised (**Table 6-4**). Biomat is assumed to have a similar response to growing conditions as biofilm.

Table 6-4 Biomat Environmental Preferences

Salinity	Depth	Sediment	Bottom Current	Exposure
Roberts Bank Specific Range				
Range: 7-17 Common: 13-17	Range: 3.6 – 2.6 Common: 3.0 – 2.6	Range: 0.009 – 0.080 Common: 0.008 – 0.040	Summer: 0 – 0.20 Common: 0.05 – 0.15 Winter: 0 – 0.20 Common: 0.05 – 0.15	Summer: 0 – 0.1 Common: 0 – 0.1 Winter: 0 – 0.2 Common: 0 – 0.2

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 0.5 indicates species does not prefer habitat but does not actively avoid it, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

6.5 BROWN ALGAE

6.5.1 Group Definition

Table 6-5 Species in the Brown Algae Functional Group

Common Name	Scientific Name
Rockweed (intertidal)	*Fucus distichus*
Winged kelp (subtidal)	*Alaria marginata*
Five ribbed kelp (subtidal)	*Costaria costata*
Bull kelp (subtidal)	*Nereocystis leutkeana*
Sugar kelp (subtidal)	*Saccharina latissima*
Wireweed (subtidal)	*Sargassum muticum*

The brown algae functional group includes a diverse group of intertidal (rockweed) and subtidal (kelps) seaweeds which typically act as shelter for invertebrates and fish while providing structural support for spawning (Christie et al. 2009). Brown algae species include annual and perennial species, and generally require a hard substrate (cobble or boulder) for attachment (Elwany et al. 2011). The distribution within Roberts Bank is along the intertidal rip-rap, cobble beaches (rockweed) and in the subtidal zone on rocky reefs (bull kelp, sugar kelp). Brown algae are hard substrate favouring species.

6.5.2 Biomass and Production

Total biomass for brown algae was estimated to be 8.2093 t/km^2. Intertidal species contributed a total of 4.1153 t/km^2 using percent cover estimates of rockweed, averaging 25% cover along the intertidal causeway. Subtidal species contributed 4.0940 t/km^2, based upon estimates of sugar kelp (3 plants/m^2 in 100% cover at 0.4 kg/plant), and bull kelp (5 plants/m^2 in 100% cover at 5 kg/plant). A P/B estimate of 9 year^{-1} was used, assuming that kelp and rockweed are the main source of brown algae biomass (Preikshot et al. 2012).

6.5.3 Environmental Preferences

The biomass of brown algae peaks in the summer when light, temperature, and nutrient levels are optimal for growth. Typically, growth for annual species such as bull kelp begins in late March and continues through to the end of October (Jamie Slogan personal observation, 2013). Roberts Bank-specific environmental preferences are summarised in **Table 6-6**.

Table 6-6 Brown Algae Environmental Preferences

Salinity	Depth	Sediment	Bottom Current	Exposure
Roberts Bank Specific Range				
Range: 19 – 31 Common: 25-26, 29-30	Range: 3.0 – 1.5 and -2.5 – -7.5 Common: 3.0 – 1.5 and -2.5 – -3.5	0.08 – 0.20 and 1.34+ Common: 1.34+	Summer: 0 – 0.45 Common: 0 – 0.45 Winter: 0 – 0.45 Common: 0.15 – 0.25 and 0.35 – 0.45	Summer: 0 – 0.4 Common: 0 – 0.4 Winter: 0 – 0.5 Common: 0 – 0.4

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 0.5 indicates species does not prefer habitat but does not actively avoid it, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

6.6 EELGRASS (NATIVE)

6.6.1 Group Definition

Table 6-7 Species in the Native Eelgrass Functional Group

Common Name	Scientific Name
Eelgrass (native)	*Zostera marina*

Native eelgrass (*Zostera marina*) was identified as a focal species by the PC-TAG due to its social, cultural and ecological value, its use as an indicator of ecosystem health, and contribution to overall productivity on the Roberts Bank ecosystem. Native eelgrass in this report does not differentiate between the three known ecotypes *typica*, *phillipsi*, and *latifolia*.

6.6.2 Biomass and Production

Biomass of native eelgrass was estimated to be 5.5804 t/km^2. Areal estimates were extrapolated from the hyperspectral imagery data for Roberts Bank and recent mapping of eelgrass beds (Hemmera 2014*d*). Dry mass estimates were based upon average densities of 150 shoots/m^2 in areas of near 100% cover beds (Hemmera 2014*d*). The dry mass of each shoot was estimated to be 12 mg (Harrison 1982). Wet weight estimates were derived by multiplying total dry weight estimates by a conversion factor of 6 (Zeng 1984, CRESP 2006) and correcting for the total study area and seasonal differences in productivity as this is perennial species (0.75).

A P/B of 18 year^{-1} was used as the average from two EwE studies (Duarte 1991, Harvey etal. 2011). For estimates of EE, it is assumed that only 5% of eelgrass is consumed directly by grazing from species including snails and amphipods (Wright 2002). Great blue heron, dabbling ducks, wigeon, pintail, mallards, and black brant geese all use eelgrass for foraging.

6.6.3 Environmental Preferences

Eelgrass distribution depends on water clarity, salinity, currents, wave exposure and temperature. Colonisation rates decrease as the water becomes more turbid, but eelgrass can exist at depths where light availability is 11% of surface irradiance (Olesen and Sand-Jensen 1993, Hemminga and Duarte 2000). The optimum salinity range for eelgrass is between 20 and 32 psu, though it can tolerate 10 to 30 psu (Wright 2002, Mumford 2007). Ocean temperature can also limit the distribution of eelgrass. Eelgrass typically occurs where water ranges between 10 – 20°C (Wright 2002, Mumford 2007). Warm water temperature may inhibit seed germination while colder temperatures promote germination (Tanner and Parham 2010). Water temperatures during field studies at Roberts Bank ranged from 1 – 22°C. Ocean temperatures at Roberts Bank are conducive to eelgrass recruitment and growth (Hemminga and Duarte 2000). Roberts Bank-specific environmental preferences are summarised in **Table 6-8**. Environmental preference curves for depth, salinity, currents and waves were smoothed (a five value running average) based upon guidance from both third party reviewers, in order to fill gaps in the Project area specific sampling created by the absence of specific values (ie, no eelgrass was sampled at 27 psu; however we know it can exit between 10 and 32 psu) see Roberts Bank Ecosystem Model Sensitivity Analyses report for detailed description. These smoothed curves extended or decrease the overall range of values in some instances, which were corrected manually.

Table 6-8 Native Eelgrass Environmental Preferences

Salinity	Depth	Sediment	Bottom Current	Exposure
Roberts Bank Specific Range				
Range: 8 - 31 Common: 8 - 31	Range: 2.5 - -5.4 Common: -0.5 - -4.9	Range: 0.06 – 0.30 Common: 0.06 – 0.26	Summer: 0 – 0.45 Common: 0 – 0.45 Winter: 0 – 0.45 Common: 0.15 – 0.25 and 0.35 – 0.45	Summer: 0 – 0.5 Common: 0.05 – 0.45 Winter: 0 – 0.5 Common: 0.05 – 0.45

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

6.7 GREEN ALGAE

6.7.1 Group Definition

Table 6-9 Species in the Green Algae Functional Group

Common Name	Scientific Name
Sea lettuce	*Ulva lactuca*
Cornrow sea lettuce	*Ulva intestinalis*
Green fish line	*Lola lubrica*

The green algae functional group at Roberts Bank is dominated by the PC-TAG selected focal species *Ulva* (sea lettuce). Sea lettuce was selected as a focal species due to its social, cultural and ecological value, its ability to respond to change in the environment, and its contribution to the overall productivity at Roberts Bank. Green algae at Roberts Bank is defined as the filamentous (*Lola* species) and bladed (*Ulva* species) green algae. The mudflat at Roberts Bank maintains a spatially and seasonally variable assemblage of marine vegetation. Green algae are ubiquitous along the west coast of North America and can form mounds or '**hummocks**', especially in areas with low angle slopes (Druehl 2000). Commonly, the hummocks are a complex of algae species including green fish line (*Lola lubrica*) and several species of sea lettuce (*Ulva* spp.) that have become intertwined due to tidal action and may be attached to the substrate. During late spring and early summer, standing biomass of sea lettuce and other green algae species increases dramatically due to increased light conditions and the availability of nutrients.

6.7.2 Biomass and Production

Biomass for green algae at Roberts Bank was estimated to be 126.3220 t/km^2. Biomass was calculated by using density data gathered during the 2012 and 2013 field surveys. One square metre of wet green algae was estimated to be 5 kg or 5,000 t/km^2 over the study area totalling 3.4537 km^2. 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.

A P/B value of 13 year^{-1} for green algae was used (Ainsworth 2006, Preikshot et al. 2012).

6.7.3 Environmental Preferences

Green algae are found across the sandflat and attached to the rocky intertidal with abundance related to light and space availability. Green algae are present from the spring through fall, but generally absent during winter months. *Ulva* species may be free-floating or attached to hard substrate with species varying due to salinity. Roberts Bank-specific environmental preferences are summarised in **Table 6-10**. Environmental preference curves for depth, currents and waves were smoothed (a five value running average) based upon guidance from both third party reviewers, in order to fill gaps in the Project area specific sampling created by the absence of specific values. These smoothed curves extended or decrease the overall range of values in some instances, which were corrected manually, see Roberts Bank Ecosystem Model Sensitivity Analyses report for detailed description. The salinity curve was based on the literature.

Table 6-10 Green Algae Environmental Preferences

Salinity	Depth	Sediment	Bottom Current	Exposure
Roberts Bank Specific Range				
Range: 0 - 32 Common: 5 – 20 (1) 20-27 (1.5) 28-32 (2)	Range: 5 – 0 Common: 4 – 0	Range: 0 – 0.60 and 1.34+ Common: 0.06 – 0.26 and 1.34+	Summer: 0 – 1.70 Common: 0 – 0.45 Winter: 0 – 0.70 Common: 0 – 0.70	Summer: 0 – 0.3 Common: 0 – 0.3 Winter: 0 – 0.4 Common: 0 – 0.4

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

6.8 JAPANESE EELGRASS (NON-NATIVE)

6.8.1 Group Definition

Table 6-11 Species in the Japanese Eelgrass Functional Group

Common Name	Scientific Name
Japanese eelgrass	*Zostera japonica*

Japanese eelgrass is a non-native species likely originating in oyster shipments from Japan (Larned 2003, Mumford 2007). The species provides a similar function as native eelgrass, offering habitat and food to some species, although it is significantly smaller and less productive. Japanese eelgrass forms a band at a tidal elevation above native eelgrass with minimal overlap (Baldwin and Lovvorn 1994*a*, *b*). Japanese eelgrass was selected by the PC-TAG due to its ecological importance, ability to act as an indicator of change, and historical records within the study area.

6.8.2 Biomass and Production

Distribution and biomass of Japanese eelgrass at Roberts Bank was determined through the eelgrass mapping programs at Roberts Bank (Hemmera 2014*d*). Japanese eelgrass biomass, within the mapped polygons was estimated to be 0.1256 t/km^2. A total biomass of 12 t was estimated based upon an aerial coverage of 1.4313 km^2. Total biomass was corrected for the study area and seasonal growth (0.4 or 40% of the growing season). A P/B of 10 year^{-1} was used based upon the value used for a generalised macrophytes group in the Strait of Georgia EwE model (Preikshot et al. 2012).

6.8.3 Environmental Preferences

Japanese eelgrass is an annual species with peak growth, at Roberts Bank, between May and September. It typically occurs above the native eelgrass and below the intertidal seaweeds of the tidal marsh (Baldwin and Lovvorn 1994*a*, *b*). Roberts Bank-specific environmental preferences are summarised in **Table 6-12**. Environmental preference curves for depth, salinity, currents and waves were smoothed, based upon guidance from both third party reviewers, in order to fill gaps in the Project area specific sampling created by the absence of specific values. These smoothed curves extended or decrease the overall range of values in some instances, which were corrected manually, see Roberts Bank Ecosystem Model Sensitivity Analyses report for detailed description.

Table 6-12 Japanese Eelgrass Environmental Preferences

Salinity	Depth	Sediment	Bottom Current	Exposure
Roberts Bank Specific Range				
Range: 0 – 30 Common: 0 – 30, highest between 28-29	Range: 4.0 – 0 Common: 4.0 – 0	Range 0.02 – 0.60 Common: 0.04 – 0.50	Summer: 0 – 1.10 Common: 0 – 0.85 Winter: 0 – 0.70 Common: 0 – 0.65	Summer: 0 – 0.3 Common: 0 – 0.3 Winter: 0 – 0.4 Common: 0 – 0.4

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

6.9 RED ALGAE

6.9.1 Group Definition

Table 6-13 Species in the Red Algae Functional Group

Common Name	Scientific Name
Turkish washcloth (intertidal)	*Mastocarpus papillatus*
Laver (intertidal)	*Porphyra* spp.
Turkish towel	*Chondracanthus exasperatus*
Ruffled red seaweed	*Cryptopleura ruprechtiana*
Delicate northern sea fan	*Euthora cristata*
Sea sac	*Halosaccion* sp.
Splendid iridescent seaweed	*Mazzaella splendens*
Sea laurel	*Osmundea spectabilis*
Red optunia	*Opuntiella californica*
Sea braid	*Plocamium* spp.
Frilly red ribbon	*Palmaria callophylloides*
Red eyelet silk	*Sparlingia pertusa*

Red algae are a mix of annual and perennial species generally adapted to low light conditions and tolerant to grazing (Graham et al. 2009). This functional group was included in the model to account for the other macroalgae species not included as focal species.

6.9.2 Biomass and Production

A biomass of 0.2779 t/km^2 was estimated from field studies in 2012 and 2013, and previous surveys at Roberts Bank (Fehr et al. 2012). In the intertidal, red algae (based upon cover of *Mastocarpus papillatus*) was estimated to occur by approximately 5% on hard substrates. In the subtidal, a 5% cover was also considered for various filamentous and bladed red algae. A P/B of 20 year^{-1} was used which is slightly higher than other studies from the region (Harvey et al. 2011).

6.9.3 Environmental Preferences

Red algae generally occur in low light conditions as a mix of annual and perennial species. They are not known to be grazed on by many species due to their ability to produce toxins including strong acids to deter grazers (Graham et al. 2009). Red algae can be found in varying levels of wave exposure and currents (Lindeberg and Lindstrom 2010). Roberts Bank-specific environmental preferences are summarised in **Table 6-14**. Smoothed environmental preference curves from brown algae were used for red algae as these two groups have similar distributions for depth, currents, salinity and waves. These smoothed curves extended or decrease the overall range of values in some instances, which were corrected manually see Roberts Bank Ecosystem Model Sensitivity Analyses report for detailed description. Red algae is also a hard substrate favouring functional group.

Table 6-14 Red Algae Environmental Preferences

Salinity	Depth	Sediment	Bottom Current	Exposure
Roberts Bank Specific Range				
Range: 9-31 Common: 25-26, 29-31	Range 2.6 – -3.3 Common: 2.6 – 1.5	0.08 – 0.20 and 1.34+ Common: 1.34+	Summer: 0 – 0.45 Common: 0 – 0.45 Winter: 0 – 0.45 Common: 0.15 – 0.25 and 0.35 – 0.45	Summer: 0 – 0.3 Common: 0 – 0.3 Winter: 0 – 0.5 Common: 0 – 0.5

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

6.10 PHYTOPLANKTON

6.10.1 Group Definition

Table 6-15 Taxa in the Phytoplankton Functional Group

Common Name	Scientific Name
Phytoplankton	Bacillariophyceae, Dinophyceae, Cyanophyta

Phytoplankton are primary producers with a significant contribution to the overall productivity of marine food webs. Phytoplankton live in the **euphotic zone** of the water column. The phytoplankton group consists of pelagic photoautotrophic microorganisms at Roberts Bank, including a diverse range of diatoms, dinoflagellates, cyanobacteria and other unicellular algae (Graham et al. 2009).

6.10.2 Biomass and Production

Phytoplankton biomass of 40 t/km^2 was used based upon the phytoplankton group in the Strait of Georgia EwE model (Preikshot et al. 2012).

A P/B of 130 year^{-1} was used based upon the value used in the EwE model of the Strait of Georgia (Preikshot et al. 2012).

6.10.3 Environmental Preferences

Phytoplankton blooms are seasonal and depend on environmental variables including light, temperature, salinity, nitrogen and dissolved organic nutrient levels (Graham et al. 2009). Phytoplankton in the Strait of Georgia typically undergo two periods of peak production, one in the spring and one in late summer (Nybakken and Bertness 2005). During periods of peak production, shading of other primary producers may limit phytoplankton overall productivity (Kavanaugh et al. 2009). Roberts Bank-specific environmental preferences are summarised in **Table 6-16**.

Table 6-16 Phytoplankton Environmental Preferences

Salinity	Depth	Sediment	Bottom Current	Exposure
Roberts Bank Specific Range				
Assumed to occur equally across the study area				

6.11 TIDAL MARSH

6.11.1 Group Definition

Table 6-17 Species in the Tidal Marsh Functional Group

Common Name	Scientific Name
Tufted bulrush	*Trichophorum cespitosum*
Three-square	*Schoenoplectus pungens*
Seashore saltgrass	*Distichlis spicata*
Sea club rush	*Bolboschoenus maritimus*
Sea arrowgrass	*Triglochin maritima*
Pickleweed	*Sarcocornia pacifica*
Lyngbye's sedge	*Carex lyngbei (*syn. *Carex lyngbyei)*
Livid sedge	*Carex livida*
Common cordgrass	*Spartina anglica*
Common clubrush	*Schoenoplectus lacustris*
Common bulrush	*Typha latifolia*
Club rush	*Bolboschoenus* sp.
Saltmarsh sandspurry	*Spergularia salina*
Broadleaf arrowhead	*Sagittaria latifolia*
Brass buttons	*Cotula coronopifolia*

The tidal marsh at Roberts Bank consists of salt and brackish marsh habitats. The distribution of these habitats is determined by mainly salinity of the water and sediment. Higher salinities approximating 30 psu are found near the causeway and intercauseway, while more brackish conditions and lower salinities occur with increasing proximity to Canoe Passage and Brunswick Point. Salt marsh habitat at Roberts Bank includes seashore saltgrass (*Distichlis spicata*), pickleweed (*Sarcocornia pacifica*), saltmarsh sandspurry (*Spergularia salina*), seaside arrowgrass (*Triglochin maritima*) and dune grass (*Leymus mollis*). The brackish marsh habitat at Roberts Bank is dominated by sedge (*Carex lyngbei*), bulrush (*Schoenoplectus americanus*) and cattail (*Typha latifolia*) (Williams et al. 2009).

Tidal marshes provide fish habitat, refugia for prey species and foraging habitat for great blue heron and waterfowl (Hayes et al. 1993, Levings and Nishimura 1996*a*, Moeller et al. 1996, Möller et al. 1999). This habitat also plays an important role in geochemical cycling and providing ecosystem services that include shoreline stabilization, gas and nutrient regulation, contaminant filtering and increased biological diversity (Adam 1993, Anisfeld 2012, Chmura et al. 2012).

6.11.2 Biomass and Production

The biomass of tidal marsh vegetation within the Roberts Bank study area is 24.3650 t/km^2. Brunswick Point contains a distinct assemblage of brackish marsh species relative to the north side of the Roberts Bank causeway and the Inter-causeway Area. Brunswick Point is characterised by having relatively more sedge (Cyperaceae), rush (Juncaceae) and grass (Poaceae) species. Three plant species that were the most dominant in percent cover included sea club rush (20%), sea arrow-grass (13.2%) and Lyngbye's sedge (9.6%). Brunswick Point had a total biomass of 2,216.1402 t over an area of 1.4494 km^2.

The north side of the Roberts Bank causeway and the Inter-causeway Area were dominated by the low lying grass seashore saltgrass (26.6%, north side of the causeway and 11.6 %, Inter-causeway Area) and succulent glasswort species (*Sarcocornia* spp.) (15.2%, north side of the causeway and 42.8%, Inter-causeway Area). Generally, the north side of the causeway and the Inter-causeway Area were more homogenous than Brunswick Point and had none or very little of the sedge, rush, and grass families present. These two regions were relatively patchy in their plant distribution which is highlighted by the relatively large mean percent cover of mud (13.2%, north side of the causeway and 32.8%, Inter-causeway Area). Biomass estimates corrected for the study area and season (0.6 or 60% of the growing season) were 0.0387 and 0.0089 t/km^2 for the north side of the causeway and the Inter-causeway Area, respectively.

A P/B of 15 year^{-1} was used assuming that production of tidal marsh grasses is similar to eelgrass (Duarte 1991).

6.11.3 Environmental Preferences

Tidal marsh distribution is determined by a combination of tidal height, inundation time, salinity, and water velocity (Levings and Nishimura 1996*b*, Williams et al. 2009). In the lower Fraser River, tidal marsh typically gives way to mud- or sandflats when immersion time is greater than 50% and water velocities exceed 0.6 m/s. Tidal marsh consists of a variety of annual and perennial species with the growing season for most species generally beginning in mid-April and lasting until early October. Plants die off in winter. Roberts Bank-specific environmental preferences are summarised in **Table 6-18**. Environmental preference curves for depth, salinity, currents and waves were smoothed based upon guidance from both third party reviewers, in order to fill gaps in the Project area specific sampling created by the absence of specific values. These smoothed curves extended or decrease the overall range of values in some instances, which were corrected manually, see Roberts Bank Ecosystem Model Sensitivity Analyses report for detailed description.

Table 6-18 Salt Marsh Environmental Preferences

Salinity	Depth	Sediment	Bottom Current	Exposure
Roberts Bank Specific Range				
Range: 0 – 29 Common: 0 – 7, and 18 – 22	Range: 5.0 – 1.0 Common: 3.1 – 2.1	Range: 0.08 – 0.70 Common: 0 – 0.16	Summer: 0 – 0.7 Common: 0 – 0.5 Winter: 0 – 0.6 Common: 0 – 0.5	Summer: 0 – 0.2 Common: 0 – 0.2 Winter: 0 – 0.3 Common: 0 – 0.3

Note: 0 indicates species does not prefer this habitat but may occur incidentally, 0.5 indicates species does not prefer habitat but does not actively avoid it, 1 indicates species occurs or prefers this habitat, and 2 indicates species strongly prefers this habitat

7.0 SUMMARY

This report presents the methods used to develop and build the Roberts Bank ecosystem model, including data sources and processes for estimating model parameters such as biomass, production and consumption rates, diet composition and environmental preferences for the model's functional groups. These parameters are used in an EwE model, which assesses potential changes in productivity at Roberts Bank resulting from the Project. The results of the EwE model are described in the accompanying Roberts Bank Ecosystem Model Development and Key Run Report (ESSA 2014*a*).

8.0 CLOSURE

We sincerely appreciate the opportunity to have worked on this ecosystem model. If there are any questions on the information in this report, please do not hesitate to contact the undersigned by phone at 604.669.0424.

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10.0 STATEMENT OF LIMITATIONS

This report was prepared by Hemmera Envirochem Inc. ("Hemmera"), based on fieldwork conducted by Hemmera, for the sole benefit and exclusive use of Port Metro Vancouver. The material in it reflects Hemmera's best judgment in light of the information available to it at the time of preparing this report. Any use that a third party makes of this Report, or any reliance on or decision made based on it, is the responsibility of such third parties. Hemmera accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on this report.

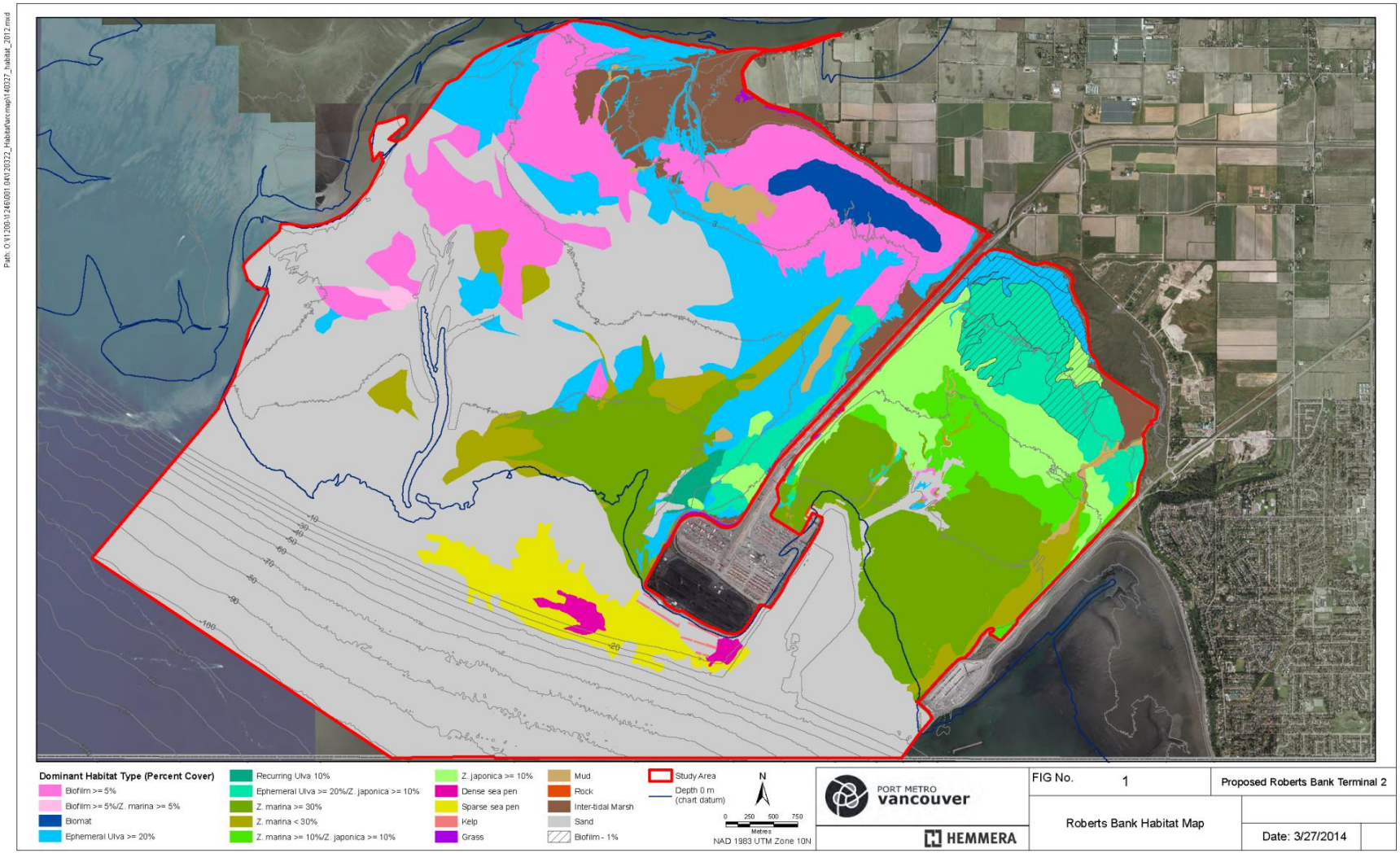
Hemmera has performed the work as described above and made the findings and conclusions set out in this report in a manner consistent with the level of care and skill normally exercised by members of the environmental science profession practicing under similar conditions at the time the work was performed.

This report represents a reasonable review of the information available to Hemmera within the established Scope, work schedule and budgetary constraints. The conclusions and recommendations contained in this report are based upon applicable legislation existing at the time the report was drafted. Any changes in the legislation may alter the conclusions and/or recommendations contained in the report. Regulatory implications discussed in this report were based on the applicable legislation existing at the time this report was written.

In preparing this report, Hemmera has relied in good faith on information provided by others as noted in this report, and has assumed that the information provided by those individuals is both factual and accurate. Hemmera accepts no responsibility for any deficiency, misstatement or inaccuracy in this Report resulting from the information provided by those individuals.

FIGURE 1

Roberts Bank Study Area and Habitat Map


Path: O:\01200-01246\001 04\120322_Habitat\arcmap\140327_habitat_2012.mxd
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-20
Dominant Habitat Type (Percent Cover)
Biofilm >= 5%
Biofilm >= 5%/Z. marina >= 5%
Biomat
Ephemeral Ulva >= 20%
Recurring Ulva 10%
Ephemeral Ulva >= 20%/Z. japonica >= 10%
Z. marina >= 30%
Z. marina < 30%
Z. marina >= 10%/Z. japonica >= 10%
Z. japonica >= 10%
Dense sea pen
Sparse sea pen
Kelp
Grass
Mud
Rock
Inter-tidal Marsh
Sand
Biofilm - 1%
Study Area
Depth 0 m
(chart datum)
N
0 250 500 750
Metres
NAD 1983 UTM Zone 10N
PORT METRO vancouver
HEMMERA
FIG No. 1
Proposed Roberts Bank Terminal 2
Roberts Bank Habitat Map
Date: 3/27/2014

APPENDIX A

Diet Matrix for Functional Groups at Roberts Bank

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Appendix A: Diet Matrix for Functional Groups at Roberts Bank

	Prey \ predator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	Baleen whales	0	0	0	0	0.0001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Dolphins/porpoises	0	0	0	0	0.0120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Pinnipeds	0	0	0	0	0.9859	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	Res. orcas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Trans. orcas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	Wigeon	0	0	0	0	0	0	0.0400	0	0	0	0	0	0.0029	0	0	0	0	0	0	0	0	0	0
7	Bald eagle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	Brant goose	0	0	0	0	0	0	0.0010	0	0	0	0	0	0.0014	0	0	0	0	0	0	0	0	0	0
9	Diving waterfowl	0	0	0	0	0.0020	0	0.0050	0	0	0	0	0	0.0346	0	0	0	0	0	0	0	0	0	0
10	Dunlin	0	0	0	0	0	0	0	0	0	0	0	0	0.0188	0	0	0	0	0	0	0	0	0	0
11	GB heron	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Gulls/terns	0	0	0	0	0	0	0.1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	Raptors	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	Shorebirds	0	0	0	0	0	0	0	0	0	0	0	0	0.0202	0	0	0	0	0	0	0	0	0	0
15	Waterfowl	0	0	0	0	0	0	0.0200	0	0	0	0	0	0.0346	0	0	0	0	0	0	0	0	0	0
16	Sandpiper	0	0	0	0	0	0	0	0	0	0	0	0	0.0188	0	0	0	0	0	0	0	0	0	0
17	Chinook adult	0	0	0.0033	0.7000	0	0	0.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	Chinook juv.	0.0056	0.003199	0.0001	0	0	0	0	0	0.0004	0	0	0.0001	0.0144	0	0	0	0.00002	0.0002	0	0.0002	0.0002	0.0001	0
19	Chum adult	0	0	0.0075	0.0550	0	0	0.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	Chum juv.	0.0056	0.003199	0.0002	0	0	0	0	0	0.0004	0	0	0.0002	0.0144	0	0	0	0.00004	0.0004	0	0.0004	0.0003	0.0001	0
21	Dogfish	0	0.0020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0000	0.00003	0	0
22	Flatfish	0	0.0070	0.0002	0	0	0	0	0	0	0	0	0.00024	0	0	0	0	0.00004	0.0004	0	0.0004	0.0003	0.0001	0
23	Forage/eulachon	0.1200	0.0920	0.3882	0	0	0	0.0100	0	0.2300	0	0.5470	0.3804	0.0404	0	0	0	0.0704	0.0150	0	0.0150	0.4959	0.2157	0
24	Herring	0.0540	0.4468	0.0161	0.0100	0	0	0.1000	0	0.1222	0	0.0227	0.0158	0.0144	0	0	0	0.0029	0.0150	0	0.0150	0.0206	0.0090	0
25	Lg. demersal	0.0580	0.0880	0.0008	0	0	0	0	0	0.0111	0	0.0012	0	0.0144	0	0	0	0.0001	0.0100	0	0.0100	0.0010	0.0005	0
26	Lingcod	0	0.0020	0.0010	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0002	0	0	0	0.0013	0	0
27	Rockfish	0	0.0080	0.0006	0.0100	0	0	0.0100	0	0	0	0	0.00061	0	0	0	0	0.0001	0	0	0	0.0008	0.0003	0
28	Salmon ad.	0	0	0.0253	0.2250	0	0	0.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	Salmon juv.	0.0090	0.0030	0	0	0	0	0	0	0.0001	0	0	0.0000	0.0144	0	0	0	0.000002	0.0003	0	0.0003	0.00002	0.00001	0
30	Sandlance	0.0400	0.0020	0	0	0	0	0.0100	0	0.0100	0	0	0.0000	0	0	0	0	0.00001	0.0001	0	0.0001	0.0001	0.00002	0
31	Shiner perch	0	0.0290	0.0036	0	0	0	0.0100	0	0.0511	0	0.0052	0	0.0144	0	0	0	0.0007	0.0050	0	0.0050	0.0047	0.0020	0
32	Skate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0000	0.0013	0.0006	0
33	Sm. demersal	0	0.1579	0.0014	0	0	0	0	0	0.0100	0	0.0019	0.0010	0	0	0	0	0.0002	0.0100	0	0.0100	0.0017	0.0008	0
34	Starry flounder	0	0.0020	0.0015	0	0	0	0	0	0.0133	0	0.00206	0.00143	0.0144	0	0	0	0.0003	0	0	0.0000	0.0019	0.0008	0
35	Carniv. zooplnk.	0.06448	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0050	0.1199	0.0100	0.1199	0.1000	0.0100	0.1074
36	Dungeness crab	0	0	0	0	0	0	0	0	0.0200	0	0.0290	0.0600	0	0.0200	0.0017	0	0	0	0	0	0.0200	0.0200	0
37	Epifaunal grazers	0.0360	0	0	0	0	0	0	0	0.0511	0.0100	0.0290	0.0200	0	0.0200	0.0350	0.0100	0	0	0	0	0.0500	0.0100	0.0166
38	Epifaunal omnivore	0.0300	0.1359	0.0441	0	0	0	0	0	0.0400	0.0100	0.0120	0.0700	0	0.0200	0.0100	0.0100	0.0100	0	0	0	0.1500	0.1800	0.0051
39	Epifauna sessile	0.0420	0	0.0015	0	0	0	0	0	0.0289	0.0010	0	0.0300	0	0.0200	0	0.0100	0	0	0	0	0.0100	0.0700	0

Appendix A: Diet Matrix for Functional Groups at Roberts Bank

	Prey \ predator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
40	Bivalve (infauna)	0.0540	0	0.0045	0	0	0	0	0	0.1950	0.2980	0	0.1001	0	0.2500	0.0067	0.0100	0	0	0	0	0.0100	0.0900	0.0107
41	Jellyfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0100	0.04997	0.0100	0.0499711	0.0100	0	0.1652
42	Macrofauna	0.25199	0	0	0	0	0	0	0	0.0067	0.1000	0	0	0	0.2000	0.0599	0.2800	0	0.3798	0	0.3798	0.0100	0.1900	0.0871
43	Meiofauna	0	0	0	0	0	0	0	0	0	0.1000	0	0	0	0.2000	0	0.2800	0	0.00999	0	0.0099942	0	0.0100	0.1133
44	Herb. zooplankton	0.2174	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0500	0	0.0500	0.0100	0.0100	0.4444
45	Polychaetes	0.0120	0	0	0	0	0	0	0	0.0233	0.0100	0	0.10005	0	0.2500	0	0.0100	0	0.0500	0	0.0500	0.0100	0.0200	0.0494
46	Orange sea pen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	Shrimp	0	0.0180	0	0	0	0	0	0	0.0730	0.0010	0	0	0	0.0200	0.0015	0	0	0.0500	0	0.0500	0.0100	0.1600	0.0009
48	Biofilm fresh	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0.1950	0	0	0	0	0	0	0
49	Biofilm marine	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0.1950	0	0	0	0	0	0	0
50	Brown algae	0	0	0	0	0	0.0259	0	0	0	0	0	0	0	0	0.0083	0	0	0	0	0	0	0	0
51	Eelgrass (Z.mar.)	0	0	0	0	0	0.0249	0	0.5200	0.0056	0	0	0	0	0	0.0316	0	0	0	0	0	0	0	0
52	Green algae	0	0	0	0	0	0.4341	0	0.0065	0.0667	0	0	0	0	0	0.0083	0	0	0	0	0	0	0	0
53	Eelgrass (Z.jap.)	0	0	0	0	0	0.0030	0	0.1235	0.0056	0	0	0	0	0	0.0100	0	0	0	0	0	0	0	0
54	Red algae	0	0	0	0	0	0.0074	0	0	0	0	0	0	0	0	0.0083	0	0	0	0	0	0	0	0
55	Phytoplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	Tidal marsh	0	0	0	0	0	0.0043	0	0	0.0056	0	0	0	0	0	0.2937	0	0	0	0	0	0	0	0
57	Biomat	0	0	0	0	0	0.0005	0	0	0	0	0	0	0	0	0.0200	0	0	0	0	0	0	0	0
58	Detritus	0	0	0	0	0	0	0	0	0.03	0	0	0.0000	0	0	0	0	0	0	0	0	0.0800	0	0
	Import	0	0	0.5000	0	0	0.5000	0.4840	0.35	0	0.2700	0.3500	0.2200	0.7271	0	0.5050	0	0.9	0.234	0.9800	0.234	0	0	0
	Sum	1	1	1	1	1	1	1	1.00001	1	1	1	1	1	1	1	1	1.000131	1	1	1	1	1	1
	(1 - Sum)	0	1.192E-07	4.65E-06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.19E-07	-2.38E-07	-1.19E-07	5.96E-08

Appendix A: Diet Matrix for Functional Groups at Roberts Bank

	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0.0001	0.0003	0.0002	0	0.0001	0	0	0.0001	0	0.0001	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0.0001	0.0004	0.0003	0	0.0002	0	0	0.0001	0	0.0001	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0.0001	0.00004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0.0001	0.0005	0.0004	0	0.0002	0	0	0.0001	0	0.0001	0	0.0009999	0	0	0	0	0	0	0	0	0	0	0
23	0	0.2011	0.7953	0.6173	0	0.0509	0	0	0.2251	0	0.1881	0	0.0600	0	0	0	0	0	0	0	0	0	0	0
24	0	0.0083	0.0330	0.0256	0.0100	0.0147	0	0	0.0093	0	0.0078	0	0.0250997	0	0	0	0	0	0	0	0	0	0	0
25	0	0.0004	0.0017	0.0113	0	0.0007	0	0	0.0005	0	0.0004	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0.0005	0.0020	0.0016	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0.0003	0.0013	0.0010	0	0.0006	0	0	0.0004	0	0.0003	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0.0131	0	0.0102	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0.00001	0.00002	0.0000	0	0.00001	0	0	0.00001	0	0.00001	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0.00002	0.0001	0.0001	0	0.00004	0	0	0.00002	0	0.00002	0	0.0010	0	0	0	0	0	0	0	0	0	0	0
31	0	0.0019	0.0075	0.0058	0	0.0033	0	0	0.0021	0	0.0018	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0.0006	0.0022	0.0017	0	0	0	0	0.0006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0.0007	0.0028	0.0022	0	0.0012	0	0	0.0008	0	0.0007	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0.0008	0.0030	0.0023	0	0.0013	0	0	0.0008	0	0.0007	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0.1678	0.0900	0	0.0100	0	0.1833	0.2000	0.1200	0	0.0800	0.0100	0.0610	0	0.0250	0	0.0611	0	0.1316	0.0419	0	0	0	0.1667	0.0961
36	0	0.0200	0.0200	0.0200	0	0	0	0.0300	0.1000	0.0267	0.0200	0	0.0050023	0	0.0198	0	0	0	0	0	0	0	0	0
37	0	0.0500	0	0.0100	0	0	0	0.0100	0	0.0533	0.0700	0	0.1807	0	0.0597	0	0	0	0	0	0	0.0135	0	0
38	0	0.1300	0	0.1400	0	0	0	0.0300	0.1200	0.1333	0.2900	0	0.0050199	0	0.0182	0	0	0	0	0	0	0.0041	0	0
39	0	0.0500	0	0.0500	0	0	0	0.0000	0.0100	0.0800	0.0800	0	0.0099	0.0004	0.0050	0	0	0	0.0002	0	0	0.0000	0	0.0216

Appendix A: Diet Matrix for Functional Groups at Roberts Bank

	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
40	0	0.0100	0	0	0	0	0	0	0.1700	0.0533	0.1800	0	0.3818	0	0.0386	0	0	0	0	0	0	0	0	0
41	0	0.0100	0	0	0	0.0509178	0	0	0	0.0133	0	0	0	0	0	0	0	0	0.0645	0	0	0	0	0
42	0.1361	0.2620	0.0500	0.0300	0	0.2546	0.2000	0.4000	0.2000	0.3467	0.1400	0.0500	0	0.0633	0.3951	0.1222	0	0.1067	0.0340	0	0	0.0709	0	0.0779
43	0	0	0	0	0	0	0	0.0300	0.0100	0.0133	0	0	0	0	0	0	0	0	0.0442	0.0500	0	0.0922	0	0.1014
44	0.6947	0.0900	0	0	0	0.1018	0.4000	0.1600	0.0100	0.0133	0	0.6010	0	0.0441	0	0.0917	0	0.5448	0.1734	0	0.0500	0.3619	0.2500	0.3977
45	0	0.0100	0.0100	0	0	0.0509	0	0.07	0.0300	0.0133	0.0100	0	0.0702792	0	0.1777	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00005	0	0	0	0.0000	0	0	0	0	0.00001
47	0.0014	0.0500	0.0700	0.0600	0	0.0550	0	0	0.1100	0.1467	0	0	0.0050	0	0.0032	0	0	0	0	0	0	0	0	0.0008
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0001	0	0	0	0	0.0001	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0001	0	0	0	0	0.0001	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0104	0.0036	0	0	0	0.0080	0	0	0	0	0
51	0	0	0	0	0	0	0	0.0100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0.1000	0.1000	0	0.0133	0	0	0	0.1741	0.0600	0	0	0	0.1344	0	0	0	0	0
53	0	0	0	0	0	0	0	0.0100	0	0	0	0	0	0	0.0004	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0030	0.0010	0	0	0	0.0023	0	0	0	0	0
55	0	0	0	0	0	0	0	0.0300	0	0	0	0.0500	0	0.4298	0.1453	0.6300	0.8571	0.1875	0.3341	0.2000	0.8500	0.3949	0.5000	0
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0001	0	0	0	0	0.0001	0	0	0	0	0
58	0	0	0	0	0	0	0.1000	0	0	0.0133	0	0.2380	0.2551	0.2497	0.0722	0.0950	0.1429	0.0294	0.1627	0.7500	0.1000	0.0625	0.0833	0.3045
	0	0	0	0	0.9900	0.23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	0	0	0	5.96E-08	0	5.96E-08	0	1.19E-07	1.19E-07	1.19E-07	5.96E-08	-4.48E-05	-1.19E-07	0	0	0	0	0	0	0	0	0	0	0

APPENDIX B

Biomass, Production Rates and Consumption Rates for Functional Groups at Roberts Bank: Basic Input

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Appendix B: Biomass, Production Rates and Consumption Rates for Functional Groups at Roberts Bank: Basic Input

	Group name	Habitat area (fraction)	Biomass in habitat area (t/km²)	Production / biomass (/year)	Consumption / biomass (/year)	Ecotrophic efficiency	Production / consumption	Unassimil. / consumption	Detritus Import (t/km²/year)
1	Baleen whales	1	0.0050	0.03	13.37	0.052	0.002	0.20	
2	Dolphins/porpoises	1	0.0050	0.16	20.06	0.780	0.008	0.20	
3	Pinnipeds	1	0.4000	0.14	15.95	0.915	0.009	0.20	
4	Res. orcas	1	0.0100	0.04	14.00	0.000	0.003	0.20	
5	Trans. orcas	1	0.0052	0.04	10.00	0.000	0.004	0.20	
6	Wigeon	1	0.0873	0.20	200.00	0.208	0.001	0.20	
7	Bald eagle	1	0.0022	0.25	41.00	0.000	0.006	0.20	
8	Brant goose	1	0.0199	0.20	200.00	0.025	0.001	0.20	
9	Diving waterfowl	1	0.0276	0.24	92.63	0.116	0.003	0.20	
10	Dunlin	1	0.0086	0.51	92.00	0.026	0.006	0.20	
11	GB heron	1	0.0123	0.49	82.00	0.000	0.006	0.20	
12	Gulls/terns	1	0.0484	0.23	70.75	0.811	0.003	0.20	
13	Raptors	1	0.0002	0.35	41.25	0.000	0.008	0.20	
14	Shorebirds	1	0.0008	0.51	92.00	0.295	0.006	0.20	
15	Waterfowl	1	0.3034	0.20	200.00	0.033	0.001	0.20	
16	Sandpiper	1	0.0011	0.51	92.00	0.215	0.006	0.20	
17	Chinook adult	1	3.4280	0.31	2.00	0.118	0.155	0.20	
18	Chinook juv.	1	0.0120	0.80	2.67	0.435	0.300	0.20	
19	Chum adult	1	2.0455	0.43	1.40	0.070	0.307	0.20	
20	Chum juv.	1	0.0090	0.90	3.00	0.703	0.300	0.20	
21	Dogfish	1	0.6587	0.12	2.70	0.004	0.044	0.20	
22	Flatfish	1	0.3745	0.37	3.53	0.203	0.105	0.20	
23	Forage/eulachon	1	10.5000	0.95	6.40	0.978	0.148	0.20	
24	Herring	1	4.4469	0.80	5.50	0.363	0.145	0.20	
25	Lg. demersal	1	0.1536	0.51	4.78	0.828	0.107	0.20	
26	Lingcod	1	0.5869	0.31	1.70	0.077	0.182	0.20	
27	Rockfish	1	0.3385	0.22	2.85	0.195	0.077	0.20	
28	Salmon adult	1	1.016025	0.43	1.40	0.500	0.307	0.20	
29	Salmon juv.	1	0.0017	0.85	2.83	0.987	0.300	0.20	
30	Sandlance	1	0.2075	0.47	4.20	0.542	0.112	0.20	
31	Shiner perch	1	0.1635	1.27	9.40	0.941	0.135	0.20	
32	Skate	1	0.2306	0.09	1.20	0.363	0.075	0.20	
33	Sm. demersal	1	0.0723	1.00	7.96	0.945	0.126	0.20	
34	Starry flounder	1	0.2098	0.40	4.60	0.761	0.087	0.20	
35	Carniv. zooplnk.	1	29.7500	7.00	20.00	0.479	0.350	0.20	
36	Dungeness crab	1	4.6312	2.50	5.00	0.109	0.500	0.20	
37	Epifaunal grazers	1	15.3111	1.45	7.24	0.737	0.200	0.40	
38	Epifaunal omnivore	1	1.9290	3.50	14.00	0.819	0.250	0.20	
39	Epifauna sessile	1	0.8955	1.71	22.20	0.761	0.077	0.40	
40	Bivalve (infauna)	1	120.7443	2.06	6.86	0.050	0.300	0.40	
41	Jellyfish	1	10.9885	9.60	13.00	0.516	0.738	0.20	
42	Macrofauna	1	50.2648	4.00	13.33	0.690	0.300	0.40	
43	Meiofauna	1	29.1069	8.00	40.00	0.612	0.200	0.20	
44	Herb. zooplankton	1	54.4300	24.00	70.00	0.751	0.343	0.40	
45	Polychaetes	1	20.1500	5.00	25.00	0.103	0.200	0.40	
46	Orange sea pen	1	0.1409	1.20	6.00	0.029	0.200	0.40	
47	Shrimp	1	0.5000	2.40	9.67	0.913	0.248	0.20	
48	Biofilm fresh	1	30.1000	36.00		0.000		0.00	
49	Biofilm marine	1	33.3400	36.00		0.000		0.00	
50	Brown algae	1	8.2093	9.00		0.103		0.00	
51	Eelgrass (Z.mar.)	1	5.5804	18.00		0.044		0.00	
52	Green algae	1	126.3220	13.00		0.073		0.00	
53	Eelgrass (Z.jap.)	1	0.1256	10.00		0.948		0.00	
54	Red algae	1	0.2779	20.00		0.453		0.00	
55	Phytoplankton	1	40.0000	130.00		0.909		0.00	
56	Tidal marsh	1	24.3650	15.00		0.049		0.00	
57	Biomat	1	22.3000	83.00		0.001		0.00	
58	Detritus	1	10.0000		0	0.163	0	0.00	0.00

Black numbers - input derived from field studies and literature; Grey numbers - calculated by Ecopath model

APPENDIX 10-C

Roberts Bank Ecosystem Model Development and Key Run

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REPORT

Roberts Bank Ecosystem Model Development and Key Run

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TECHNICAL REPORT/TECHNICAL DATA REPORT DISCLAIMER

The Canadian Environmental Assessment Agency determined the scope of the proposed Roberts Bank Terminal 2 Project (RBT2 or the Project) and the scope of the assessment in the Final Environmental Impact Statement Guidelines (EISG) issued January 7, 2014. The scope of the Project includes the project components and physical activities to be considered in the environmental assessment. The scope of the assessment includes the factors to be considered and the scope of those factors. The Environmental Impact Statement (EIS) has been prepared in accordance with the scope of the Project and the scope of the assessment specified in the EISG. For each component of the natural or human environment considered in the EIS, the geographic scope of the assessment depends on the extent of potential effects.

At the time supporting technical studies were initiated in 2011, with the objective of ensuring adequate information would be available to inform the environmental assessment of the Project, neither the scope of the Project nor the scope of the assessment had been determined.

Therefore, the scope of supporting studies may include physical activities that are not included in the scope of the Project as determined by the Agency. Similarly, the scope of supporting studies may also include spatial areas that are not expected to be affected by the Project.

This out-of-scope information is included in the Technical Report (TR)/Technical Data Report (TDR) for each study, but may not be considered in the assessment of potential effects of the Project unless relevant for understanding the context of those effects or to assessing potential cumulative effects.

EXECUTIVE SUMMARY

The Roberts Bank Terminal 2 Project (RBT2 or Project) is a proposed new three-berth marine terminal at Roberts Bank in Delta, B.C. that could provide 2.4 million TEUs (twenty-foot equivalent unit containers) of additional container capacity annually. The proposed Roberts Bank Terminal 2 Project is subject to a federal environmental assessment (EA) by an independent review panel. As part of the preparation for the EA, Port Metro Vancouver (PMV) established a Productive Capacity Technical Advisory Group (PC-TAG) that gathered scientific and technical expertise to evaluate how productive potential of Roberts Bank can be defined ecologically, and how habitat changes in productivity related to RBT2 can be quantified.

The PC-TAG recommended the use of an ecosystem-modelling approach and software, Ecopath with Ecosim (EwE), as one of the methodologies to quantify the productive potential of the area. This report describes the methodology and key results from the modelling. The EwE modelling complex has three main components:

- Ecopath is a static, mass-balance snapshot of the ecosystem,
- Ecosim is a time dynamic simulation module for policy exploration, and
- Ecospace is a spatial and temporal dynamic module primarily designed for exploring impacts as a result of protected areas placement, but can also be used to evaluate ecosystem effects as a result of changes to environmental and oceanographic conditions.

The ecosystem model study develops and describes a comprehensive analysis of the productivity at Roberts Bank described within this report. The Roberts Bank ecosystem model comprises a study area of 54.68 km^2. The model consists of 58 functional groups, to represent the complex interactions of this ecosystem. Of these 58 functional groups, 28 focal species were chosen by the PC-TAG. A detailed food web model was developed for the Roberts Bank study area, parameterised with subcontractors from field studies conducted as part of the preparations for the EA of the proposed Project. Based on habitat mapping, sampling, and literature, environmental preference functions were constructed for the 58 functional groups, which were used in the EwE to model spatial species distributions. Based on output from the coastal geomorphology model of Roberts Bank and supplemented with maps of hard/soft substrate distributions, environmental conditions (i.e., bottom current,

salinity, wave height, depth, and hard/soft bottom) with and without the proposed Project were used in the EwE model to forecast changes in productivity (measured in biomass and production) for the functional groups in the study area.

The Roberts Bank ecosystem model forecasts minor overall changes in biomasses as annualised averages for the functional groups. Approximately 40% of the functional groups are forecast to change no more than 5%, which is a change that is judged to be within the uncertainty of the model runs. Further, two-thirds of all functional groups are forecast to change less than 10%. Biomasses of the bird functional groups increased by 2.7%, and primary producers increased by 3.0%. However, biomasses decreased by 2.4% for fish and 1.3% for invertebrates. The greatest relative decline is forecast for orange sea pens (55%). In both absolute and relative terms, the largest biomass increase was for freshwater biofilm (89%, 1,470 t), and the largest absolute decline was for green algae (-8%, 583 t). The second largest relative increase was for raptors (31%).

Results are based on annualised averages and do not, therefore, take into account seasonality. This needs to be considered when comparing results to models that are based on different spatial or temporal scales. An analysis of uncertainty is considered in an accompanying report (Roberts Bank Ecosystem Model Sensitivity Analyses (ESSA 2014)).

The forecast changes in productive potential may not be realized for a group or species that only inhabits the study area for a part of its life history (e.g. migratory species) as factors outside the study may be limiting its productive potential. This may be the case for upper trophic level species or groups, in particular for marine mammals. For lower trophic levels that are sessile and easier to sample, the forecast change is more likely to be realised.

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LIST OF ACRONYMS

EA	environmental assessment
EIS	environmental impact statement
EwE	Ecopath with Ecosim and Ecospace, ecosystem modelling approach and framework
GIS	geographic information system
NOAA	U.S. National Oceanographic and Atmospheric Organization
PC-TAG	Productive Capacity Technical Advisory Group
PMV	Port Metro Vancouver
Project / RBT2	Roberts Bank Terminal 2 Project ()
TL	Trophic Level
UBC	University of British Columbia

SYMBOLS, MEASUREMENTS, AND ABBREVIATIONS

°C	degrees Celsius
d	day
dm	decimetre
g	gram
kg	kilogram
km	kilometre
m	metre
sec	second
t	tonnes (metric)
ha	hectare

GLOSSARY

biomass (B) (t)	The mass of living tissue in either an individual or cumulatively across organisms in a population or ecosystem. Expressed in wet weight as area biomass (t km^{-2} = g m^{-2}) or total biomass (t) over the study area (54.68 km^2).
Biomass ratio (with/without Project)	Indicator for if biomass for a functional or aggregated group increased or decreased with the Project relative to without the Project. The ratio is calculated as the biomass for a functional or aggregated group 'with Project' divided by the biomass 'without Project'. A ratio below 1 indicates a decrease in biomass with the Project.
biomass accumulation (t km^{-2} $year^{-1}$)	Difference in biomass at the end of the study period and before the study period (typically a year). Biomass accumulation is a production term in the Ecopath model.
chart datum (CD)	The low water plane to which are referenced the depths of water over features permanently covered by the sea and the elevations of those features which are periodically covered and uncovered. In tidal waters, the Canadian Hydrographic Service uses the level of Lower Low Water, Large Tide or Lowest Normal Tide as its reference plan for chart datum.
confidence interval (CI)	An estimated range of values that is likely to include an unknown population parameter. Expressed in this report relative to mean.
consumption/biomass ratio (Q/B) ($year^{-1}$)	The amount of food consumed by a group relative to its biomass over a period of time and is expressed as the ratio of consumption (Q) over biomass (B). Absolute consumption (Q) is defined as a flow and expressed in t/km^2/yr; B is the amount of biomass per area, resulting in Q/B being expressed as per year ($year^{-1}$).
ecotrophic efficiency (EE)	In ecosystem models, the fraction of the production used in the system, i.e., either passed up the food web, used for biomass accumulation, migration or export.

	Ecotrophic efficiency is difficult to measure directly. It varies between 0 and 1 and can be expected to approach 1 for groups with considerable predation pressure.
environmental preference function	Function that expresses how biomass for a group correlates with environmental parameters.
functional group	Species or collections of species that share similar life history traits and ecological function. The functional group is a modelling unit, which can consist of a group with similar ecological characteristics, (e.g., rockfish), a species, (e.g., bald eagle), or a life stage (e.g., juvenile chum salmon).
hectare	i.e., 100 x 100 m (or 0.01 km^2). This is the grid cell size for the spatial Roberts Bank model described in this report.
high tide level (HTL, m)	Used as reference level for bottom depth.
key run	The key run is a well-defined model reference run that serves as basis for further evaluations of uncertainty as well as of alternative model scenarios.
net migration ($t\ km^{-2}\ year^{-1}$)	The difference between immigration to and emigration from the study area.
other mortality ($t\ km^{-2}\ year^{-1}$)	Other mortality is mortality that is not considered in the Ecopath model, where it enters as a production term. For instance, mortality associated with organisms dying due to diseases, starvation, and the animals/plants that become part of detritus.
pedigree	Indicator for how well rooted the model is in local data (no unit; range is [0,1] with 1 being fully based on local, high quality data).
predation ($t\ km^{-2}\ year^{-1}$)	Consumption by one functional group on any functional group. Predation is a mortality term in the Ecopath model.
production (P) ($t\ km^{-2}\ year^{-1} = g\ m^{-2}\ year^{-1}$)	Elaboration of tissue (whether it survives or not) by a group over the period considered. In ecosystem modelling, a ratio of production over biomass is used

	(P/B; both expressed in the same units), which is equivalent to total mortality (Z). In the Ecopath model, production is estimated as the sum of the predation mortality, fishing mortality, net migration, biomass accumulation, and other mortality terms.
production/biomass ratio (P/B) ($year^{-1}$)	Elaboration of tissue (whether it survives or not) by a group over the period considered. In ecosystem modelling, a ratio of production over biomass is used (P/B; both expressed in the same units), which is equivalent to total mortality (Z).
production/consumption ratio (P/Q)	The production/consumption ratio is physiologically constrained and can be used to estimate Q/B based on the P/B ratio.
respiration (t km^{-2} $year^{-1}$)	Respiration is the process of releasing energy from food and is a term in the Ecopath consumption equation. In trophic models, a flow (or flows) of mass or energy that is (are) not directed toward, nor could be used by any other functional groups.
trophic level (TL)	Position in the food chain, determined by the number of energy-transfer steps to that level.
unassimilated food (t km^{-2} $year^{-1}$)	Food that is excreted or egested. Unassimilated food is a term in the Ecopath consumption equation.
with	Used to describe analysis with the proposed RBT2.
without	Used to describe analysis without the proposed RBT2 (i.e., modelled existing conditions).

1.0 INTRODUCTION

The Roberts Bank Terminal 2 Project (RBT2 or Project) is a proposed new three-berth marine terminal at Roberts Bank in Delta, B.C. that could provide 2.4 million twenty-foot equivalent units (TEUs) of additional container capacity annually. The Project is part of Port Metro Vancouver's Container Capacity Improvement Program, a long-term strategy to deliver projects to meet anticipated growth in demand for container capacity to 2030. The Project is undergoing a federal environmental assessment (EA) independent panel review under the *Canadian Environmental Assessment Act 2012*. Port Metro Vancouver (PMV) established a Productive Capacity Technical Advisory Group (PC-TAG) that gathered scientific and technical expertise to evaluate how productive potential of Roberts Bank can be defined ecologically, and how habitat changes in productivity related to the Project can be quantified.

The PC-TAG evaluated the suitability of alternative modelling approaches for these tasks, and selected the spatial module (Ecospace) of the Ecopath with Ecosim (EwE) modelling complex to be used for evaluating potential productivity effects as a result of the proposed Project. Given that Roberts Bank is a productive area with freshwater, estuarine and marine environments, and with high biodiversity, the PC-TAG selected 25 focal species for assessing potential changes in productivity related to the proposed Project. The focal species were drawn from **functional groups**, including marine mammals, birds, fish, invertebrates, and primary producers (listed in **Table 2.1**). Originally, 25 focal species were chosen, however, it was determined during the modelling process that juvenile and adult life stages of chinook and chum salmon had to be treated as individual focal species, due to differences in life history patterns and diet. Also, biofilm was divided into two communities: freshwater and marine. This resulted in a total of 28 focal species (Hemmera 2014).

The first step in compiling the Roberts Bank ecosystem model is the development of a representation of the food web that provides an overview of the ecological resources at Roberts Bank. The Roberts Bank ecosystem model consists of 58 functional groups, including the 28 focal species (Hemmera 2014). The functional groups include species (e.g., western sandpiper), life stages within a species (e.g., juvenile and adult chinook salmon), and broader functional groups (e.g., forage fish). Ecological resources at Roberts Bank, input parameters used for the dynamic and spatial modelling, as well as information needed to construct the **environmental preference functions** (see **Section 2.12** Environmental Preference are described in the Roberts Bank Model Parameter Estimates Report (Hemmera 2014).

This report describes the methodology of spatial modelling of Roberts Bank, the relationship to the coastal geomorphology, and results for a key run that describes changes in productivity (measured in **biomass** and **production**) for the functional groups in the study area.

The key run is a well-defined model reference that serves as basis for further evaluations of uncertainty as well as of alternative model scenarios. The key run provides the basis for evaluating how likely alternative scenarios may be. Evaluating how uncertainty may impact the findings is presented in the accompanying Roberts Bank Ecosystem Model Sensitivity Analyses Report (ESSA 2014).

1.1 Ecosystem Modelling and Roberts Bank Terminal 2

1.2 About Ecopath with Ecosim and Ecospace

Ecopath with Ecosim and Ecospace (EwE) is an ecological modelling framework and software that has been under development since 1990, and builds on the Ecopath model initially published in 1984 (Polovina 1984). The development of EwE is centred at the University of British Columbia (UBC) Fisheries Centre, and is coordinated through an international consortium of up to 20 institutional partners as members, including the U.S. National Oceanographic and Atmospheric Organization (NOAA). In 2009, NOAA declared EwE one of the 10 biggest scientific breakthroughs in the organisation's 200-year history (NOAA 2009).

The EwE modelling tool has more than 3,000 registered users in 124 countries, and more than 400 ecosystem models applying the software have been published (Colléter et al. 2013). Thirteen of the published models describe marine areas in British Columbia, and six of these are for the Strait of Georgia. The methodology is thoroughly documented in the scientific literature (e.g., Christensen and Pauly 1992; Christensen and Walters 2004). The EwE is the world's most used for modelling webs and simulating ecosystem dynamics and assessing management options (Plaganyi 2007).

There are three main modules in the EwE framework: Ecopath – mass-balanced model of an ecosystem at a given time; Ecosim – a time-dynamic simulation module for examining regime-related changes to policy; and Ecospace – a spatial and time dynamic module, which can be used to evaluate ecosystem effects as a result of changes to environmental and oceanographic conditions.

The Ecopath model provides a representation of the species, or amalgamated species groups in an ecosystem. The model represents link between those during a given time period with trophic interactions, represented by a diet matrix (Christensen and Pauly 1992). Functional groups consist of a single species, a group of species representing ecological guilds (exploit the same resources in related ways), or a group can represent life history stages of a given species (Walters et al. 2010). Ecopath data requirements are relatively simple: biomass, total mortality, consumption, diet composition and fishery catches. Such data is available from stock assessment, ecological studies. For the Roberts Bank ecosystem model, a considerable part of the input parameters originates from local environmental field studies.

The parameterisation of an Ecopath model is based on satisfying two 'master' equations. The first equation describes how the production term for each group can be divided:

> Production = catch + **predation** + **net migration** + **biomass accumulation** + **other mortality**

Ecopath aims to describe all mortality factors; hence 'other mortality' should only include minor factors such as mortality due to old age, diseases, etc.

The Roberts Bank ecosystem model does not consider catches or net migration, as the purpose of this analysis is to forecast productive changes for the area as a result of the proposed Project's footprint.

The second 'master' equation is based on the principle of conservation of matter within a group:

> Consumption = production + **respiration** + **unassimilated food**

In general, Ecopath requires input of three of the following four 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). EE expresses the proportion of the production used in the system, (i.e., it incorporates all production terms apart from 'other mortality'). If all four basic parameters are available for a group, the program can estimate either biomass accumulation or net migration. Ecopath sets up a series of linear equations to solve for unknown values establishing mass balance in the same operation. For the Roberts Bank ecosystem model, there were estimates of B,

P/B, and Q/B for all groups, except for the adult salmon functional group for which B was estimated based on an assumed EE of 0.5 (Hemmera 2014).

Ecosim provides a dynamic simulation capability at the ecosystem level, with key initial parameters inherited from the base Ecopath model. The key computational aspects are in summary:

- Use of mass-balance results (from Ecopath) for the basic parameters needed for the dynamic runs. This includes initial estimates for biomass, production, consumption, and diet, as well as initial "search rates", i.e., expressions for how much volume a predator searches in order to meet a given prey type. The initial parameter estimates change dynamically during model runs in response to changes in predator and prey abundances change.

- The model incorporates variable speed splitting that reflect the dynamics of both 'fast' (e.g., phytoplankton) and 'slow' growing groups (e.g., whales), but with model time steps that are long compared to the turnover rates for the faster groups. This approach generally makes it possible to use monthly time steps for the model runs.

- Effects of micro-scale behaviours on macro-scale rates: a continuum of density dependence ranging from top-down to bottom-up control is incorporated.

Ecosim uses a system of differential equations that express biomass flux rates among functional groups as a function of time-varying biomass and harvest rates (see Walters et al. 1997; 2000). Predator-prey interactions are moderated by prey behaviour to limit exposure to predation (Walters et al. 2000; Ahrens et al. 2012). Conducting repeated simulations, Ecosim allows for the fitting of predicted biomasses to time series data, thereby providing insight the relative importance of ecological, fisheries, and environmental mechanisms in the observed trajectory of one or more functional groups (Christensen et al. 2011).

Ecospace models spatial ecosystem dynamics in a grid of spatial cells, each cell incorporating an initially identical Ecosim models. Each cell is modified by habitat characteristics, and expressed at the user interface as a map. Each cell in the map, excluding land cells, is linked through two processes: dispersal of organisms and the redistribution of fishing effort due to changing profit patterns or the creation of areas closed to fishing (Walters et al. 1999). However, for the Roberts Bank ecosystem model, fisheries

are not treated explicitly, as the focus is simulating how the productivity of the ecosystem may change, including species exploited in commercial, recreational, or Aboriginal (CRA) fisheries, due to the proposed Project footprint.

The Roberts Bank ecosystem model also evaluates how changes in productivity (measured in biomass and in production) could be channelled through the food web. This capability benefits from the inclusion of habitat capacity model (see **Section 2.11**), which uses information from a geographic information system (GIS) model and sampling to derive environmental preference functions to model spatial distributions.

The benefit of using EwE is that it has a 30-year development history that is well documented (Polovina 1984; Christensen 2013). The EwE approach has been the subject of numerous reviews and evaluations. A review of 27 different types of models that have been used in ecosystem approaches to fisheries for the United Nations Food and Agricultural Organization concluded that the two top-rated models were EwE and Atlantis (Plagányi 2007). Ecopath with Ecosim and Ecospace has a greater history of applications (including several in British Columbia); and has many built-in routines for 'sensitivity analysis'. The history of applications of EwE models provide values of input data parameters. Furthermore, the world's leading experts in applying EwE are in B.C.

With regards to using the EwE approach for making predictions based on alternative future scenarios, the Institute for European Environmental Policy concluded that EwE was the most suitable for the development of scenarios for exploring future trends of marine biodiversity and changes in ecosystem services compared to other available model types for marine ecosystems (Sukhdev 2008). EwE is experiencing increased use for this purpose (Christensen et al. 2015).

Ecospace has been widely applied to quantify the spatial impact of fisheries on marine species (e.g., Christensen et al. 2003; Christensen, Piroddi, et al. 2014). Ecospace analyses the impact of management scenarios such as the establishment of marine protected areas, and assesses the correlation of spatial distributions of marine species and fishing effort (Walters 2000; Martell et al. 2005; e.g., Fouzai et al. 2012). Ecospace can also be used to develop spatial optimisation routines, and to assess the effect of climate change on ecosystem productivity (Christensen et al. 2009; Fulton 2011). Ecospace can also determine the effect of environmental parameters on ecological groups forming the food web (Steenbeek et al. 2013).

1.3 STUDY OBJECTIVES

This report documents the development of a model of the Roberts Bank ecosystem to evaluate how productivity (measured in biomass and in production) may be affected by the proposed Project. The Roberts Bank ecosystem model only considers effects associated with the proposed widening of the Roberts Bank causeway and terminal placement and does not account for potential effects associated with specific Project construction or operation activities. In addition, the report presents parameters for and results from the model key run.

2.0 METHODOLOGY

2.1 THE STUDY AREA

The ecosystem model is focused on Roberts Bank, in Delta, B.C., and has been developed using information from field studies that occurred between 2012 and 2013 in preparation for the Projects EIS (Hemmera 2014). The study area is 54.58 km^2, and extends from the **high tide level** (HTL) northeast to the -100 m **chart datum** (CD) depth contour in the west to Canoe Passage in the northwest and the B.C. Ferries Tsawwassen terminal in the southeast. The total proposed Project has a footprint of 179 ha (1.79 km^2) including the temporary disturbances associated with the transfer pit and the tug basin. The EwE model incorporated the permanent alterations associated with the construction of the causeway and the terminal totalling 160 ha (1.6 km^2), which corresponds to 2.9 percent (%) of the total study area (54.58 km^2).

Roberts Bank is a productive estuarine ecosystem characterised by varying degrees of salinity, ranging from almost fresh water at Canoe Passage, to marine water in the deeper sections of the study area. There are extensive productive tidal flats that form important staging and foraging areas for many bird species, as well as rearing areas for juvenile fish and invertebrates, including commercially, culturally, and ecologically important species.

2.2 COASTAL GEOMORPHOLOGY MODEL

Factors that change over time and/or space are needed in temporal or spatial models to generate dynamics. Such factors are generally called 'drivers'. To assess the potential changes in productivity associated with terminal placement, causeway widening, and construction of the dredge basin, the present study evaluated the impact of changes in physical and environmental characteristics related to the proposed Project.

For the Roberts Bank ecosystem model, the drivers were selected from the coastal geomorphology model developed by Northwest Hydraulic Consultants' Coastal Geomorphology study (NHC 2014). The coastal geomorphology model involved the development, implementation and calibration of a triple coupling (wave-current-sediment transport) Strait of Georgia numerical model based on the TELEMAC-MASCARET modelling system. Spatial drivers used in the Roberts Bank ecosystem model included (1) depth, (2) salinity, (3) bottom current, and (4) wave height, and were considered for two equilibrium situations: **without** and **with** the proposed Project.

The ecosystem model runs consider five spatial layers as drivers, while additional factors are discussed in the accompanying Roberts Bank Ecosystem Model Sensitivity Analyses Report (ESSA 2014). The implementation of the five spatial layers in the EwE modelling framework involve data transformation procedures. For seasonally varying parameters (i.e., salinity, bottom current, and wave height), the annual averages are used.

The main reason for using annual averages for the evaluations in this report is that this was considered sufficient. It is possible to evaluate the impact of seasonally varying environmental drivers, but this calls for information about seasonality in production for the functional groups, and the sampling scheme for the study area was not designed to consider this. For additional information, refer to the accompanying Roberts Bank Ecosystem Model Sensitivity Analyses Report (ESSA 2014).

2.2.1 *Data Transformations*

This section describes the steps required to incorporate the coastal geomorphology study's numerical model into Ecospace.

The numerical model data for depth, salinity, bottom current, and wave height were delivered in the NAD 1983 UTM Zone 10N projection, and issued in three different file formats: i) as t3s files; ii) as ESRI shape files; and iii) as XYZ (X-coordinate, Y-coordinate and (Z) value) text files. All three data formats describe the data in the form of values of a single environmental variable across the study area at a given moment in time, where the data is provided as irregular distributed series of points, each point providing a value for the environmental variable at a known location.

In order to use this data within Ecospace, these point data are converted to a gridded format in the following series of steps.

2.2.1.1 Data Clean up

First, invalid or unusable values that may cause problems in consecutive conversion steps were removed from the source data. For example, some salt marsh areas that rarely become inundated, did not contain usable salinity values with and without Project simulations.

2.2.1.2 Conversion of Point Data to a Generic Format

The point data delivered by Northwest Hydraulic Consultants describes a continuous surface of environmental data in the form of irregularly spaced, discrete points. This data type is referred to in GIS as a Triangulated Irregular Network (TIN) – a network of connected triangles. The point data needed to be converted explicitly to a TIN format for further processing. The T3S data format could not be directly used for this purpose, and required an extra processing step.

The T3S data format is proprietary and is not supported by mainstream GIS software. A data conversion model was needed to get to a common data format. The landXML data format was selected. A proprietary program was developed to convert the T3S data into landXML data, which enabled the further data processing.

2.2.1.3 Conversion to Triangulated Irregular Network Format

The generic point data (either in landXML format, ESRI shape file point format or XYZ text format) was imported to ArcGIS software version 10.3 to generate a continuous surface in TIN format for every month of data, for every required environmental variable. The resulting TIN surfaces maintained the original NAD 1983 UTM Zone 10N projection.

2.2.1.4 Triangulated Irregular Network Format to Rasterization

Once the point data were available as continuous surfaces, the data could be converted to discrete grids with 100-m cell sizes in the NAD 1983 UTM Zone 10N projection using ArcGIS software version 10.3.

2.2.1.5 Raster Averaging

Ecospace simulations were based on annual average conditions represented by the foundation Ecopath model. Therefore, some environmental variables needed to be converted to annual averages: salinity was available for the freshet (May, June, July), and the autumn/winter period (October, November and December). The annual average was

assumed to be the average of the two periods. For wave height and bottom current, estimates were provided for 12 months, and the annual averages were thus applied over all months. The grids for these variables were added and then divided by the number of months of data using ArcGIS software version 10.3.

2.2.1.6 Raster Re-projection

Another processing step was needed because the data was defined in NAD 1983 UTM Zone 10N projection, which is incompatible with Ecospace. Using ArcGIS, the grids were therefore projected to the World Geodetic System (EPSG:4326) projection native to Ecospace.

2.2.1.7 Data Export

As a last processing step, the projected grids were exported as ESRI ASCII text files using ArcGIS.

2.2.1.8 Integration

For environmental map integration with Ecospace, two existing tools were used:

- The Ecospace scenario wizard builds map layers for an existing or new Ecospace simulations, integrating the ASCII grid maps produced above into the starting conditions of Ecospace.
- The spatial-temporal data framework integrates the ASCII maps representing environmental conditions at a post-construction stage into a running Ecospace simulation (Steenbeek et al. 2013).

It was also necessary to continually fine-tune the data conversion process to ensure correct alignment of the imported data-layers.

2.2.2 *Depth*

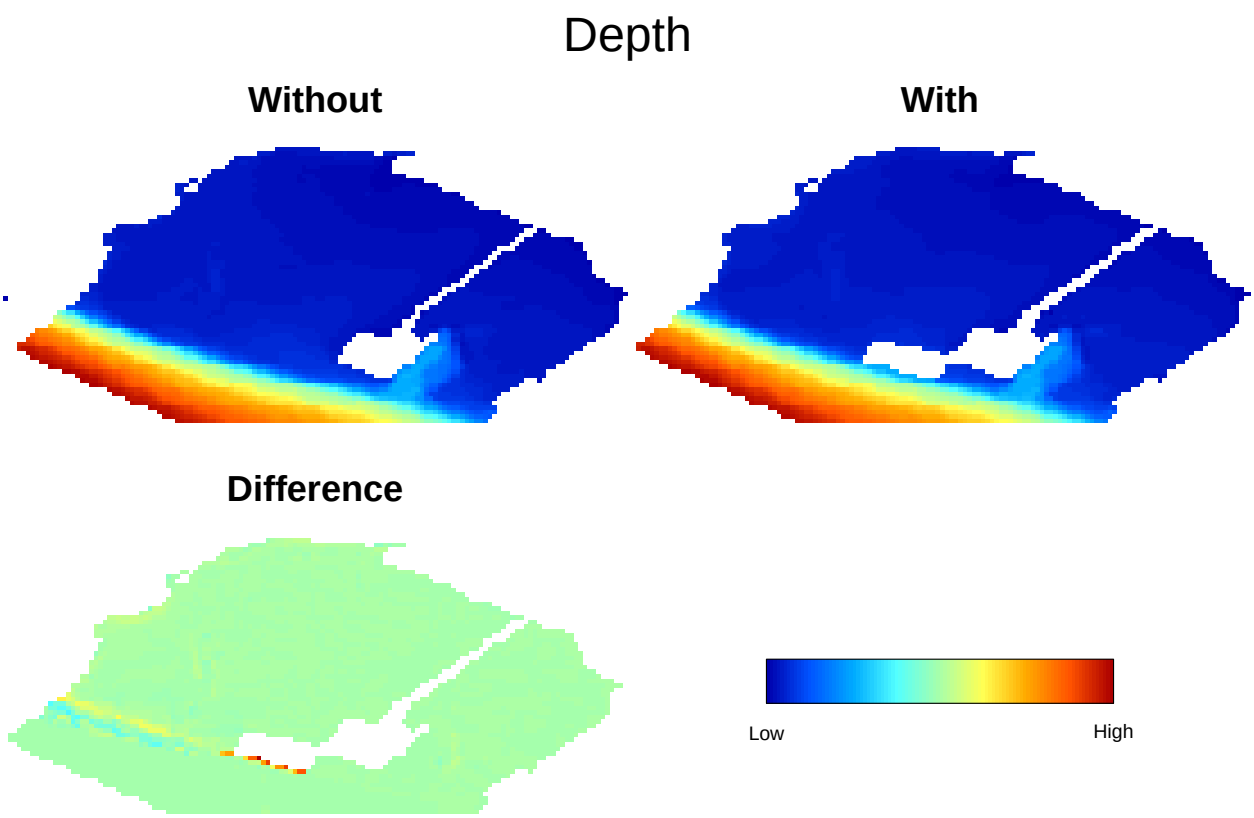
The depth layers were converted to decimetre (dm) values for use within the Roberts Bank ecosystem model, as EwE uses integer values for depths.

The coastal geomorphology study indicates only minor changes in water depths, with a depth increase on the outside of RBT2 and with bands of slightly lower or greater depths stretching northwest from just outside RBT2 (**Figure 2-1**). The depth changes in the intertidal layers are mostly minor (less than 1 m), but such changes may have an effect on intertidal species. This is explored by evaluating species change with and without

incorporating the depth layer changes. The results of this analysis are described in the accompanying Roberts Bank Ecosystem Model Sensitivity Analyses Report (ESSA 2014).

The depths were not forecast to change noticeably in the inter-causeway area. A more complete synopsis of the coastal geomorphology changes associated with the Project are in the Coastal Geomorphology Study (NHC 2014).

Figure 2-1 Estimated Average Water Depths from the Coastal Geomorphology Model, Representing Without the Project, With the Project, and the Difference (With - Without)



Note: Average water depths are below HTL, unit is m (not shown on plots). The colour scale indicates values from low (blue) to high (red)

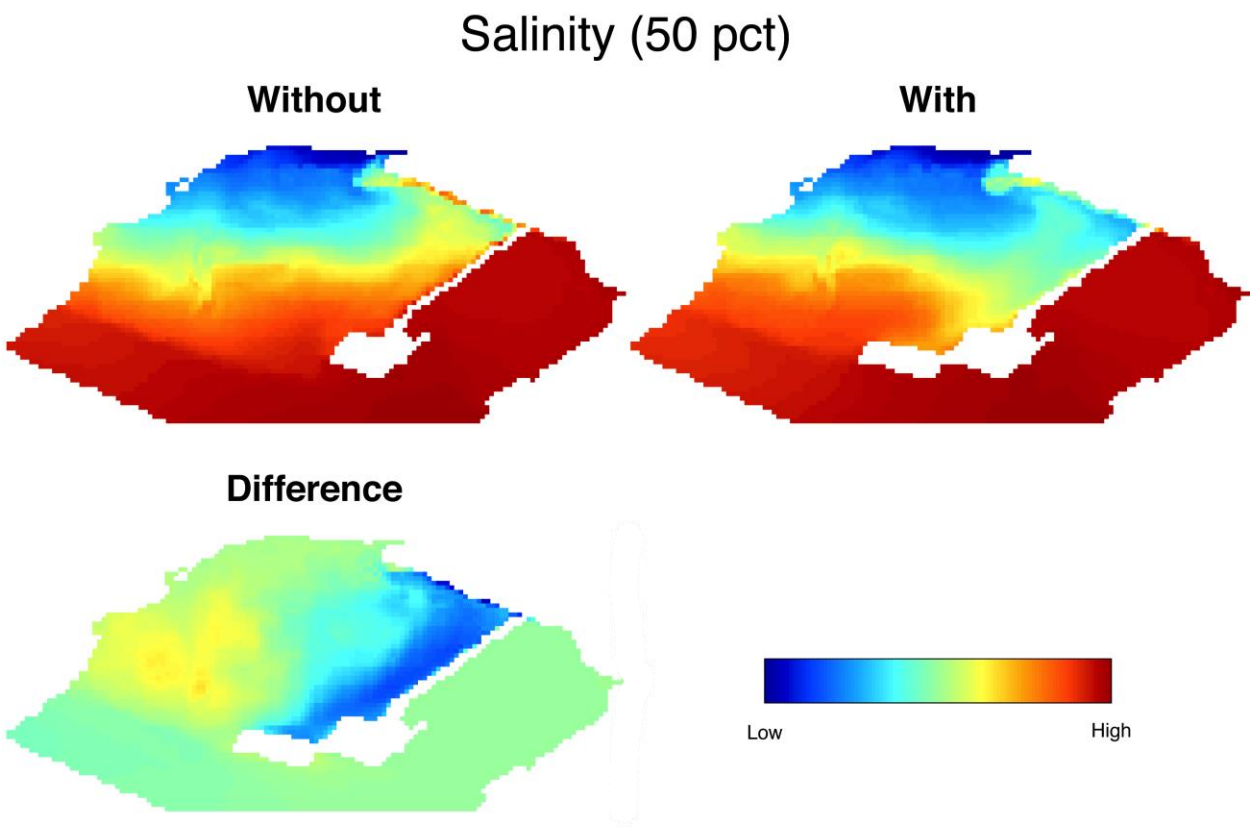
2.2.3 *Salinity*

The Roberts Bank area experiences large daily variation in salinity. The functional groups in the study area are accustomed to large daily fluctuations in salinity. As there may be potential effects to the ecosystem when the average conditions change (either increase or decrease in salinity), the 50th percentile conditions were used in the Roberts Bank ecosystem model, instead of the 90th percentile conditions to capture lower threshold

events. The analyses in this report were done using the 50th percentile salinity averaged over the summer freshet months (May, June, and July), and the non-freshet months (October, November, and December). The key changes in salinity are a band of fresher water along the northwest side of the Roberts Bank causeway, and salinity increases in the area northwest of the Project (**Figure 2-2**). There is no change in salinity forecasted for the inter-causeway area.

A more detailed description of the coastal geomorphology changes associated with the Project is in the Coastal Geomorphology Study (NHC 2014).

Figure 2-2 Estimated Average Salinity from the Coastal Geomorphology Model, Representing Without the Project, With the Project, and the Difference (With - Without)



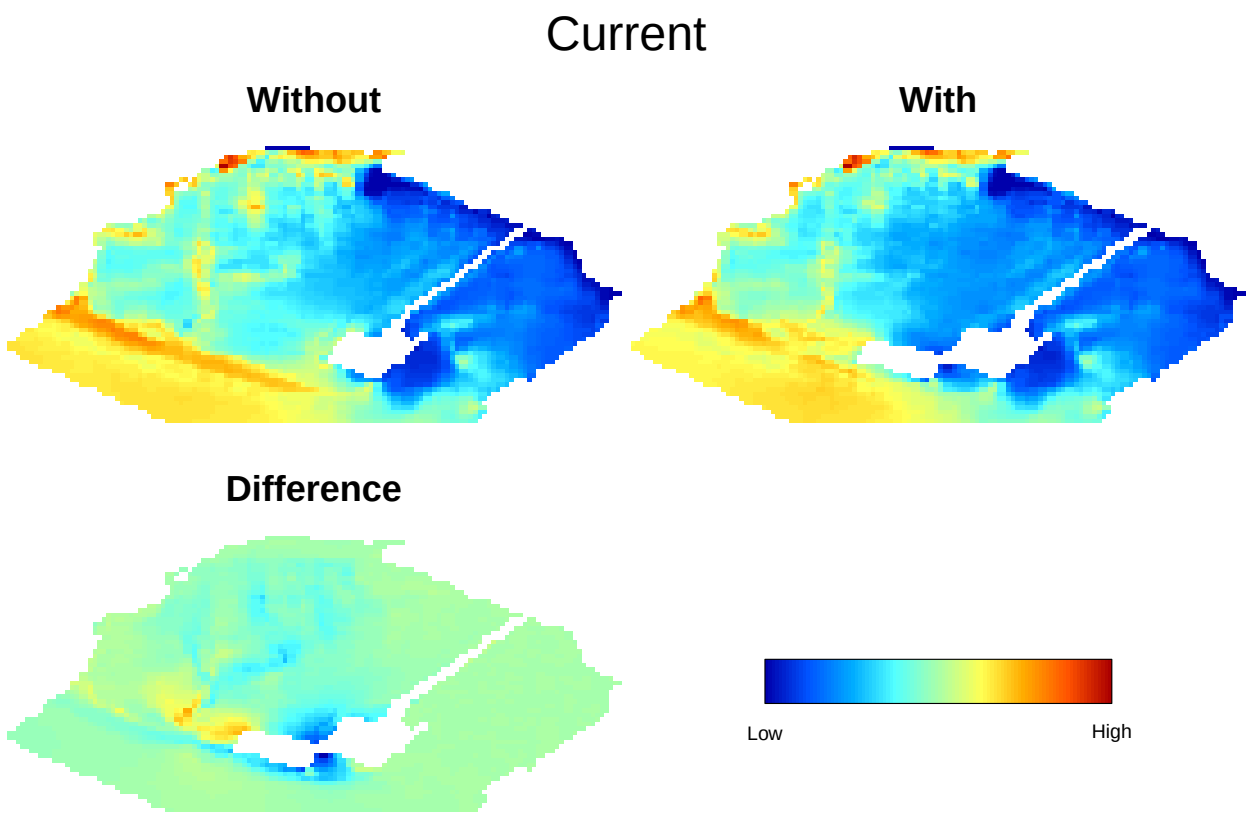
Note: Average salinity conditions use the 50th percentile (pct), unit is psu (not shown on plots). The colour scale indicates values from low (blue) to high (red)

2.2.4 *Bottom Currents*

The average bottom currents in the areas at the intersections of the existing Roberts Bank terminals and RBT2, both on the inside and outside of the terminals are forecasted to

decrease with the project (**Figure 2-3**). Further, there is an increase in bottom currents (due to higher tidal flows) to the northwest of the Project. This is because tidal water in the numerical model has to move around the proposed new terminal four times daily. There is no indication of change in average bottom currents in the inter-causeway area.

Figure 2-3 Estimated Average Bottom Current from the Coastal Geomorphology Model, Representing Without the Project, With the Project, and the Difference (With - Without)



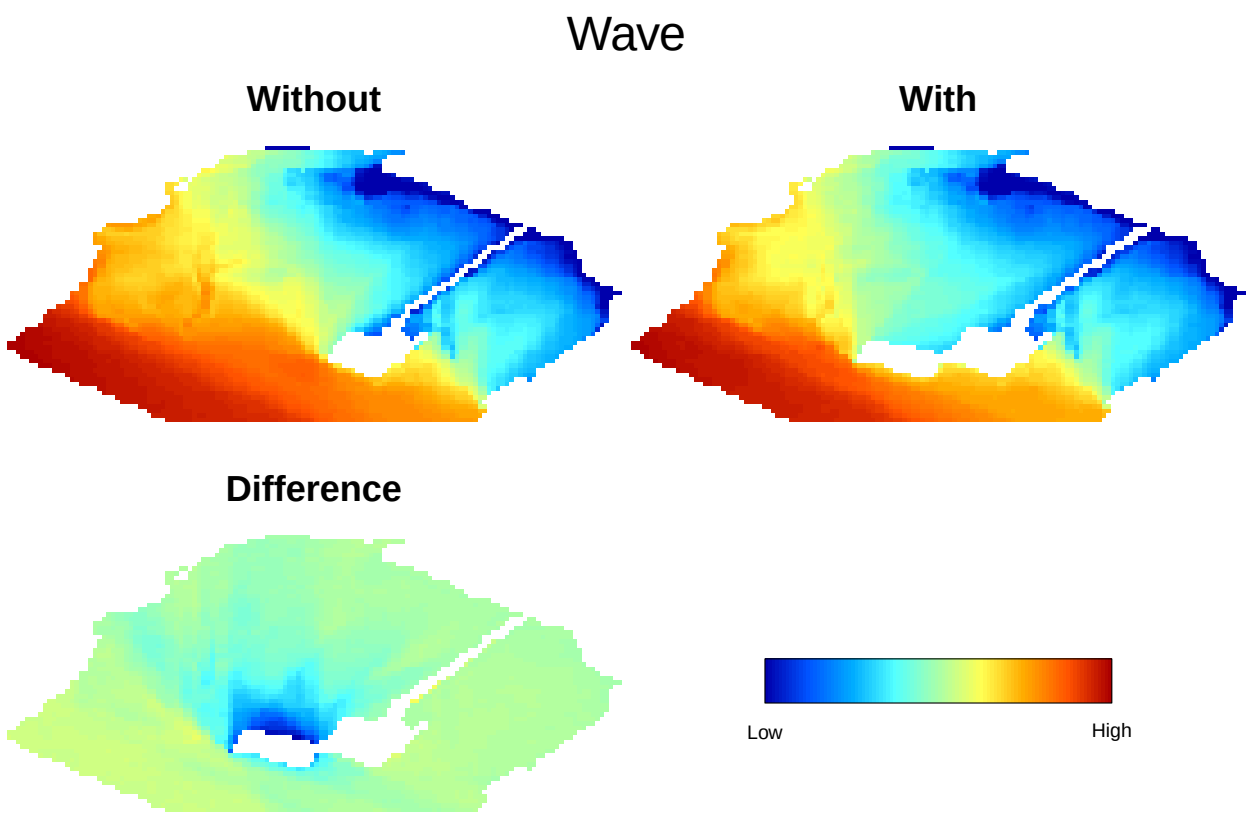
Note: Average bottom current conditions use the 90th percentile; unit is m/sec (not shown on plots). The colour scale indicates values from low (blue) to high (red)

2.2.5 *Wave Height*

The coastal geomorphology model forecasts that the main change in average wave height will be due to a wave shadow spreading out in a fan-like manner behind the Project (i.e., to the north and to some degree to northwest and northeast, **Figure 2-4**).

The average bottom wave heights are not forecasted to change in the inter-causeway area.

Figure 2-4 Estimated Average Wave Height from the Coastal Geomorphology Model, Representing Without the Project, With the Project, and the Difference (With - Without)



Note: Average wave height conditions use the 90th percentile; unit is m (not shown on plots). The colour scale indicates values from low (blue) to high (red)

2.3 Hard Bottom Layer

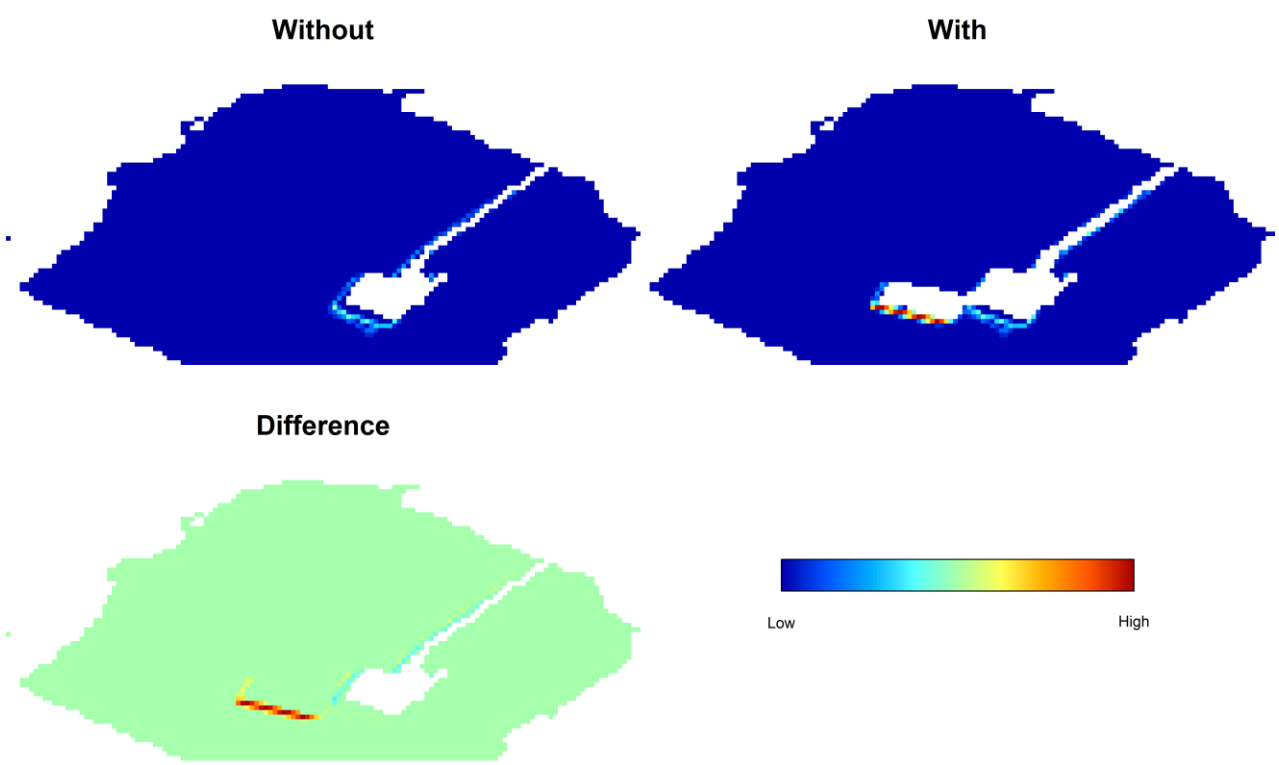
Hard (or rocky) bottom (e.g., cobble, boulder or rip rap) serves as preferred habitat for many species (e.g., brown algae), and its areal distribution may be affected by the proposed Project. For use within the Roberts Bank ecosystem model, two spatial layers representing hard bottom with and without the Project were constructed (Hemmera 2014).

To distinguish hard from soft substrate, ArcGIS was used to create, with and without RBT2, binary raster surfaces. For the without RBT2 surface, complex polygon habitat maps were reclassified and converted to a 5-metre resolution raster surface. Hard substrate cover was reclassified as 1 and all other substrates were classified as 0. For the with RBT2 surface, the Project footprint was used to clip out the footprint area from the without project raster. The terminal engineering CAD drawings were converted into shape files and the tidally exposed, hard substrate footprint of the causeway and terminal structure were isolated, classified as

1, and exported as a separate shape file. The project surface was then merged with the without project hard surface footprint adding to the existing hard surface not clipped by the Project footprint. This produced a surface that had the area of the proposed terminal removed from the raster, but included rocky substrate created by the Project.

The hard bottom layer is expressed as the proportion of a cell that was hard bottom [0-1]. It is assumed that the inverse of the layer expresses the proportion that is soft bottom, i.e., if the proportion of hard bottom in a cell is 0.9, then the proportion of soft bottom in that cell is assumed to be 1 – 0.9 = 0.1. Hard bottom is limited to the area adjacent to the Roberts Bank causeway, RBT and RBT2 terminals (**Figure 2-5**).

Figure 2-5 Estimated Hard Bottom, Representing Without the Project, With the Project, and the Difference (With - Without)



Note: Hard bottom is a proportion of a cell as an interval [0, 1]. The colour scale indicates values from low (blue) to high (red)

2.4 THE STATIC MASS-BALANCE FOOD WEB MODEL, ECOPATH

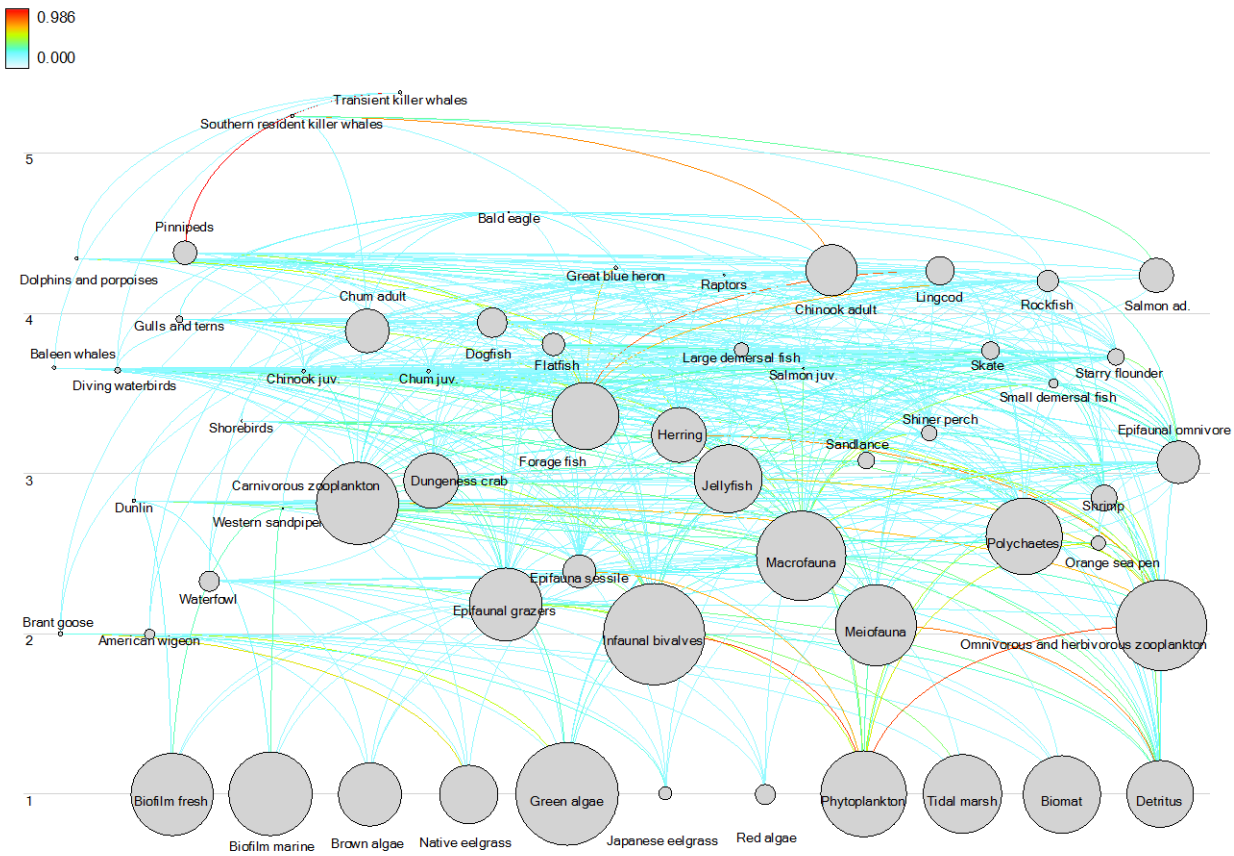
The Roberts Bank ecosystem model builds on a trophic mass-balance Ecopath model that was developed to assess changes in productivity associated with the proposed RBT2. The Ecopath model was parameterised to the extent possible based on biological and ecological data obtained from field sampling in the study area in 2012 and 2013. The Ecopath model was developed based on the EwE approach and software as described in the Roberts Bank Ecosystem Model Parameter Estimates Report, which provides an overview of the functional groups in the study area as well as the parameters for the Ecopath model (Hemmera 2014). **Table 2.1** provides a list of the functional groups and focal species used in the Roberts Bank ecosystem model.

Table 2.1 Overview of Functional Groups in the Roberts Bank Ecopath Model

Functional groups					
Marine mammals		19	Chum salmon* juvenile	39	Epifaunal sessile suspension feeders
1	Baleen whales	20	Chum salmon* juvenile	40	Infaunal bivalve*
2	Dolphins and porpoises	21	Dogfish	41	Jellyfish
3	Pinnipeds	22	Flatfish	42	Macrofauna*
4	Southern resident killer whales*	23	Forage fish	43	Meiofauna
5	Transient killer whales*	24	Herring	44	Omnivorous and herbivorous zooplankton
Birds		25	Large demersal fish	45	Polychaetes*
6	American wigeon*	26	Lingcod*	46	Orange sea pen
7	Bald eagle*	27	Rockfish*	47	Shrimp
8	Brant goose*	28	Salmon adult	Primary producers	
9	Diving waterbirds	29	Salmon juvenile	48	Biofilm fresh*
10	Dunlin*	30	Sandlance*	49	Biofilm marine*
11	Great blue heron*	31	Shiner perch*	50	Brown algae*
12	Gulls and terns	32	Skate	51	Eelgrass (native)*
13	Raptors	33	Small demersal fish	52	Green algae*
14	Shorebirds	34	Starry flounder*	53	Japanese eelgrass (non-native)*
15	Waterfowl			54	Red algae
16	Western sandpiper*	Invertebrates		55	Phytoplankton
		35	Carnivorous zooplankton	56	Tidal marsh*
Fish		36	Dungeness crab*	57	Biomat
17	Chinook salmon* adult	37	Epifaunal grazer	Detritus	
18	Chinook salmon* juvenile	38	Epifaunal omnivores	58	Detritus

Note: * indicates focal species as identified by the PC-TAG

Figure 2-6 Representation of the Food Web in the Roberts Bank Ecosystem Model



Note: Functional groups are arranged after **trophic level** (TL, Y-axis) with primary producers and detritus at TL 1, and consumers at increasing TLs depending on their diets. The three-dimensional volumes represented by the circles are proportional to the biomass for each functional group. The colours indicate interactions strength based on diet compositions, with strength ranging from 0 to 1 (colour scale)

The food web in the Ecopath model is shown on **Figure 2-6**. The lines on the diagram indicate how the functional groups are connected through predator prey linkages. The functional groups are arranged vertically by trophic level (TL). Primary producers and detritus are at TL 1, while the TLs for consumer groups were estimated in the Ecopath model so that the TL of a functional group is one higher than the average TL of the functional group's prey. As an example, a functional group that feeds exclusively on primary producers will have a TL of 2, and a group that feeds 50% on that group and 50% on primary producers will have TL = (1 + 2)/2 + 1 = 2.5.

Transient killer whales are the top predators at Roberts Bank and the Strait of Georgia in general, with a TL of 5.4, followed by southern resident killer whales, whose TL is 5.2 (**Figure 2-6**). The 'habitat forming' groups (comprising primary producers and orange sea pens), occupy the first trophic level, with the exception of orange sea pens, with a TL of 2.6.

2.5 ECOPATH MODEL PEDIGREE

The pedigree describes the origin of data in the basic Ecopath model, with assumed uncertainty parameters associated with the input quality. Inputs derived from local data (i.e., from field sampling at Roberts Bank) represent local conditions better than data from elsewhere, be they based on professional judgement, derived from empirical relationships, other models or sampling locally or in a different location. This follows the logic, which linked the pedigree of estimates with the quality of models they were based on (Funtowicz and Ravetz 1990).

The data pedigree of the Ecopath model provides:

- A clear overview of the degree to which model parameters are based on local, field-based data;
- A basis for computing an overall index of model 'quality' (a model has high quality when it is constructed mainly using precise estimates of various parameters, based on data from the system to be represented by the model); and
- Default parameter ranges for evaluating of how uncertainty in the input parameters may impact the model findings (ESSA 2014).

The pedigree information can be used for two different purposes:

1. The approximate **confidence interval** (CI; in % of mean) associated with the indicators are used for subsequent Monte Carlo uncertainty evaluation; and
2. The pedigree indicator scores (ranging from 0.0 to 1.0) are averaged over all parameters and functional groups of a model to provide an index of that model's 'quality'.

The reasoning behind (2) is that a model based on locally, well-sampled high-precision data is considered to be of higher quality than a model whose input values were provided by professional judgement, or estimated based on other models.

2.5.1 *Biomass*

This scale was based on the observation that the functional groups' biomass is difficult to estimate accurately, and that there are different levels of uncertainty depending on the pedigree of data used (**Table 2.2**). This also applies to biomass estimates that are obtained from other models, where local conditions may be different.

Table 2.2 Model Pedigree Definitions for Biomass

No.	Parameter	Index	CI (%)
1	'Missing' parameter (estimated by Ecopath)	0.0	n.a.
2	From other models	0.0	80
3	Based on professional judgement	0.0	80
4	Approximate or indirect method	0.4	50
5	Sampling based, low precision	0.7	30
6	Sampling based, high precision	1.0	10

Note: The pedigree evaluates quality of the data sources. The index value is used for estimating the overall pedigree index. CI indicates the confidence interval expressed relative to the mean.

2.5.2 *Production/Biomass and Consumption/Biomass Ratios*

This scale is based on the P/B and Q/B ratios being conservative parameters that are functions of species' size and population dynamics, i.e., characteristics for which there is ample information available (e.g., from empirical models or FishBase; (Froese and Pauly 2006)). See **Table 2.3** for P/B and Q/B pedigree definitions.

Table 2.3 Model Pedigree Definitions for Production/Biomass and Consumption/Biomass Ratios

No.	Parameter	Index	CI (%)
1	'Missing' parameter (estimated by Ecopath)	0.0	n.a.
2	Professional judgement	0.1	70
3	From other models	0.2	60
4	Empirical relationships	0.5	50
5	Similar group/species, similar system	0.6	40
6	Similar group/species, same system	0.7	30
7	Same group/species, similar system	0.8	20
8	Same group/species, same system	1.0	10

Note: The index value is used for estimating the overall pedigree index. CI indicates the confidence interval expressed relative to the mean.

2.5.3 *Diets*

Species' diet compositions can be spatially temporally variable, and thus locally observed diets for the time period models tend to be more reliable than those derived from other systems and/or species groups.

Pedigree definitions for diets are given in **Table 2.4**.

Table 2.4 Model Pedigree Definitions for Diet Compositions

No.	Parameter	Index	CI (%)
1	General knowledge of related group/species	0.0	100
2	From other models	0.0	100
3	General knowledge for same group/species	0.2	80
4	Qualitative diet composition study	0.5	50
5	Quantitative but limited diet composition study	0.7	40
6	Quantitative, detailed, diet composition study	1.0	30

Note: The index value is used for estimating the overall pedigree index. CI indicates the confidence interval expressed relative to the mean.

2.6 ECOPATH MODEL BALANCING

A mass-balance model serves to summarise and evaluate ecosystem-level information for internal consistency. Production of prey groups has to meet the consumption demand of predators. Ecopath checks the balance by evaluating the ecotrophic efficiencies (EE) of all functional groups. If the EE of a group exceeds 1, it means the demand of predators exceeds the production of their prey groups.

An Ecopath model is rarely balanced when it is first constructed. Balancing is an iterative process that requires careful evaluation of parameter inputs of those functional groups whose mass does not balance. Evaluation is done by, for instance, changing input parameters, such as diet composition, before running the model again. This iterative process continues until the model is balanced. The mass-balance condition provides limits within which parameter combinations are possible, thus the balanced model has to operate within these limits. The Roberts Bank ecosystem model was balanced by identifying potential errors in data inputs.

The procedure followed for the Roberts Bank Ecopath model included model parameterisation and mass balancing by different teams. As a rule for balancing, diets are changed first, followed by P/B and Q/B values, and, if necessary biomass estimates are changed. Values for input parameters, including diet compositions, enable the model to be constructed (Hemmera 2014). The model was balanced by compiling a list of errors and suggested corrections, which were evaluated and corrective action was implemented. This iterative process continued until the model was mass-balanced and parameters were within acceptable limits.

2.6.1 *Diet Composition Changes*

Diet compositions for the Roberts Bank ecosystem model included those of groups that were later aggregated, and whose diets were added to the diet proportions of the groups they were merged with.

Mass balancing started by confirming that the sum of all diet proportions within each functional group was equal to 1. Where this was not the case (generally because of rounding errors), or where items were removed from the diets, the 'missing' diet fraction was added to the group with the biggest contribution to the diet (or subtracted where the sum of the diet proportions was greater than 1).

For illustration purposes, the following are examples of diet composition changes that were made to balance the Roberts Bank Ecopath model:

- The pinnipeds caused excessive predation mortalities on numerous fish functional groups. The biomass of pinnipeds 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.

- The initial input diet of transient killer whales resulted in an EE of 83 for baleen whales and 12.5 for dolphins and porpoises (EE values should range between 0 and 1). The P/B input parameters of these prey groups were reasonable, hence their contribution to the transient killer whale diet was reduced by a factor of 200 and 20, respectively. The 'missing' diet proportion of transient killer whales was assumed to be pinnipeds.

- Initially, bald eagle was assumed to prey on chinook and chum salmon, but this was later changed to a site-specific preference for gulls. The EE of brant goose was 1.6 due to bald eagle predation. As P/B input parameters of bald eagle were reasonable, brant goose contribution to the bald eagle diet was lowered, and bald eagle were assumed to prey also on diving waterbirds.

The resulting basic input parameters (B, P/B, Q/B, and EE) for the Roberts Bank ecosystem model are presented in **Table 2.5**. The model requires three of four input parameters for each species or group.

Table 2.5 Basic Input Parameters for the Roberts Bank Ecosystem Model after Model Balancing

No	Group name	TL	B	P/B	Q/B	EE
1	Baleen whales	*3.66*	0.005	0.03	13.4	*0.05*
2	Dolphins and porpoises	*4.34*	0.005	0.16	20.1	*0.78*
3	Pinnipeds	*4.38*	0.4	0.14	16.0	*0.92*
4	Southern resident killer whales	*5.23*	0.01	0.04	14	*0.00*
5	Transient killer whales	*5.38*	0.0052	0.04	10	*0.00*
6	American wigeon	*2*	0.0873	0.2	200	*0.21*
7	Bald eagle	*4.63*	0.0022	0.25	41	*0.00*
8	Brant goose	*2*	0.0199	0.2	200	*0.02*
9	Diving waterbirds	*3.65*	0.0276	0.24	92.6	*0.12*
10	Dunlin	*2.83*	0.0086	0.51	92	*0.03*
11	Great blue heron	*4.28*	0.0123	0.49	82	*0.00*
12	Gulls and terns	*3.96*	0.0484	0.23	70.8	*0.81*
13	Raptors	*4.24*	0.0002	0.35	41.3	*0.00*
14	Shorebirds	*3.33*	0.0008	0.51	92	*0.30*
15	Waterfowl	*2.33*	0.303	0.2	200	*0.03*
16	Western sandpiper	*2.78*	0.0011	0.51	92	*0.21*
17	Chinook adult	*4.27*	3.43	0.31	2	*0.12*
18	Chinook juvenile	*3.64*	0.012	0.8	*2.67*	*0.44*
19	Chum adult	*3.89*	2.05	0.43	1.4	*0.07*
20	Chum juvenile	*3.64*	0.009	0.9	*3*	*0.70*
21	Dogfish	*3.95*	0.659	0.12	*2.77*	*0.00*
22	Flatfish	*3.8*	0.375	0.37	3.53	*0.20*
23	Forage fish	*3.36*	10.5	0.95	6.4	*0.98*
24	Herring	*3.24*	4.45	0.8	5.5	*0.36*
25	Large demersal fish	*3.77*	0.154	0.51	4.78	*0.83*
26	Lingcod	*4.27*	0.587	0.31	1.7	*0.08*
27	Rockfish	*4.2*	0.339	0.22	2.85	*0.19*
28	Salmon adult	*4.24*	*1.02*	0.43	1.4	0.50
29	Salmon juvenile	*3.66*	0.0017	0.85	*2.83*	*0.99*
30	Sandlance	*3.08*	0.208	0.47	4.2	*0.54*
31	Shiner perch	*3.26*	0.164	1.27	9.4	*0.94*
32	Skate	*3.76*	0.231	0.09	1.2	*0.36*
33	Small demersal fish	*3.56*	0.0723	1	7.96	*0.95*
34	Starry flounder	*3.73*	0.210	0.4	4.6	*0.76*
35	Carnivorous zooplankton	*2.82*	29.8	7	20	*0.48*
36	Dungeness crab	*2.96*	4.63	2.5	5	*0.11*
37	Epifaunal grazers	*2.19*	15.3	1.45	*7.24*	*0.74*
38	Epifaunal omnivore	*3.07*	1.93	3.5	14	*0.82*
39	Epifauna sessile	*2.39*	0.896	1.71	22.2	*0.76*
40	Infaunal bivalves	*2*	121	2.06	6.86	*0.05*

No	Group name	TL	B	P/B	Q/B	EE
41	Jellyfish	*2.97*	11.0	9.6	13	*0.52*
42	Macrofauna	*2.48*	50.3	4	*13.3*	*0.69*
43	Meiofauna	*2.05*	29.1	8	*40*	*0.61*
44	Omnivorous and herbivorous zooplankton	*2.05*	54.4	24	70	*0.75*
45	Polychaetes	*2.61*	20.2	5	*25*	*0.10*
46	Orange sea pen	*2.57*	0.141	1.2	*6*	*0.03*
47	Shrimp	*2.85*	0.5	2.4	*9.67*	*0.91*
48	Biofilm fresh	*1*	30.1	36		*0.00*
49	Biofilm marine	*1*	33.3	36	-	*0.00*
50	Brown algae	*1*	8.21	9	-	*0.10*
51	Native eelgrass	*1*	5.58	18	-	*0.04*
52	Green algae	*1*	126	13	-	*0.07*
53	Japanese eelgrass	*1*	0.126	10	-	*0.95*
54	Red algae	*1*	0.278	20	-	*0.45*
55	Phytoplankton	*1*	40	130	-	*0.91*
56	Tidal marsh	*1*	24.4	15	-	*0.05*
57	Biomat	*1*	22.3	83	-	*0.00*
58	Detritus	*1*	10	-	-	0.16

Note: B is biomass (t km^{-2}), P/B is production/biomass ratio ($year^{-1}$), Q/B is consumption/biomass ratio ($year^{-1}$), and EE the ecotrophic efficiency (proportion). There are no input values for the grey shaded cells. Q/B's in italics were based on assumed **production/consumption** (P/Q) ratios. Other values in *italics* are estimated through mass balance. Trophic levels (TL) are estimated from the diet compositions.

2.6.2 *Fixed Selectivity Principle for Diets*

For most groups in the Roberts Bank ecosystem model, diet information was qualitative rather than quantitative. It was therefore reasonable to assume that the prey preference for such predators when feeding on fish should be comparable across species. This principle of 'fixed selectivity' was used to adjust the diet composition of pinnipeds, diving waterbirds, great blue heron, shorebirds, chinook adult, chinook juvenile, chum juvenile, dogfish, flatfish, large demersals, lingcod, rockfish, salmon juvenile, skate, and starry flounder. The total contribution of fish in the diet of these predators was maintained, but the distribution among prey groups was estimated relative to prey productivity.

The 'fixed selectivity' principle was also used to adjust the contribution of invertebrates in the diets of diving waterbirds, waterfowl, forage fish, herring, carnivorous zooplankton, jellyfish, macrofauna, and polychaetes. Contribution of vegetation was also adjusted in a similar way in the diets of American wigeon, waterfowl, epifaunal grazer, epifaunal

omnivore, and macrofauna. 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.

The resulting diet composition for the Roberts Bank ecosystem model after mass balancing is presented in the Roberts Bank Ecosystem Model Parameter Estimates Report (Hemmera 2014).

2.7 MIXED TROPHIC IMPACTS (MTI)

Hannon (1973) modified an economic model for ecological application, and thereby made it possible to describe the direct and indirect impact of any group in an ecosystem on all other groups in the ecosystem. Ulanowicz and Puccia (1990) developed a similar approach, and a module based on their method is implemented in the Ecopath system. The approach is called a Mixed Trophic Impact (MTI) routine, and it can be regarded as a form of 'ordinary' sensitivity analysis (Majkowski 1982).

The MTI uses the Ecopath diet composition to evaluate how each group in an ecosystem impacts all other groups directly or indirectly through the food web. A predator will thus have a direct positive-negative impact on its prey (and also a negative impact on its competitors for that prey) and an indirect positive impact on the prey of the prey. Also, where two consumers compete for the same resource, the MTI will estimate the negative impacts such groups will have on each other, even if the impact is indirect or separated with several steps between trophic levels within the food web.

The MTI analysis has seen wide use through its incorporation in the EwE approach and ecosystem modelling software, and there is by now considerable experience with the methodology, which thus can be considered well established.

2.8 ECOSIM - TIME DYNAMIC MODULE

Ecosim has been used for hundreds of applications, and its input requirements, capabilities, and limitations are well documented (Christensen and Walters 2004; 2011). The mass-balance Ecopath model is the starting point of Ecosim, which simulates biomass changes of functional groups over time, based on drivers such as environmental or habitat effects and exploitation patterns (Walters et al. 1997; 2000). An additional key input that requires parameterisation in Ecosim includes vulnerability. Vulnerability represents how far a given

group is from its carrying capacity. Ecosim includes vulnerability, which incorporates density-dependence in the model.

For example, vulnerability equal to 10 indicates that a predator can increase predation mortality onto its prey by no greater than 10 times. Vulnerability set to 1 (the lower limit for vulnerability) implies that the predator can not increase the prey's predation mortality. In these two instances, the former predator is farther from its carrying capacity than the latter, which is at or very near carrying capacity.

In Ecosim, time dynamic simulations are fitted to time series data (Christensen et al. 2011). However, this was not possible for the Roberts Bank ecosystem model for which there was no time series data. Instead, alternative assumptions about the impact of vulnerability settings on productivity changes are evaluated in the accompanying Roberts Bank Ecosystem Model Sensitivity Analyses Report (ESSA 2014).

2.9 ECOSPACE - SPATIAL MODEL

The spatial model created in Ecospace inherits information from the static Ecopath model and the time dynamic Ecosim module, to which spatially-explicit parameters are added (Walters et al. 1999; 2010). For the Roberts Bank ecosystem model, this process involved definition of the spatial model's geographic extent, and the spatial layers the model would consider.

Ecospace uses a regular two-dimensional grid, and is typically implemented with monthly time steps. Monthly time steps were used for the Roberts Bank ecosystem model to assess long-term productivity changes. Moreover, there was insufficient information available to address shorter-term impacts, such as, for example, those caused by tidal current events. It was assumed that such impacts would be captured by changes in average conditions (e.g., average current conditions). Ecospace uses variable speed-splitting to integrate dynamics of fast turnover species (e.g., biofilm) with slow turnover species (e.g., killer whales). This approach results in fast model runtime and provides results that are very similar to what would be obtained when using fast turnover species to dictate time steps (Walters et al. 1999).

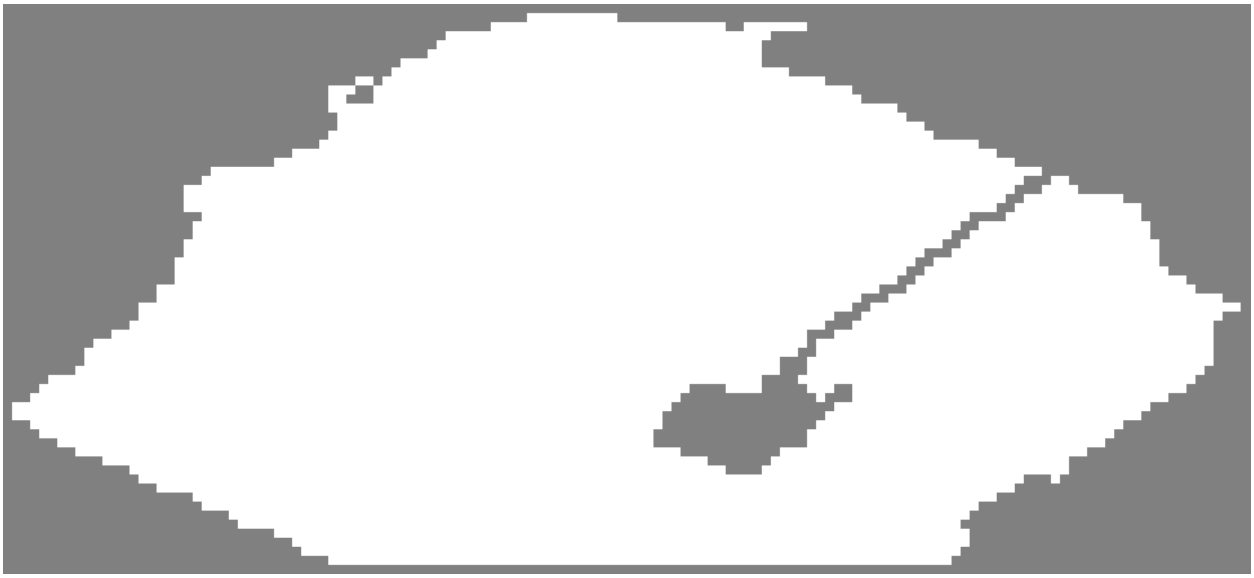
2.9.1 *Model Area and Resolution*

The coastal geomorphology model used for Roberts Bank covers the central and southern parts of the Strait of Georgia, which has its finest spatial resolution at Roberts Bank (**Figure**

2-7) (NHC 2014). Although the model forecasted minimal geomorphology changes outside Roberts Bank as a result of the Project, it was decided that the spatial ecosystem model would only consider Roberts Bank.

The geomorphic model (NHC 2014) has a varying resolution down to around 25 m in the study area. The biological information is, however, not available at such fine scale, and it was decided to use a more coarse resolution for the ecosystem model. The EwE study area is 54.68 km^2 (without the proposed Project), and was modelled in Ecospace using a uniform grid of 100 x 100 m (i.e., 1 ha) cells, for a total of 138 columns by 63 rows, resulting in 8,694 grid cells.

Figure 2-7 The Study Area of the Spatial Roberts Bank Ecosystem Model



Note: Grid size was 100 x 100 m (1 ha) cells, with a total of 8,694 grid cells. Only the 5,468 files in the non-shaded area were included in the calculations, however

2.9.2 *Spatial Model Parameters*

Ecospace for the Roberts Bank ecosystem model was parameterised using the static Ecopath model, Ecosim and adding spatial parameters for the distribution of the functional groups.

The most important parameter was the dispersal rate between spatial cells. This is generally group-specific, but for Roberts Bank it was set to 1 km $year^{-1}$, which is a relatively low value, for all groups. The implication of this was that Ecospace focused on forecasting

productivity within cells and how these might be affected by the proposed Project, rather than on spill-over effects between cells.

2.9.3 *Model Code Development*

The EwE methodology is proven within literature and can be adapted when applied to specific, localized contexts. In compiling the Roberts Bank ecosystem model, instead of developing methodology, the focus was on model application. Some new features (described next) were added to EwE to address issues specific to the Roberts Bank ecosystem model.

EwE is modular and allows for the development of 'plug-ins'. Plug-ins can communicate with the core software, acquire and set parameters, and acquire results. For the Roberts Bank ecosystem model, two plug-ins were added and one adjustment made to the core software. The first plug-in was constructed to repeat the initial modelling conditions and approach an equilibrium state by the start of the runs. The second plug-in allowed for changes in depths during spatial runs. This was required to incorporate the direct footprint of the proposed Project.

The adjustment allowed EwE to use an 'exclusion layer' and mask cells that should not be included in calculations. Masked cells included water cells outside the study area, but within the overall model area. Masking allowed calculations to proceed faster by defining study area boundaries, and skipping model calculations for cells outside the study area.

2.9.4 *Model Run Time*

The spatial model ran until it approached equilibrium, which took 10 years. After one additional year, the model read changes due to the Project using the temporal-spatial framework described above. The results of the initial 10-year run were read after an additional run of nine years, for a total run time of 20 years, which established the 'with the Project' conditions.

The 'without the Project' conditions were established by making similar 20-year runs, but without reading in temporal-spatial changes due to the Project. The difference in the forecasted outcomes represented the difference in conditions between 'with' and 'without' the Project.

2.10 TEMPORAL-DYNAMIC MODULE LAYERS

The Roberts Bank ecosystem model used spatial drivers that had the potential to change over time as a result of the proposed Project. Spatial drivers were identified by the coastal geomorphology model and included depth, salinity, bottom current, wave height (see **Section 2.2** Coastal Geomorphology), and substrate type (hard or soft) (see **Section 2.3** Hard Bottom Layer). Spatial drivers were integrated in Ecospace by applying a recently developed temporal-spatial data layer framework (Steenbeek et al. 2013) (see **Section 2.11** The Habitat Capacity Model). This is a flexible framework that incorporates GIS data into Ecospace by setting and implementing interoperability protocols and data standards.

2.11 THE HABITAT CAPACITY MODEL

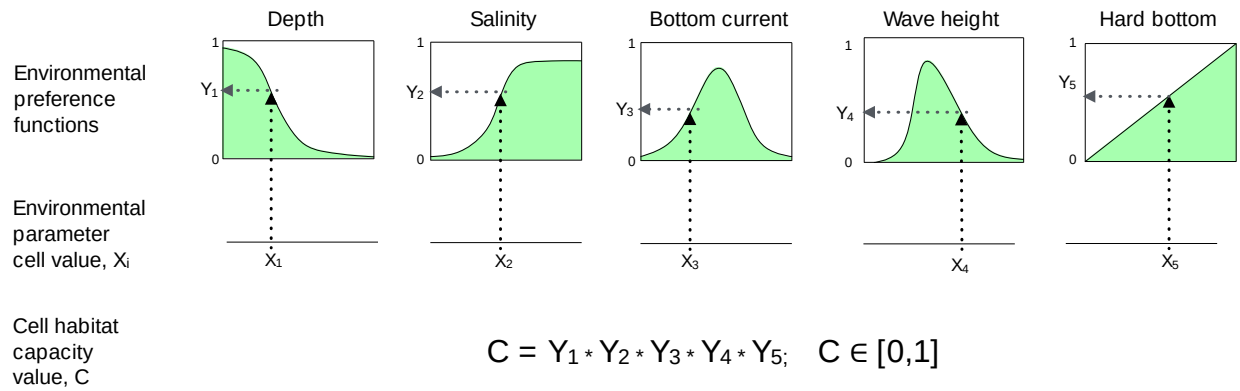
The Roberts Bank ecosystem model used a recently developed EwE habitat capacity modelling approach that combines ecosystem models with species distribution models to examine impacts of variable habitat quality on modelled spatial population distributions (Christensen et al. 2014). The habitat capacity model estimates a continuous habitat suitability factor (range [0,1]), which describes the area that species can use in each cell, as determined by functional responses to spatial drivers. The model offers the ability to influence consumer species' ability to forage (foraging capacity) using a combination of spatial drivers, such as physical, oceanographic, and environmental factors (e.g., depth, bottom type, salinity, bottom current, wave height) (see **Section 2.10** Temporal-dynamic Module Layers). Foraging capacity per cell was calculated for each functional group at every time step.

The model uses similar calculations to directly impact the productivity of primary producers based on environmental preference functions.

The continuous relative habitat capacity C_{rcj} is defined for each group j in each cell r,c, where C_{rcj} varies from 0 to 1, and is calculated for each cell as a function of a vector of habitat attributes $Y_{rc} = (Y_1,Y_2,\ldots Y_v)_{rc}$ of that cell, i.e., $C_{rcj} = f_j(Y_{rc})$. In the case of the Roberts Bank ecosystem model, spatial drivers can be interpreted so that, in each cell, Y_1 is water depth, Y_2 is proportion of hard substrate, Y_3 is average bottom current, Y_4 is average wave height, and Y_5 is average salinity. **Figure 2-8** provides a schematic overview of the calculations in the habitat capacity model. No weighting was used, but weighting can be

considered by altering the shapes of the environmental preferences which is the scope of the accompanying Roberts Bank Ecosystem Model Sensitivity Analyses Report (ESSA 2014).

Figure 2-8 Schematic Diagrams of Environmental Preference Functions for Depth, Salinity, Bottom Current, Wave Height, and Hard/Soft Substrate, Used in the Habitat Capacity Model Calculations of the Roberts Bank Ecosystem Model



2.12 Environmental Preference Functions

Environmental preference functions for the Roberts Bank ecosystem model describe the response of each functional group to changes in depth, salinity, bottom current, and wave height conditions described by the coastal geomorphology model with and without RBT2 (NHC 2014). Information on the functional groups' association with hard substrate was also used (Hemmera 2014). Environmental preference functions of functional groups integrated in the Roberts Bank ecosystem model are presented below.

The horizontal axes of the environmental preference functions extend beyond the values indicated below. However, they are not shown here, because the functional response was assumed to be the same as that exhibited at the higher end of the values range. For instance, occurrence of marine mammals in the study area is not confined in depths ranging from 0 to 35 m. Instead, it was assumed that marine mammals exhibited the same preference for depths equal to and greater than 35 m.

In a number of cases, groups were assumed not to have preference to given environmental parameters. Such cases are represented with uniform preference functions in the following figures. See American wigeon in **Figure 2-11** for an example.

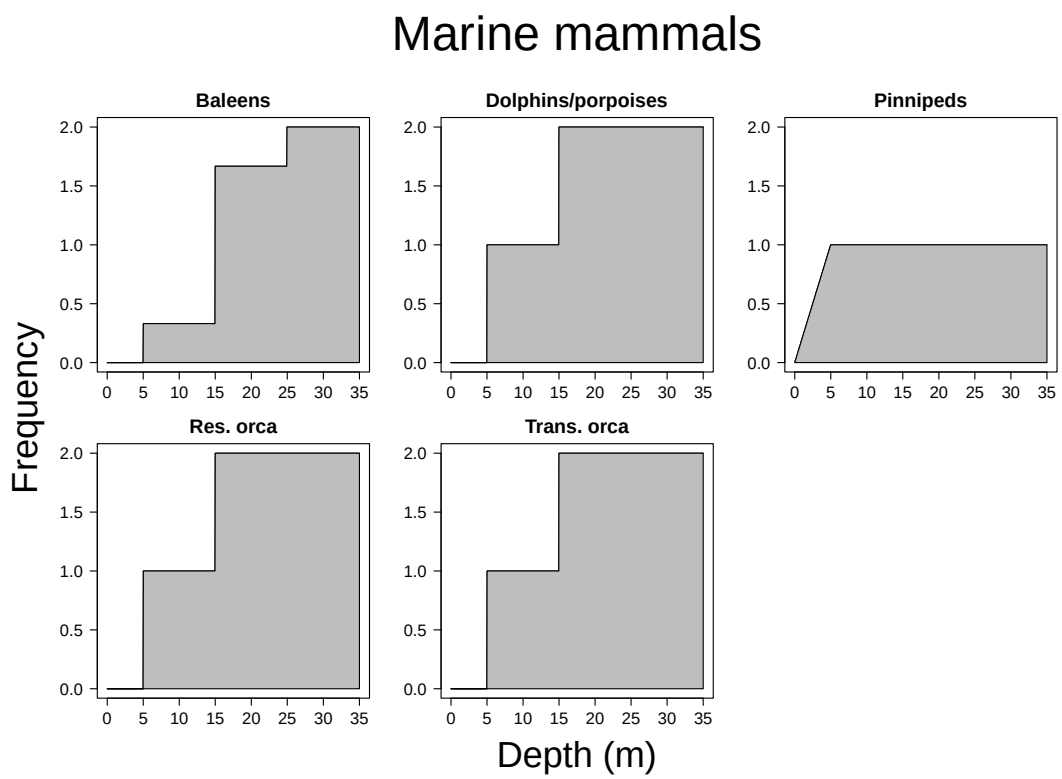
Uniform preference functions represent cases (e.g., bald eagle) where no preference functions were used in the model.

2.12.1 *Marine Mammals*

Functional response of marine mammals was limited to depth (**Figure 2-9**), and it was assumed that marine mammals are non-selective of salinity, bottom current, wave height, and hard/soft substrate. Marine mammal depth preference was obtained from literature (Hemmera 2014). The depth profile of pinnipeds considers only the water column, because no haul-out sites have been reported at Roberts Bank (Bigg 1988; Olesiuk 1999; Jeffries et al. 2000).

Marine mammals can be affected by sound. Although sound implications can be considered in Ecospace through mediation, they were not considered in this study (Christensen and Walters 2004). Potential effects to marine mammals from sound generated during Project construction and operation are assessed in **Section 14 Marine Mammals Effects Assessment** of the proposed Roberts Bank Terminal 2 Environmental Impact Statement.

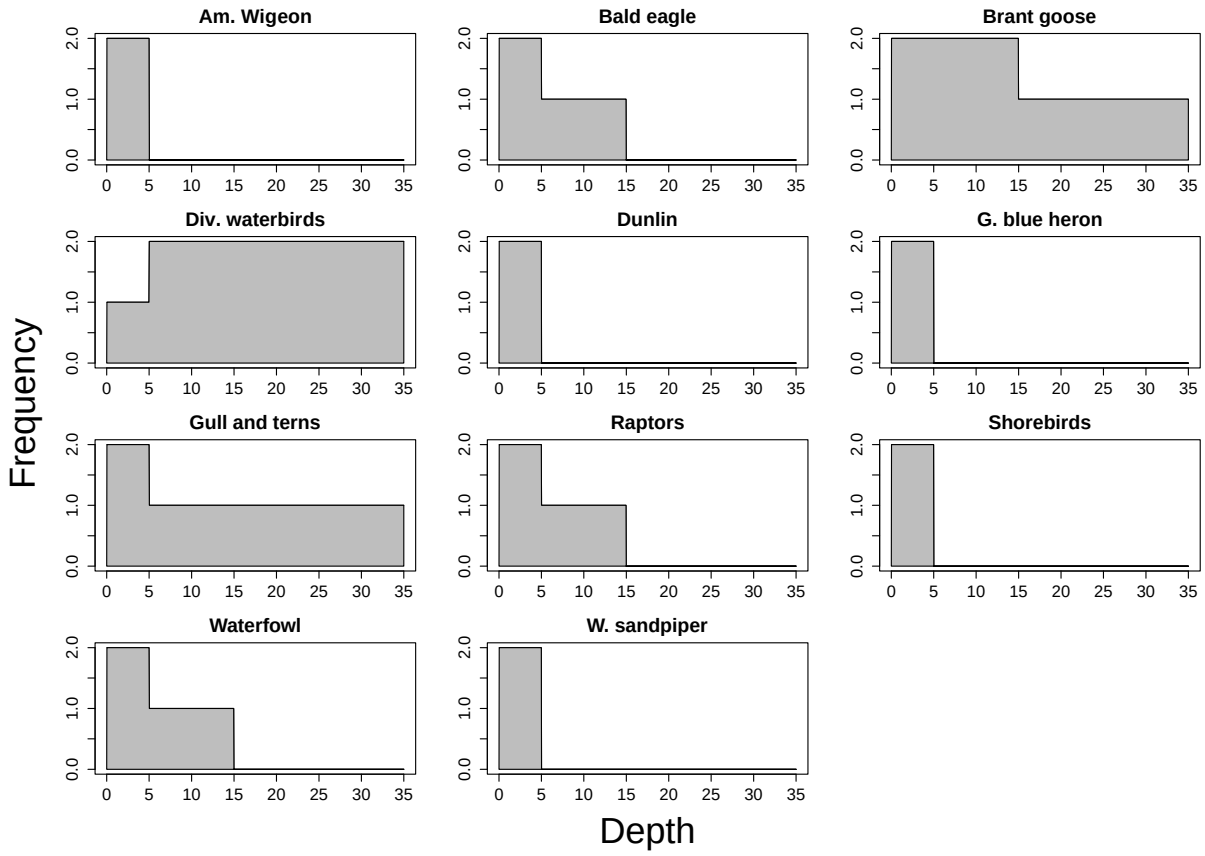
Figure 2-9 Environmental Preference Functions for Marine Mammals and Depth (Below High Tide Level, m)



2.12.2 *Birds*

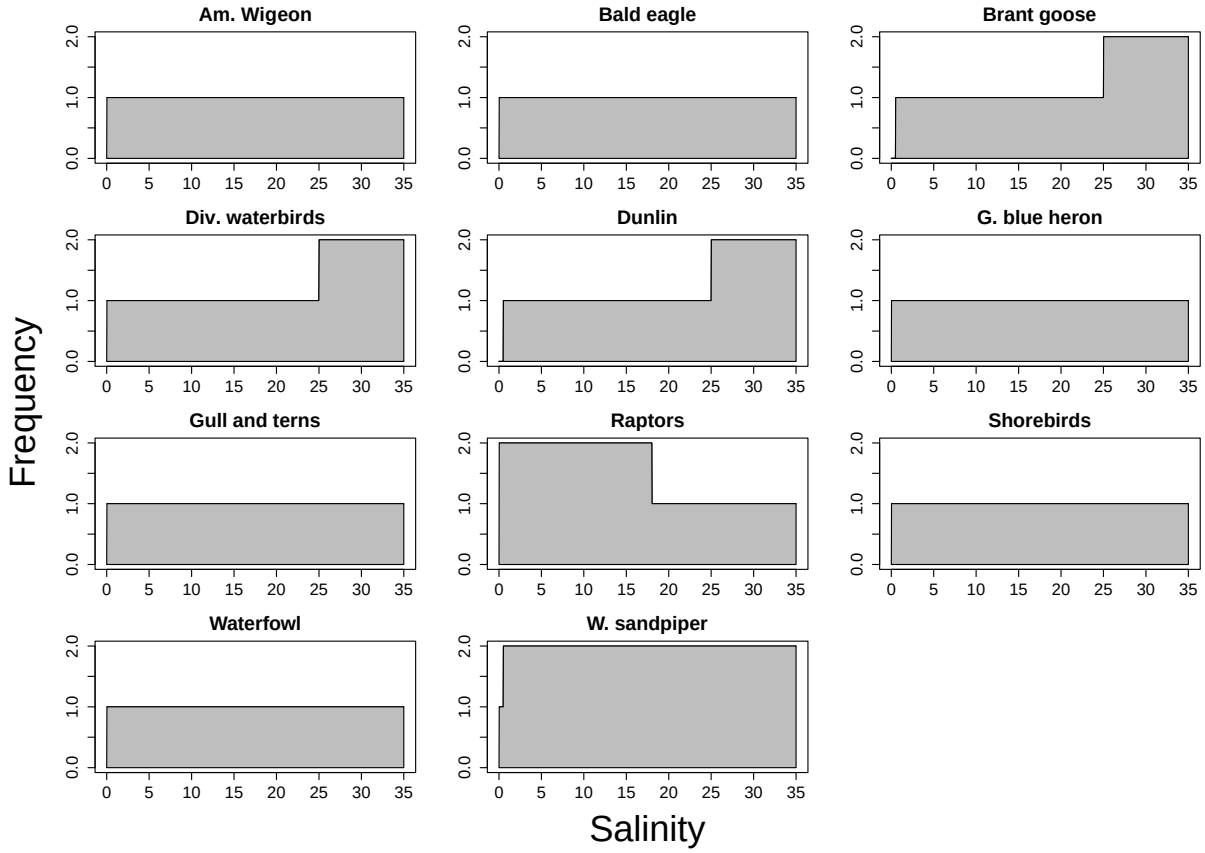
Environmental preference functions derived for depth (**Figure 2-10**) and for salinity (**Figure 2-11**) were obtained from data gathered during field studies conducted for the Project and supplemented by the literature (Hemmera 2014). It was further assumed that American wigeon, brant goose, dunlin, great blue heron, shorebirds, waterfowl, and Western sandpiper favour soft bottom as discussed in Section 2.13.

Figure 2-10 Environmental Preference Functions for Birds and Depth (Below High Tide Level, m)



Note: Am. Wigeon is American wigeon; Div. waterbirds is diving waterbirds; G. blue heron is great blue heron; W. sandpiper is Western sandpiper

Figure 2-11 Environmental Preference Functions for Birds and Salinity (psu)



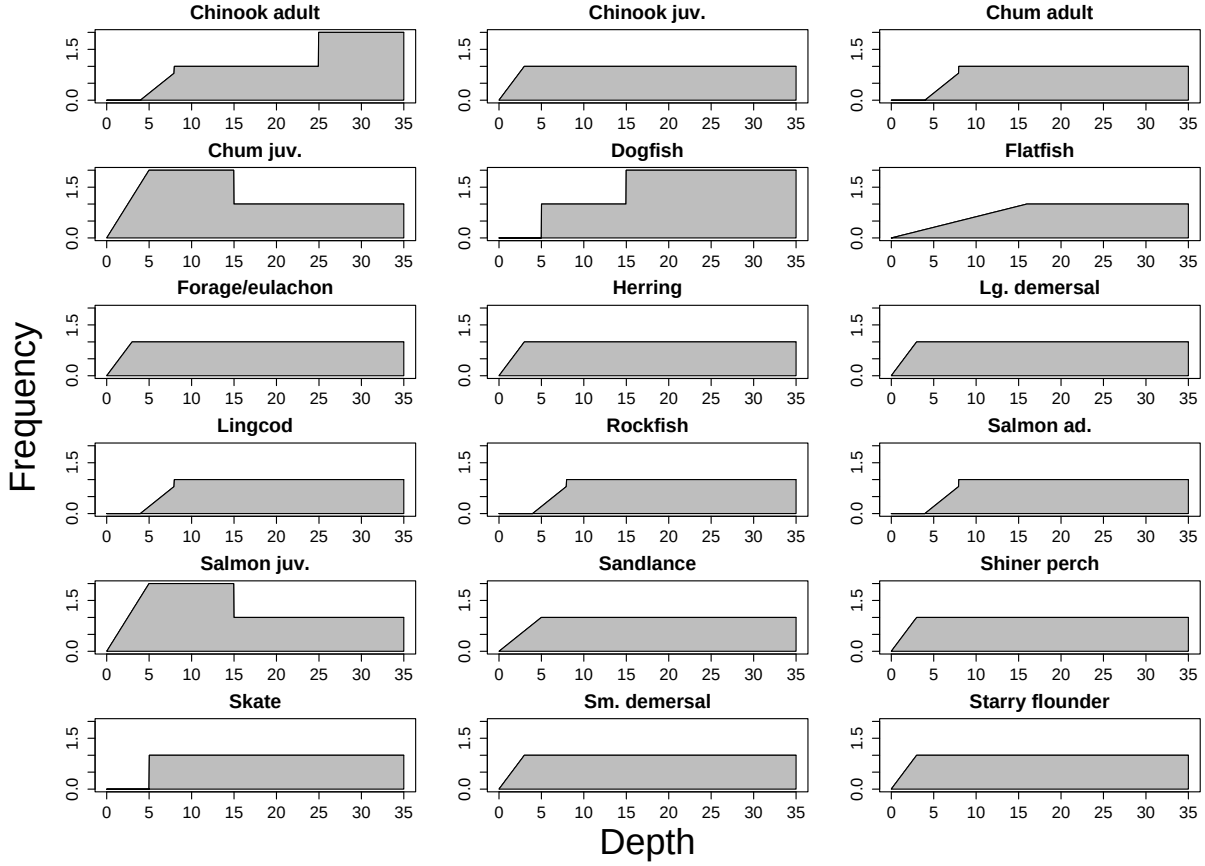
Note: Am. Wigeon is American wigeon; Div. waterbirds is diving waterbirds; G. blue heron is great blue heron; W. sandpiper is Western sandpiper.

2.12.3 *Fish*

Functional responses to depth (**Figure 2-12**) and salinity (**Figure 2-13**) were considered for fish. Depth and salinity preferences were obtained from FishBase[1] (Froese and Pauly 2006), and the literature (Hemmera 2014). For fish species that move to deeper waters with the ebbing tide, preference to depths ranging from 0 to 5 m was assumed to increase linearly with increasing depth.

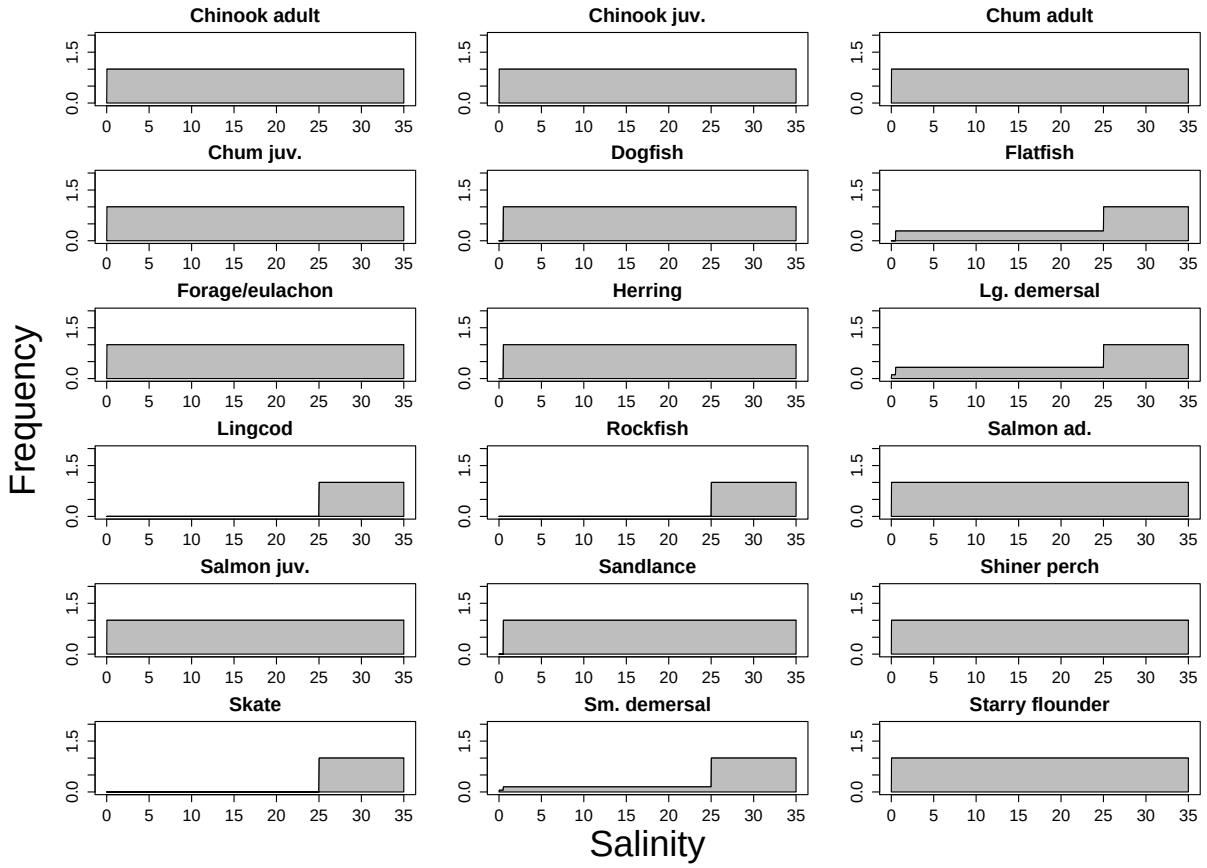
[1] FishBase is a global information database system about fish, developed at the WorldFish Center in collaboration with the United Nations Food and Agriculture Organization

Figure 2-12 Environmental Preference Functions for Fish and Depth (Below High Tide Level, m)



Note: Am. Wigeon is American wigeon; Div. waterbirds is Diving waterbirds; G. blue heron is Great blue heron; W. sandpiper is Western sandpiper

Figure 2-13 Environmental Preference Functions for Fish and Salinity (psu)

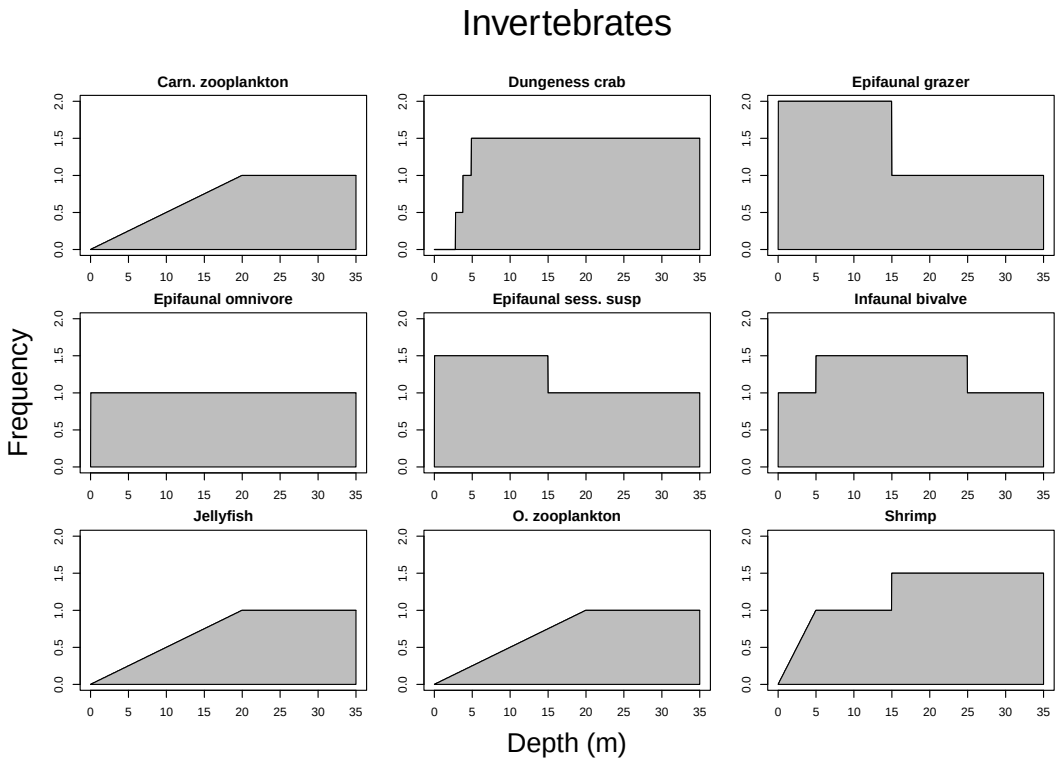


Note: Am. Wigeon is American wigeon; Div. waterbirds is Diving waterbirds; G. blue heron is Great blue heron; W. sandpiper is Western sandpiper

2.12.4 *Invertebrates*

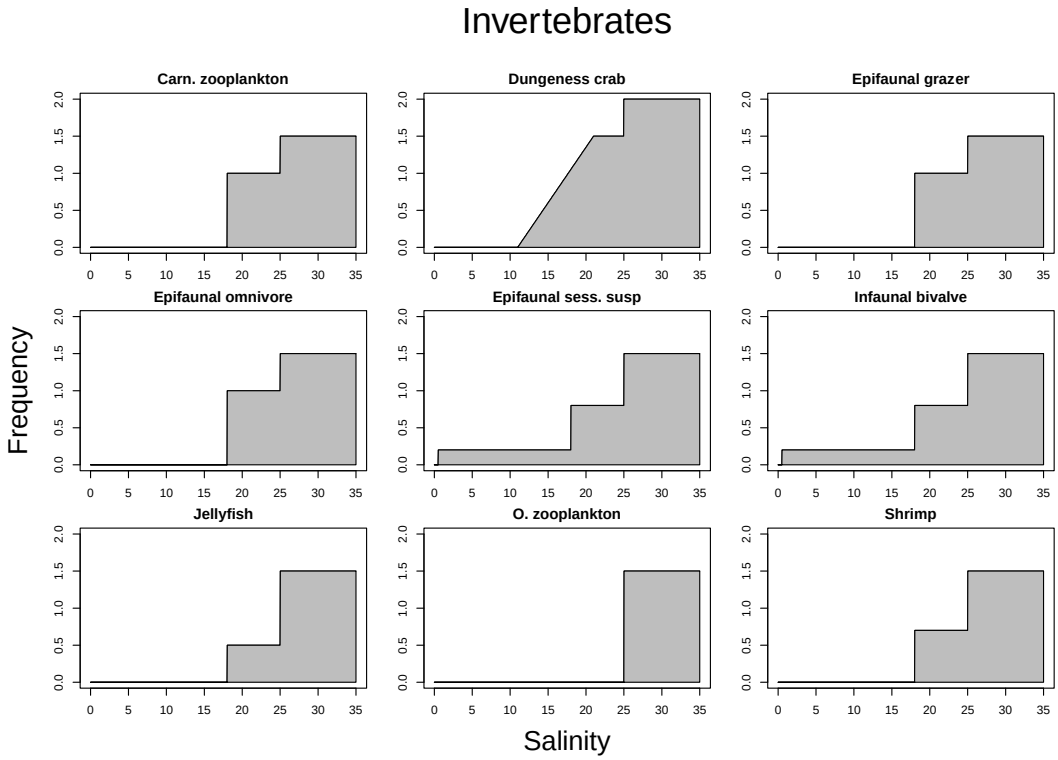
Functional responses to depth (**Figure 2-14**), salinity (**Figure 2-15**), bottom current (**Figure 2-16**), and wave height (**Figure 2-17**) were considered for invertebrates. Environmental preferences of invertebrates, excluding macrofauna, meiofauna, polychaetes, and orange sea pen were obtained from the literature (Hemmera 2014).

Figure 2-14 Environmental Preference Functions for Invertebrates (Excluding Macrofauna, Meiofauna, Polychaetes, and Orange Sea Pen) and Depth (Below High Tide Level, m)



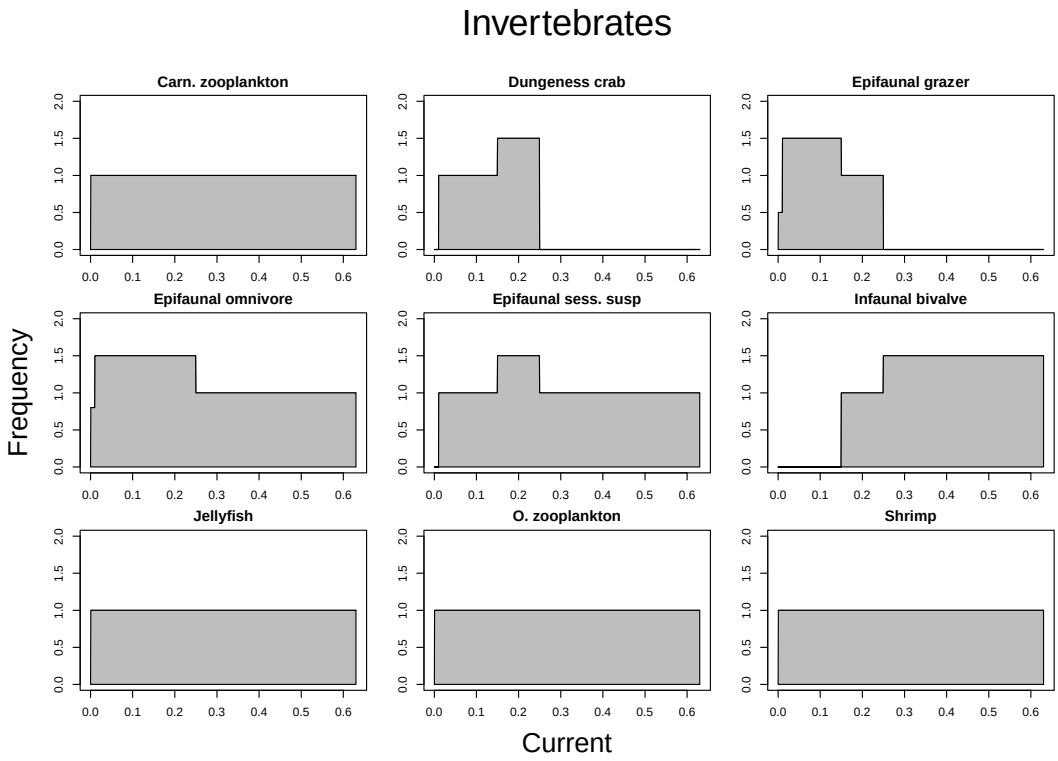
Note: Carn. zooplankton is carnivorous zooplankton; Epifaunal sess. susp is Epifaunal sessile suspension feeder; O. zooplankton is Omnivorous and herbivorous zooplankton

Figure 2-15 Environmental Preference Functions for Invertebrates (Excluding Macrofauna, Meiofauna, Polychaetes, and Orange Sea Pen) and Salinity (psu)



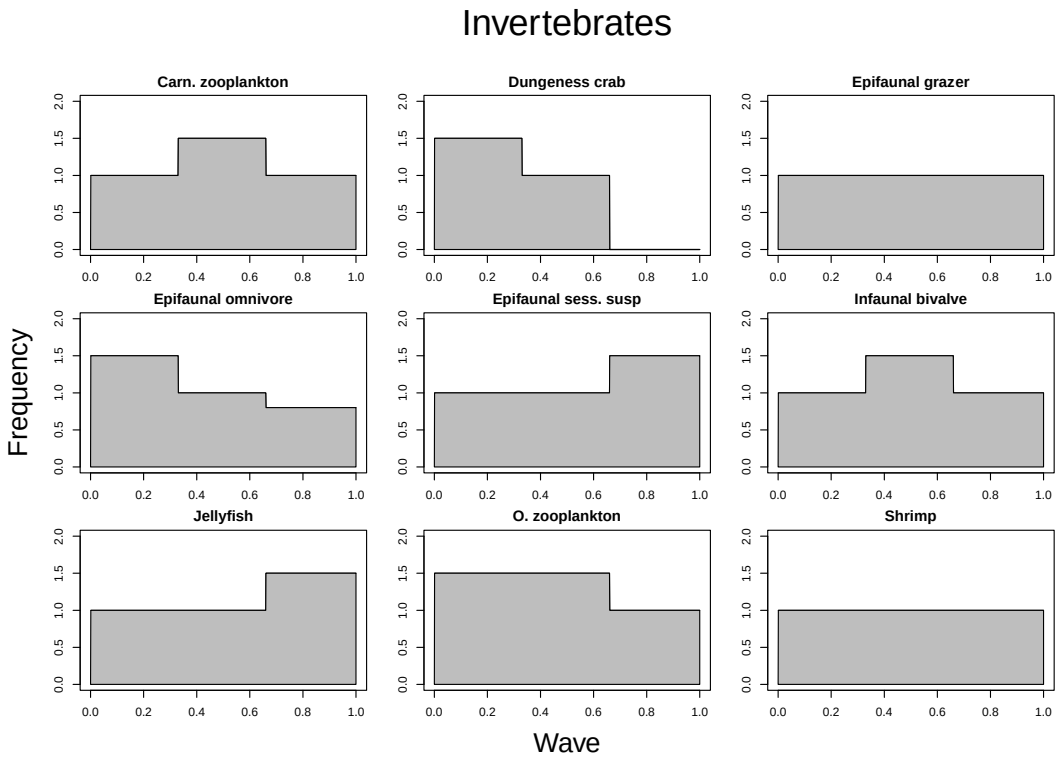
Note: Carn. zooplankton is carnivorous zooplankton; Epifaunal sess. susp is Epifaunal sessile suspension feeder; O. zooplankton is Omnivorous and herbivorous zooplankton

Figure 2-16 Environmental Preference Functions for Invertebrates (Excluding Macrofauna, Meiofauna, Polychaetes, and Orange Sea Pen) and Bottom Current (m sec^{-1})



Note: Carn. zooplankton is carnivorous zooplankton; Epifaunal sess. susp is Epifaunal sessile suspension feeder; O. zooplankton is Omnivorous and herbivorous zooplankton

Figure 2-17 Environmental Preference Functions for Invertebrates (Excluding Macrofauna, Meiofauna, Polychaetes, and Orange Sea Pen) and Wave Height (m)



Note: Carn. zooplankton is carnivorous zooplankton; Epifaunal sess. susp is Epifaunal sessile suspension feeder; O. zooplankton is Omnivorous and herbivorous zooplankton

Environmental preferences for macrofauna, meiofauna, and polychaetes were determined for depth (**Figure 2-18**) salinity (**Figure 2-19**) bottom current (**Figure 2-20**), and wave height (**Figure 2-21**) using data collected in the study area for the Project (Hemmera 2014). Environmental preference functions were established by spatially correlating sampling data with environmental parameter layers obtained by the coastal geomorphology model (NHC 2014). The habitat mapping methodology is described in **Section 11 Marine Vegetation Effects Assessment** of the Project's environmental assessment.

Sampling of macrofauna, meiofauna, and polychaetes was limited to the intertidal zone (i.e., to depths of less than 5 m depth). Therefore, environmental preference functions established for these three invertebrate groups only apply to the intertidal zone with the exception of macrofauna for which the depth preference was extended to the full depth

range based on literature information (Hemmera 2014). Overall, the focus on the intertidal zone for these groups should be considered appropriate, given that changes in spatial drivers as a result of the Project mainly occur in the intertidal zone in the coastal geomorphology model (NHC 2014).

Figure 2-18 Environmental Preference Functions for Macrofauna, Meiofauna, and Polychaetes, and Depth (Below High Tide Level, m)

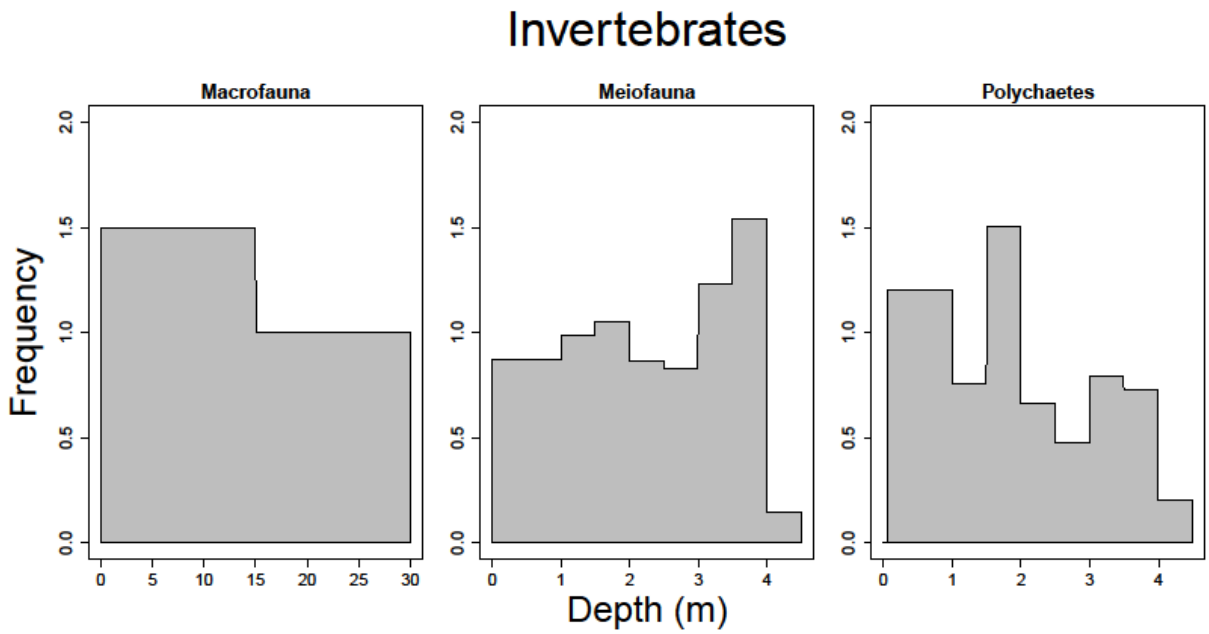


Figure 2-19 Environmental Preference Functions for Macrofauna, Meiofauna, and Polychaetes, and Salinity (psu)

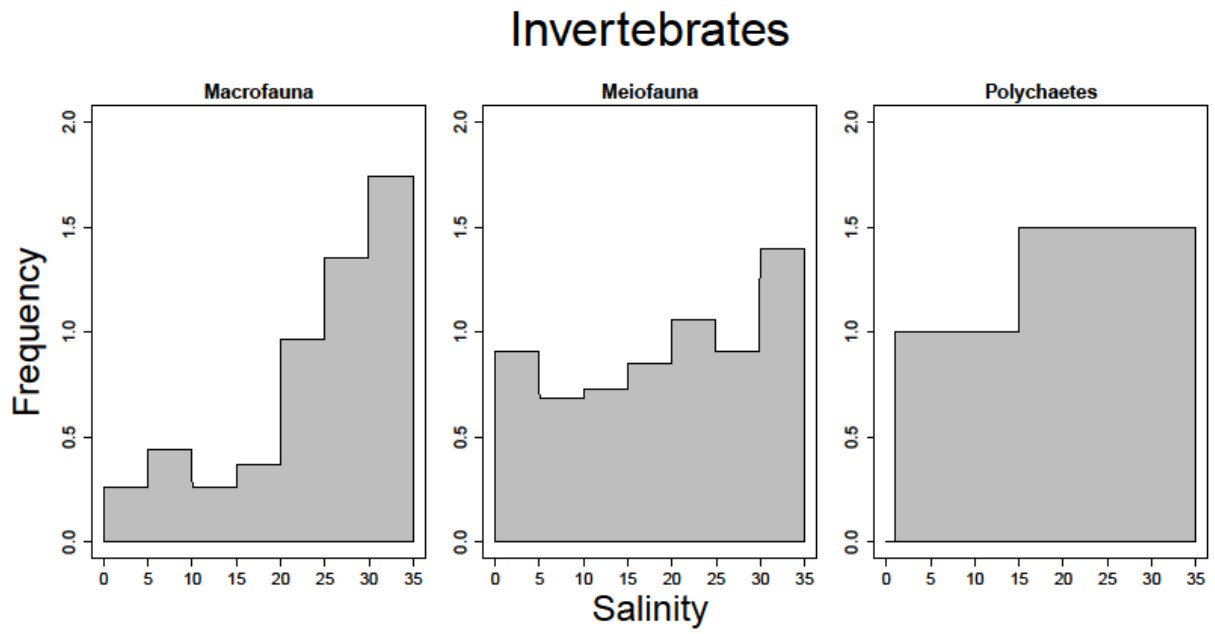


Figure 2-20 Environmental Preference Functions for Macrofauna, Meiofauna, and Polychaetes, and Bottom Current (m sec^{-1})

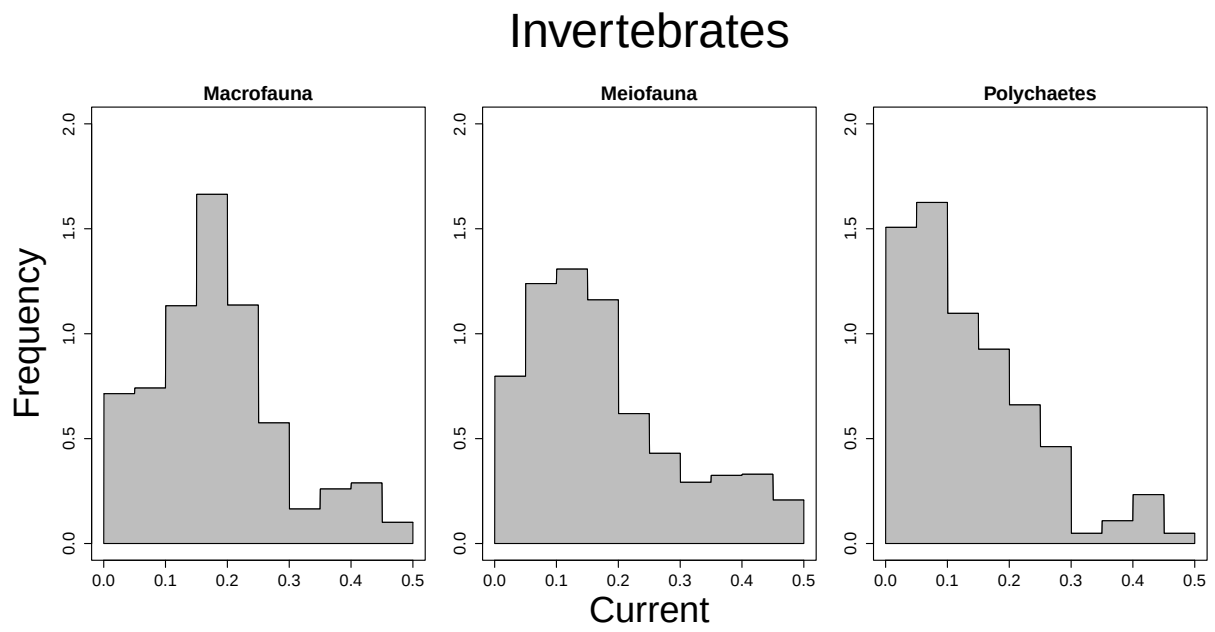
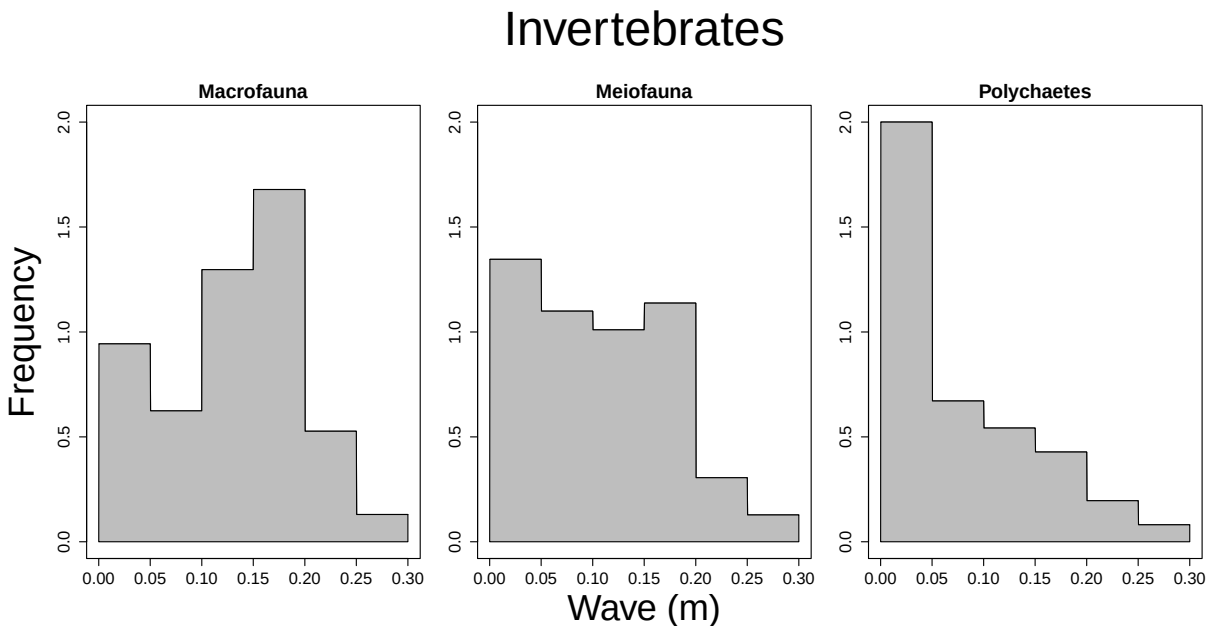


Figure 2-21 Environmental Preference Functions for Macrofauna, Meiofauna, and Polychaetes, and Wave Height (m)



2.12.5 *Habitat Forming Groups*

Habitat forming groups include most primary producers (listed in **Table 2.1** excluding phytoplankton). Functional responses for the habitat forming groups to depth (**Figure 2-22**), salinity (

Figure 2-23), bottom current (**Figure 2-24**), and wave height (**Figure 2-25**) were estimated using habitat mapping correlated with spatial driver layers produced by the coastal geomorphology model (NHC 2014). The environmental preference functions were smoothed relative to the original sampled distributions. Further, the wave preference functions for brown algae and red algae were adjusted based on literature information as the sampled distributions had too limited ranges to cover the potential preference conditions for these groups. The habitat mapping methodology is described in **Section 11 Marine Vegetation Effects Assessment** of the Project's environmental assessment.

Figure 2-22 Environmental Preference Functions for Habitat-forming Groups and Depth (Below High Tide Level, m)

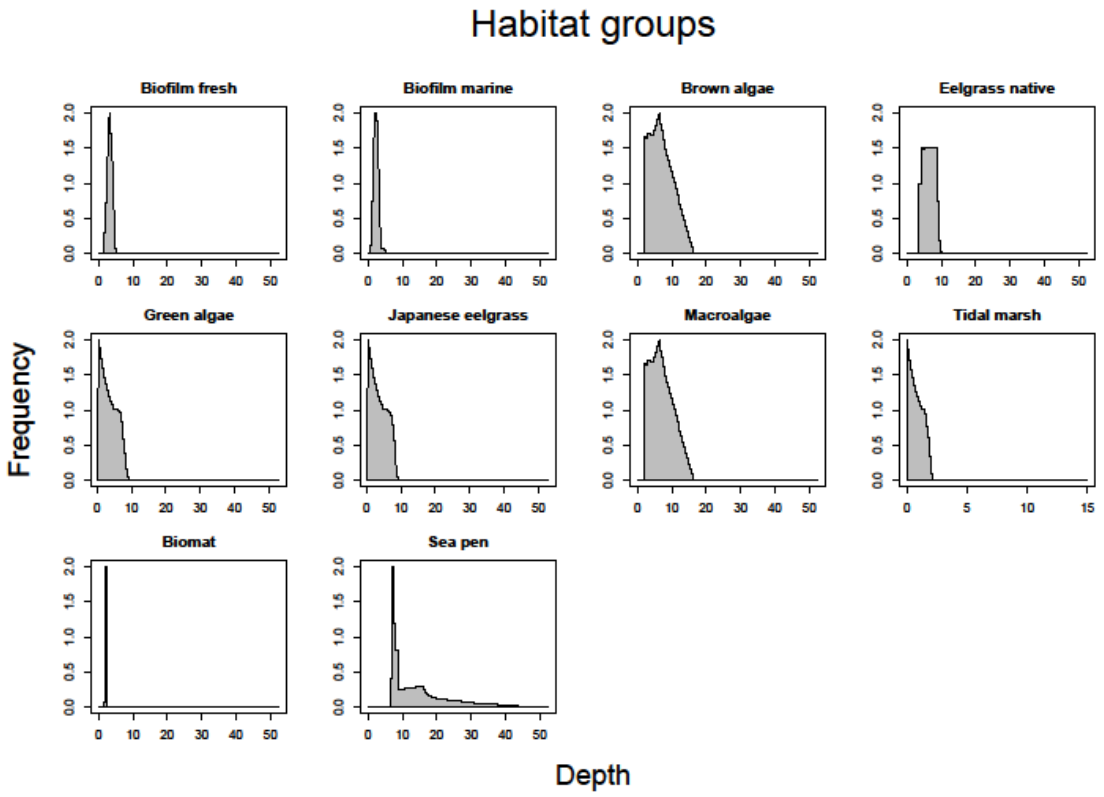


Figure 2-23 Environmental Preference Functions for Habitat-forming Groups and Salinity (50th Percentile, psu)

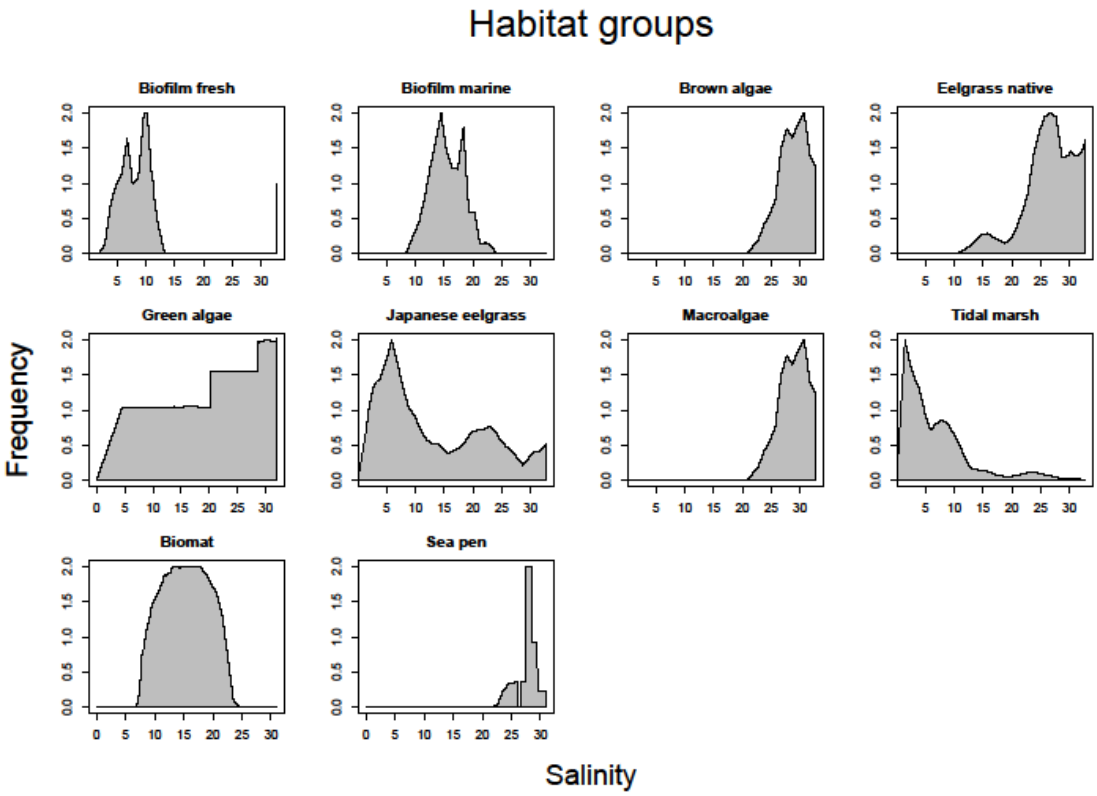


Figure 2-24 Environmental Preference Functions for Habitat-forming Groups and Bottom Current (m sec^{-1})

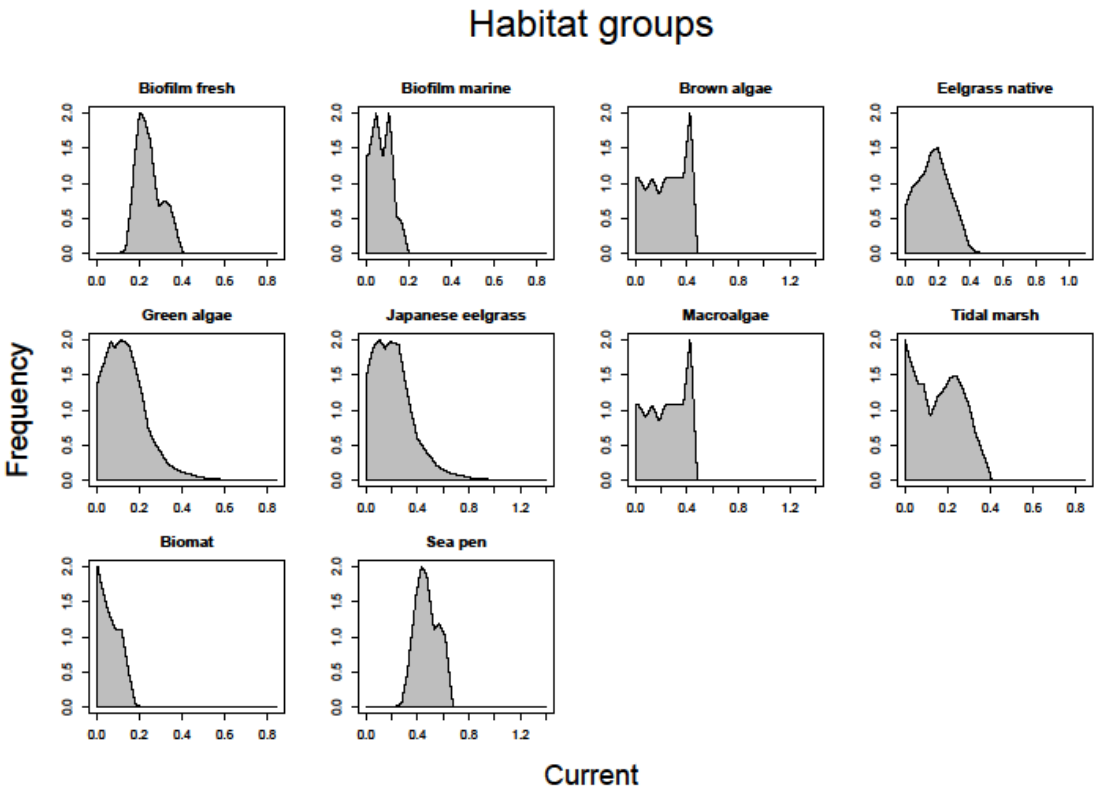
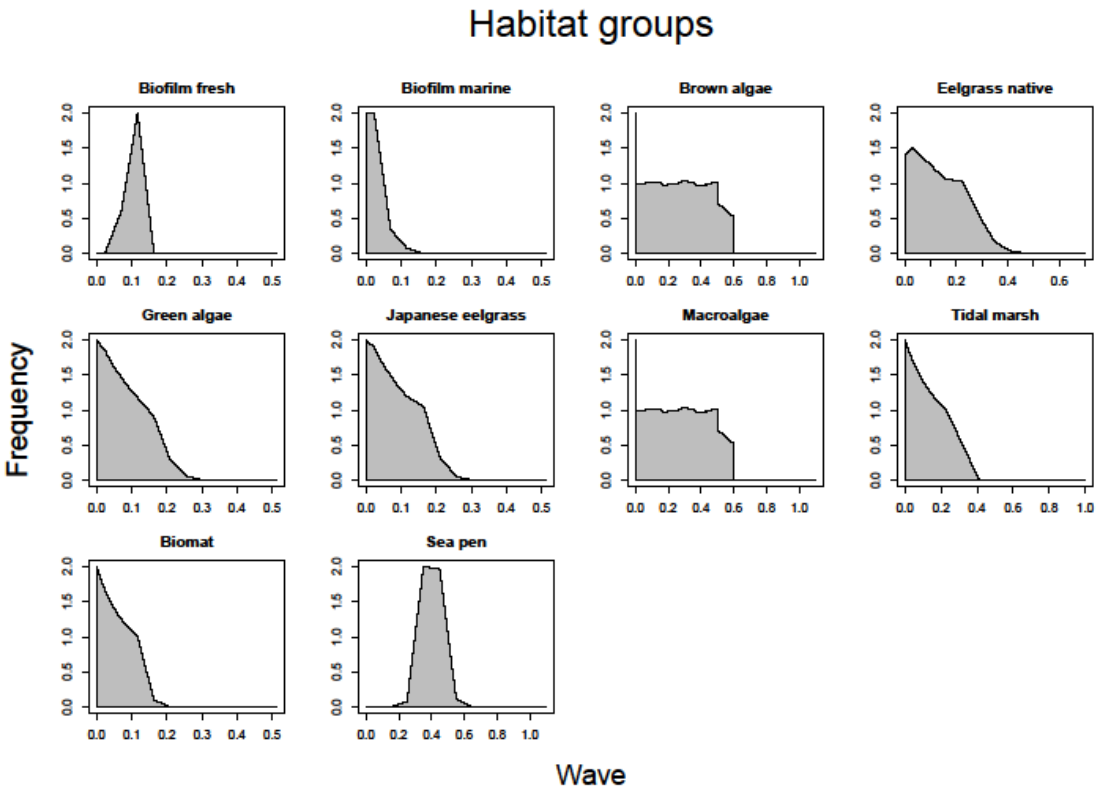


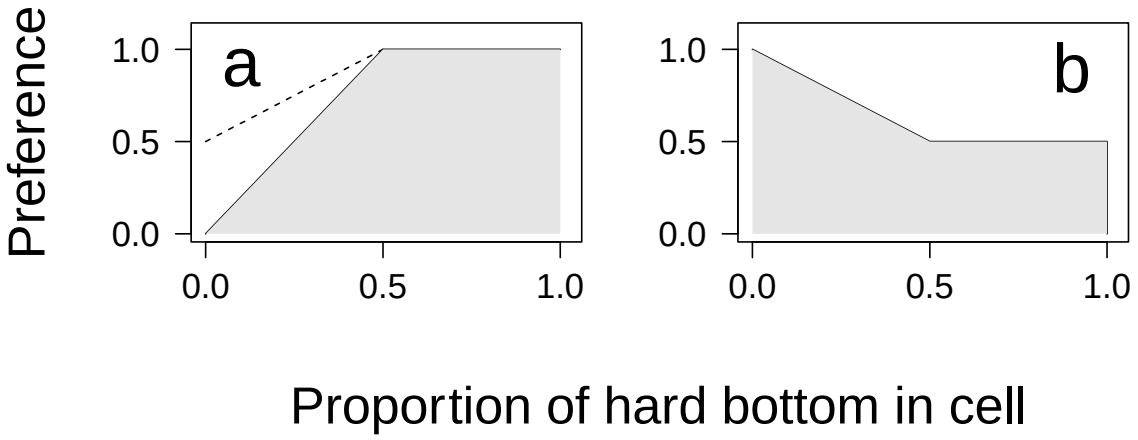
Figure 2-25 Environmental Preference Functions for Habitat-forming Groups and Wave Height (m)



2.13 Preference for Hard or Soft Bottom

Changes in sediment grain size distribution as a result of the Project were not assessed in the coastal geomorphology model (NHC 2014). Instead, the Roberts Bank ecosystem model considered a hard/soft bottom layer that was created as described in **Section 2.3 Hard Bottom Layer**. Environmental preference for hard substrate was considered for lingcod, rockfish, shiner perch, epifaunal sessile suspension feeder, red algae, and brown algae (**Figure 2-26 a**). In contrast, environmental preference for soft substrate was considered for American wigeon, brant goose, dunlin, great blue heron, shorebirds, waterfowl, western sandpiper, flatfish, forage fish, sandlance, skate, starry flounder, epifaunal omnivore, infaunal bivalves, macrofauna, meiofauna, polychaetes, orange sea pen, shrimp, native eelgrass, Japanese eelgrass, tidal marsh, and biomat (**Figure 2-26 b**).

Figure 2-26 Environmental Preference Functions for Functional Groups Favouring (a) Hard Substrate, and (b) Soft Substrate



Note: The dashed line in (a) indicates the preference function that was used for shiner perch and red algae

3.0 RESULTS

This section presents changes in productivity of functional groups as a result of the Project, forecasted during the **key run** of the Roberts Bank ecosystem model. The key run is used further to evaluate uncertainty in model creation and parameterisation in the accompanying Roberts Bank Ecosystem Model Sensitivity Analyses Report (ESSA 2014). Changes in productivity of functional groups that serve as valued components in the EIS are assessed for significance during the Project's EA.

3.1 PEDIGREE

The **pedigree** analysis evaluates how well rooted the Roberts Bank ecosystem model is in local data. Pedigree parameterisation also provides estimates of model parameter uncertainty that is considered further in the accompanying Roberts Bank Ecosystem Model Sensitivity Analyses Report (ESSA 2014). The pedigree table (**Table 3.1**) for the Roberts Bank ecosystem model was populated using information provided in the Roberts Bank Ecosystem Model Parameter Estimates Report (Hemmera 2014).

Table 3.1 Pedigree of Input Parameters of Functional Groups Included in the Roberts Bank Ecosystem Model

No	Functional Group	Biomass	P/B	Q/B	Diet
1	Baleen whales	4	3	3	3
2	Dolphins and porpoises	4	3	3	5
3	Pinnipeds	5	3	3	5
4	Southern resident killer whales	5	7	4	5
5	Transient killer whales	5	7	4	5
6	American wigeon	6	4	4	4
7	Bald eagle	6	4	4	4
8	Brant goose	6	4	4	4
9	Diving waterbirds	6	4	4	4
10	Dunlin	6	4	4	4
11	Great blue heron	6	4	4	4
12	Gulls and terns	6	4	4	4
13	Raptors	6	4	4	4
14	Shorebirds	6	4	4	4
15	Waterfowl	6	4	4	4
16	Western sandpiper	6	4	4	4
17	Chinook adult	4	7	4	3
18	Chinook juvenile	5	2	3	3
19	Chum adult	3	4	4	3
20	Chum juvenile	5	2	3	3
21	Dogfish	3	4	4	3
22	Flatfish	5	4	4	3
23	Forage fish	5	4	4	3
24	Herring	5	4	4	3
25	Large demersal fish	5	4	4	3
26	Lingcod	5	4	4	3
27	Rockfish	5	4	4	3
28	Salmon adult	1	4	4	3
29	Salmon juvenile	5	4	4	3
30	Sandlance	5	4	4	3
31	Shiner perch	5	4	4	3
32	Skate	3	4	4	3
33	Small demersal fish	5	4	4	3
34	Starry flounder	5	4	4	3
35	Carnivorous zooplankton	4	3	3	3
36	Dungeness crab	5	6	3	3
37	Epifaunal grazers	4	3	3	3
38	Epifaunal omnivore	4	3	3	3
39	Epifauna sessile	1	4	3	3
40	Infaunal bivalves	5	3	4	3

No	Functional Group	Biomass	P/B	Q/B	Diet
41	Jellyfish	4	3	3	3
42	Macrofauna	6	3	4	3
43	Meiofauna	6	3	4	3
44	Omnivorous and herbivorous zooplankton	5	3	4	3
45	Polychaetes	6	5	4	3
46	Orange sea pen	6	4	4	3
47	Shrimp	4	3	3	3
48	Biofilm fresh	6	2		
49	Biofilm marine	6	2		
50	Brown algae	5	3		
51	Native eelgrass	6	3		
52	Green algae	5	3		
53	Japanese eelgrass	6	3		
54	Red algae	5	3		
55	Phytoplankton	2	3		
56	Tidal marsh	6	3		
57	Biomat	6	2		

Note: Numbers in the table refer to pedigree grades. For interpretation of colours and grades, see **Table 2.2** to **Table 2.4**. The colour scale ranges from green (low pedigree) to red (high pedigree). Detritus is not listed as P/B, Q/B, and diets are undefined for this group, and the biomass has no implications for the model runs.

The pedigree index of the Roberts Bank ecosystem model is 0.54, which demonstrates that the model is more strongly rooted in local data than most ecosystem models. As mentioned in **Section 3.5**, inputs that arise from local data (i.e., from field sampling at Roberts Bank) represent local conditions better than data from elsewhere. For comparison, out of 50 ecosystem models whose pedigree was assessed, only 15% had pedigree values that exceeded 0.54 (Morisette 2007).

3.2 Mixed Trophic Impacts (MTI)

The MTI routine analyses the direct and indirect impact that any group in an ecosystem may have on all other groups in the system. For the Roberts Bank ecosystem model the results from the MTI routine are presented in **Figure 3-1**.

Figure 3-1 Mixed Trophic Impacts in the Roberts Bank Ecosystem Model

Note: the impacts scale linearly from -1 (black circle) to +1 (open circle). Impacting groups are listed in rows, and impacted groups in columns. Marine mammals are included in the EwE model for their important role as top predators, but the EwE model is not being used to assess effects to marine mammals. In the Productive Capacity Technical Advisory Group, Transient killer whales were identified as a focal species. In the marine mammal effects assessment, southern resident killer whales represent transient killer whales. For more information, see **Section 14.0 Marine Mammals**.

Bald eagle has a positive impact on native eelgrass, Japanese eelgrass, tidal marsh, and biomat. These impacts are primarily due to the negative impact that bald eagle has on waterfowl, which in turn has a strong negative impact on those primary producers. Raptors have a strong positive impact on biofilm due to their predation on dunlin, which have a strong negative impact on biofilm.

Fish groups have limited impact on other groups in the ecosystem, though forage fish have positive impacts on their many predators. Forage fish also have a negative impact on polychaetes.

The invertebrate groups are generally strong interactors with impact on groups throughout the ecosystem. Macrobenthos have strong negative impact on jellyfish, orange sea pen, brown algae, green algae, and red algae.

Among the primary producers, the strongest impacts are by native eelgrass on brant goose (positive); by both freshwater and marine biofilm on western sandpiper (positive) and dunlin (positive); and by green algae on American wigeon (positive).

The results sections below describing the various species in the ecosystem model includes species-specific representations of which other groups that have the most positive or most negative impacts on each group based on the MTI routine.

3.3 Biomass and Production Estimates from Key Run

This section presents net changes in biomass and production of functional groups at Roberts Bank as a result of the Project once the ecosystem becomes stable (see **Table 3.2/Figure 3-2** for biomass changes, and **Table 3.3/Figure 3-3** for production changes). Spatial changes in the productivity of functional groups identified as focal species by the PC-TAG are presented in maps shown in **Sections 3.4.1 to 3.9**. Maps of change in productivity of the remaining functional groups of the Roberts Bank ecosystem model are appended in this report. The maps represent how productive (low to high) the study area is forecasted to be with and without the project.

As a guideline for evaluating the results, where a change is no more than 5% when comparing the Without Project and the With Project, such a change is small enough to be within the uncertainty of the model runs, and hence should be considered insignificant.

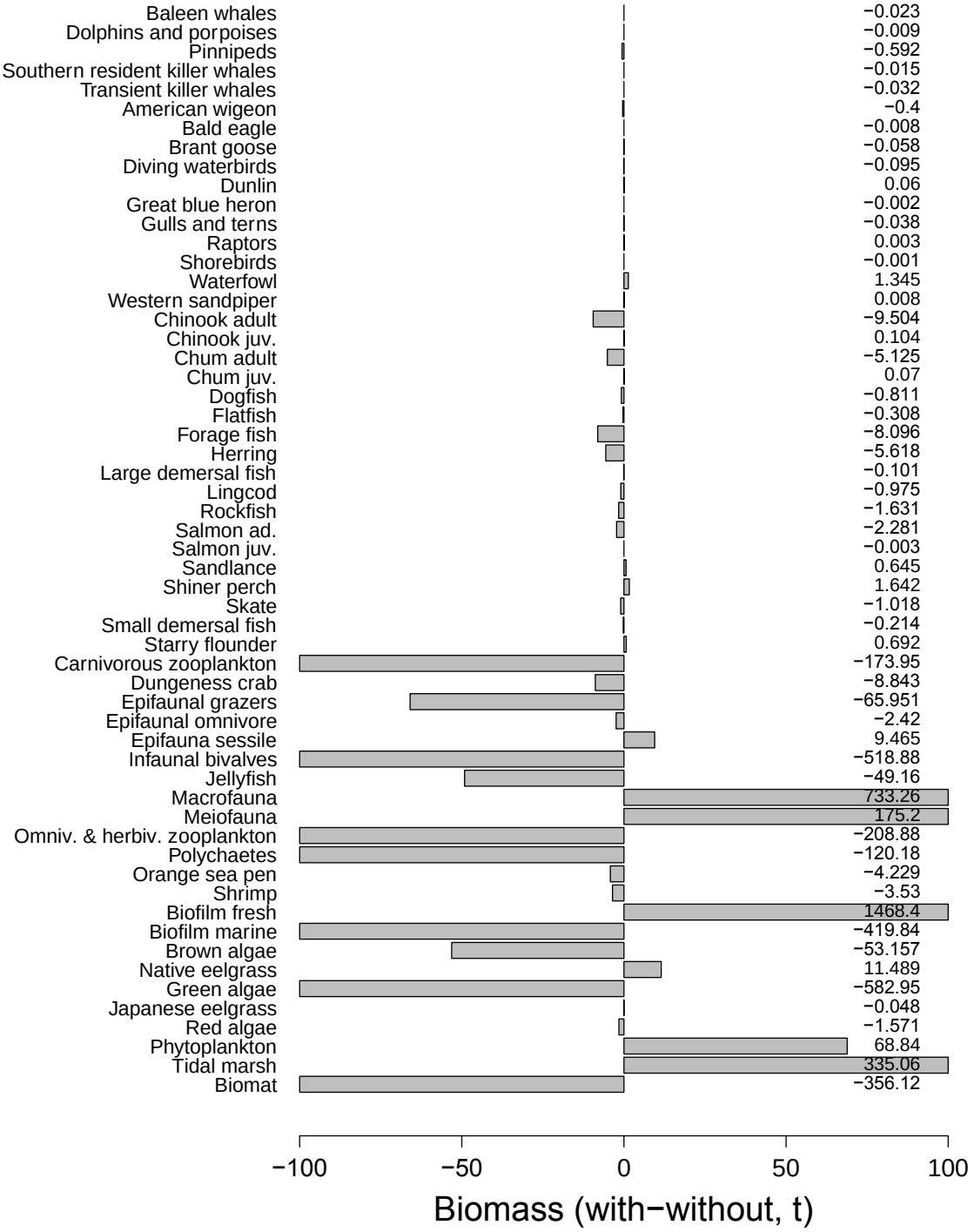
Table 3.2 Biomass Estimates from the Key Run, Without and With the Project

No.	Group	Biomass (without, t)	Biomass (with, t)	Ratio	Difference (with - without, t)
1	Baleen whales*	0.273	0.250	0.92	-0.023
2	Dolphins and porpoises*	0.273	0.264	0.97	-0.009
3	Pinnipeds*	21.832	21.240	0.97	-0.592
4	Southern resident killer whales*	0.546	0.531	0.97	-0.015
5	Transient killer whales*	0.284	0.252	0.89	-0.032
6	American wigeon	4.765	4.365	0.92	-0.400
7	Bald eagle	0.120	0.112	0.93	-0.008
8	Brant goose	1.088	1.031	0.95	-0.058
9	Diving waterbirds	1.506	1.412	0.94	-0.095
10	Dunlin	0.471	0.531	1.13	0.060
11	Great blue heron	0.671	0.669	1.00	-0.002
12	Gulls and terns	2.639	2.602	0.99	-0.038
13	Raptors	0.008	0.011	1.31	0.003
14	Shorebirds	0.045	0.044	0.98	-0.001
15	Waterfowl	16.559	17.904	1.08	1.345
16	Western sandpiper	0.058	0.066	1.13	0.008
17	Chinook adult	187.099	177.595	0.95	-9.504
18	Chinook juvenile	0.655	0.759	1.16	0.104
19	Chum adult	111.643	106.517	0.95	-5.125
20	Chum juvenile	0.491	0.561	1.14	0.070
21	Dogfish	35.953	35.142	0.98	-0.811
22	Flatfish	20.441	20.133	0.98	-0.308
23	Forage fish	573.086	564.989	0.99	-8.096
24	Herring	242.712	237.094	0.98	-5.618
25	Large demersal fish	8.386	8.285	0.99	-0.101
26	Lingcod	32.031	31.055	0.97	-0.975
27	Rockfish	18.475	16.844	0.91	-1.631
28	Salmon adult	55.454	53.173	0.96	-2.281
29	Salmon juvenile	0.092	0.090	0.97	-0.003
30	Sandlance	11.323	11.969	1.06	0.645
31	Shiner perch	8.921	10.563	1.18	1.642
32	Skate	12.584	11.565	0.92	-1.018
33	Small demersal fish	3.945	3.732	0.95	-0.214
34	Starry flounder	11.453	12.145	1.06	0.692
35	Carnivorous zooplankton	1623.743	1449.794	0.89	-173.949

No.	Group	Biomass (without, t)	Biomass (with, t)	Ratio	Difference (with - without, t)
36	Dungeness crab	252.769	243.926	0.97	-8.843
37	Epifaunal grazers	835.674	769.722	0.92	-65.951
38	Epifaunal omnivore	105.284	102.864	0.98	-2.420
39	Epifauna sessile	48.876	58.341	1.19	9.465
40	Infaunal bivalves	6590.176	6071.293	0.92	-518.883
41	Jellyfish	599.746	550.586	0.92	-49.160
42	Macrofauna	2743.430	3476.688	1.27	733.258
43	Meiofauna	1588.644	1763.839	1.11	175.196
44	Omnivorous and herbivorous zooplankton	2970.768	2761.889	0.93	-208.879
45	Polychaetes	1099.779	979.598	0.89	-120.180
46	Orange sea pen	7.692	3.463	0.45	-4.229
47	Shrimp	27.290	23.759	0.87	-3.530
48	Biofilm fresh	1642.846	3111.264	1.89	1468.419
49	Biofilm marine	1819.684	1399.847	0.77	-419.837
50	Brown algae	448.060	394.903	0.88	-53.157
51	Native eelgrass	304.576	316.065	1.04	11.489
52	Green algae	6894.604	6311.657	0.92	-582.947
53	Japanese eelgrass	6.855	6.807	0.99	-0.048
54	Red algae	15.168	13.596	0.90	-1.572
55	Phytoplankton	2183.184	2252.024	1.03	68.840
56	Tidal marsh	1329.832	1664.890	1.25	335.059
57	Biomat	1217.125	861.010	0.71	-356.115
58	Detritus	545.796	550.549	1.01	4.753

Note: Estimates are rounded; information is at a point in time after equilibrium stabilizes. * Marine mammals are included in the EwE model for their important role as top predators, but the EwE model is not being used to assess effects to marine mammals. In the Productive Capacity Technical Advisory Group, Transient killer whales were identified as a focal species. In the marine mammal effects assessment, southern resident killer whales represent transient killer whales. For more information, see **Section 14.0 Marine Mammals**.

Figure 3-2 Difference in Biomass (t) of Functional Groups, Estimated With and Without the Project



Note: the bars were truncated at +/-100 t. Estimates are rounded to three significant digits. Marine mammals are included in the EwE model for their important role as top predators, but the EwE model is not being used to assess effects to marine mammals. In the Productive Capacity Technical Advisory

Group, Transient killer whales were identified as a focal species. In the marine mammal effects assessment, southern resident killer whales represent transient killer whales. For more information, see **Section 14.0 Marine Mammals**.

Table 3.3 Production Estimates from the Key Run, Without and With the Project

No.	Group	Production (without, t year^{-1})	Production (with, t year^{-1})	Difference (with – without, t year^{-1})
1	Baleen whales*	0.008	0.008	-0.001
2	Dolphins and porpoises	0.044	0.042	-0.001
3	Pinnipeds*	3.056	2.974	-0.083
4	Southern resident killer whales*	0.022	0.021	-0.001
5	Transient killer whales*	0.011	0.010	-0.001
6	American wigeon	0.953	0.873	-0.080
7	Bald eagle	0.030	0.028	-0.002
8	Brant goose	0.218	0.206	-0.012
9	Diving waterbirds	0.362	0.339	-0.023
10	Dunlin	0.240	0.271	0.031
11	Great blue heron	0.329	0.328	-0.001
12	Gulls and terns	0.607	0.598	-0.009
13	Raptors	0.003	0.004	0.001
14	Shorebirds	0.023	0.023	0.000
15	Waterfowl	3.312	3.581	0.269
16	Western sandpiper	0.030	0.033	0.004
17	Chinook adult	58.001	55.054	-2.946
18	Chinook juvenile	0.524	0.607	0.083
19	Chum adult	48.006	45.802	-2.204
20	Chum juvenile	0.442	0.505	0.063
21	Dogfish	4.314	4.217	-0.097
22	Flatfish	7.563	7.449	-0.114
23	Forage fish	544.432	536.740	-7.692
24	Herring	194.170	189.675	-4.494
25	Large demersal fish	4.277	4.225	-0.052
26	Lingcod	9.929	9.627	-0.302
27	Rockfish	4.065	3.706	-0.359
28	Salmon adult	23.845	22.865	-0.981
29	Salmon juvenile	0.079	0.076	-0.002
30	Sandlance	5.322	5.625	0.303
31	Shiner perch	11.330	13.415	2.085
32	Skate	1.133	1.041	-0.092
33	Small demersal fish	3.945	3.732	-0.214
34	Starry flounder	4.581	4.858	0.277

No.	Group	Production (without, t year^{-1})	Production (with, t year^{-1})	Difference (with – without, t year^{-1})
35	Carnivorous zooplankton	11366.20	10148.56	-1217.64
36	Dungeness crab	631.92	609.81	-22.11
37	Epifaunal grazers	1210.06	1114.56	-95.50
38	Epifaunal omnivore	368.49	360.02	-8.47
39	Epifauna sessile	83.35	99.49	16.14
40	Infaunal bivalves	13569.17	12500.79	-1068.38
41	Jellyfish	5757.56	5285.63	-471.93
42	Macrofauna	10973.72	13906.75	2933.03
43	Meiofauna	12709.15	14110.71	1401.57
44	Omnivorous and herbivorous zooplankton	71298.42	66285.33	-5013.10
45	Polychaetes	5498.89	4897.99	-600.90
46	Orange sea pen	9.23	4.16	-5.08
47	Shrimp	65.50	57.02	-8.47
48	Biofilm fresh	59142.45	112005.52	52863.07
49	Biofilm marine	65508.62	50394.49	-15114.13
50	Brown algae	4032.54	3554.13	-478.41
51	Native eelgrass	5482.37	5689.18	206.81
52	Green algae	89629.86	82051.54	-7578.32
53	Japanese eelgrass	68.55	68.07	-0.48
54	Red algae	303.35	271.92	-31.43
55	Phytoplankton	283813.92	292763.17	8949.25
56	Tidal marsh	19947.48	24973.36	5025.88
57	Biomat	101021.38	71463.80	-29557.58

Note: production is not defined for group 58 (i.e. detritus) as this is a non-living group. Estimates are rounded; information is at a point in time after equilibrium stabilizes. * Marine mammals are included in the EwE model for their important role as top predators, but the EwE model is not being used to assess effects to marine mammals. In the Productive Capacity Technical Advisory Group, Transient killer whales were identified as a focal species. In the marine mammal effects assessment, southern resident killer whales represent transient killer whales. For more information, see **Section 14.0 Marine Mammals**.

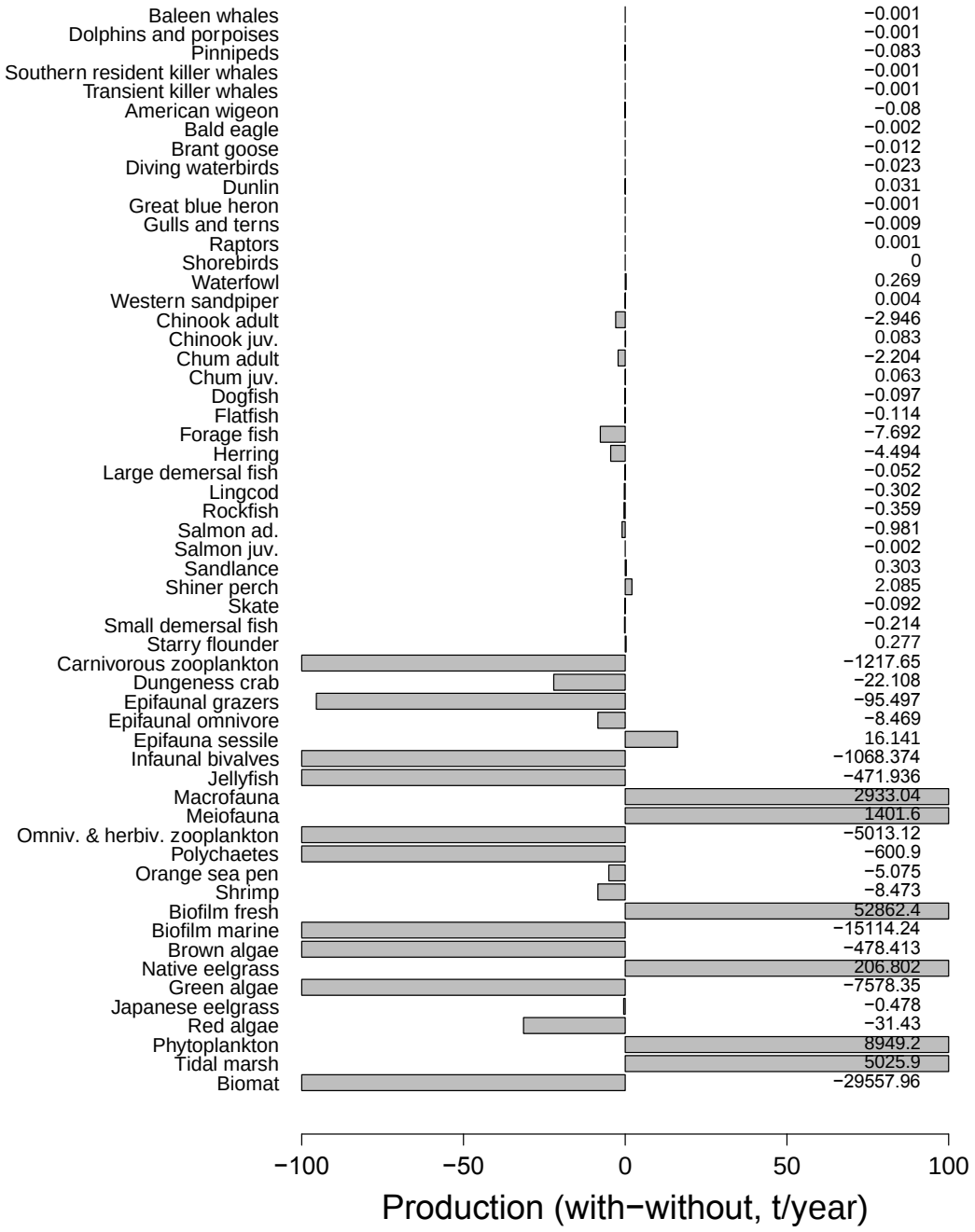
In summary, model results indicate that biomass with the Project is forecasted to:

- increase by 2.7% (0.76 t) for birds;
- decrease by 2.4% (-32.3 t) for fish;
- decrease by 1.3%, (-234) for invertebrates; and
- increase by 3.0% (467 t) for primary producers.

Forecasted changes in biomass with the Project were mostly subtle. The largest absolute decrease in biomass was forecast for green algae, amounting to 583 t (-8%), as a result of terminal expansion in their spatial distribution.

In contrast, freshwater biofilm is forecast to increase by 89% (1,468 t) in response to longer freshwater retention in the Canoe Passage area. Also, macrofauna is forecast to benefit from modifications related to the Project, with a corresponding increase in biomass of 733 t (27%). Biomat, in contrast, is forecast to decrease with almost 30% in biomass.

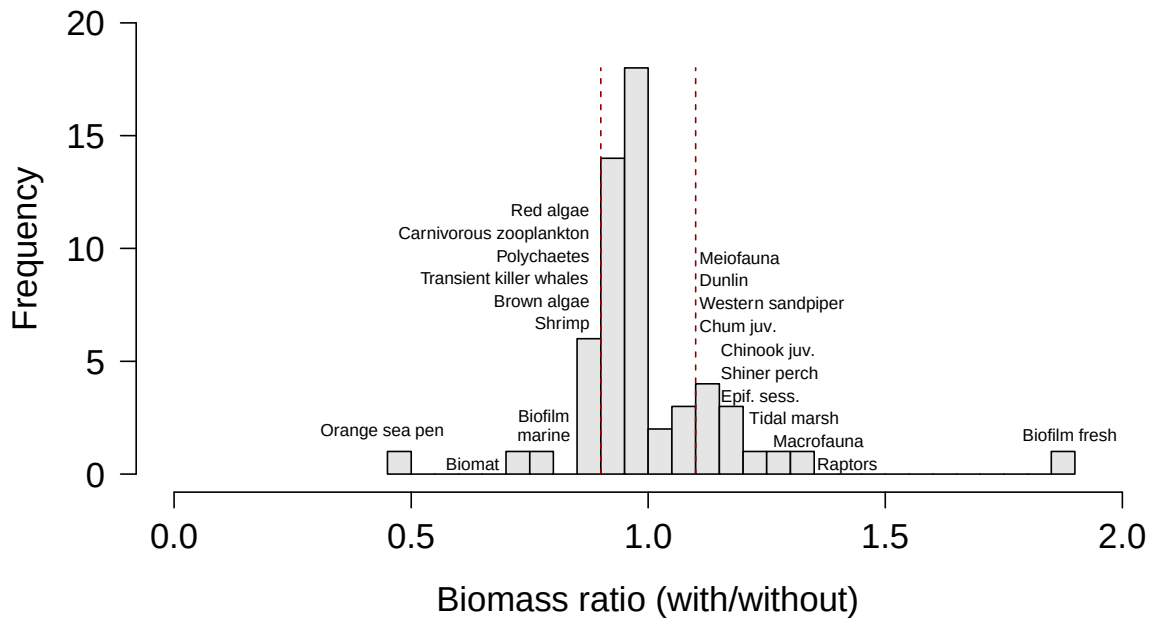
Figure 3-3 Difference in Production (t year^{-1}) of Functional Groups, Estimated With and Without the Project



Note: the bars were truncated at +/-100 t year^{-1}. Estimates are rounded; Marine mammals are included in the EwE model for their important role as top predators, but the EwE model is not being used to assess effects to marine mammals. In the Productive Capacity Technical Advisory Group, Transient killer whales were identified as a focal species. In the marine mammal effects assessment, southern resident killer whales represent transient killer whales. For more information, see **Section 14.0 Marine Mammals**.

Overall, biomass of 67% of the functional groups is forecasted to change with the Project less than 10% (**Figure 3-4**) The largest relative biomass decrease (0.40-0.45 range) is forecasted for orange sea pens, while the largest relative production increase (1.90-1.95 range) is for freshwater biofilm (**Table 3.2**).

Figure 3-4 Biomass Ratio Histogram for the Roberts Bank Ecosystem Model



Note: Labels indicate names of groups that change with more than +/- 10% (indicated by vertical stippled lines). The cut-off point of +/- 10% for labelling groups is an arbitrary choice to limit how may groups that are labelled and does not imply significance of the results.

3.4 Model Biomass Distribution Fit to Observed Distributions

3.4.1 *Primary producers*

Sampling at Roberts Bank conducted for marine vegetation indicates that the Roberts Bank ecosystem model adequately forecasts biomass distributions of these functional groups in existing conditions (**Figure 3-5** to **Figure 3-8**).

Figure 3-5 Biofilm Distribution (a) Based on 2012-2014 Field Studies, Beside (b) Forecasted Without Project Conditions in Model for Freshwater (Top) and Marine (Below) Biofilm.

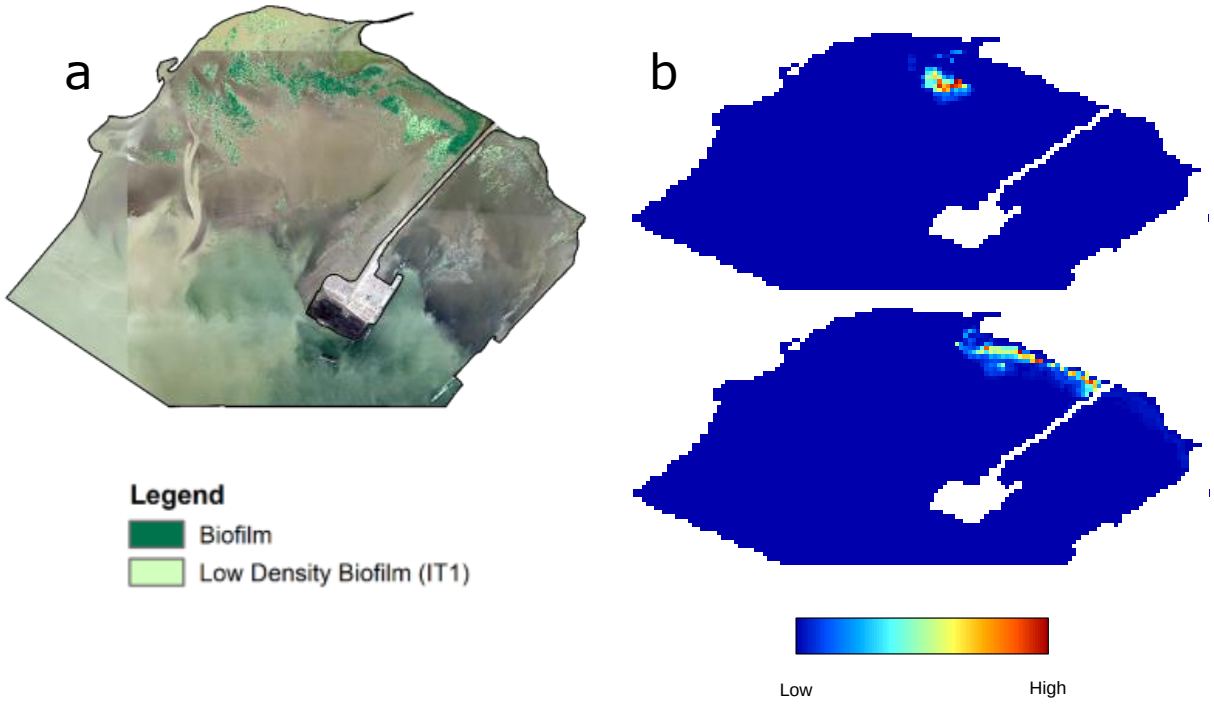


Figure 3-6 Brown Algae Distribution (a) Based on 2012-2014 Field Studies, Beside (b) Forecasted Without Project Conditions in Model

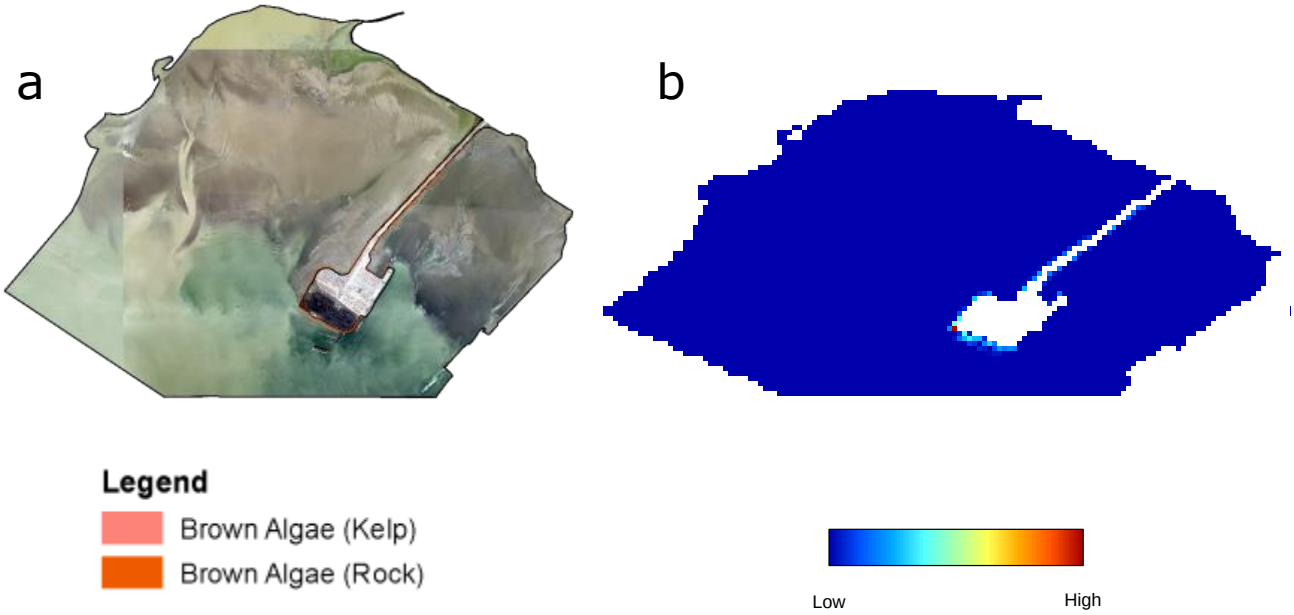


Figure 3-7 Native Eelgrass Distribution (a) Based on 2012-2014 Field Studies, Beside (b) Forecasted Without Project Conditions in Model

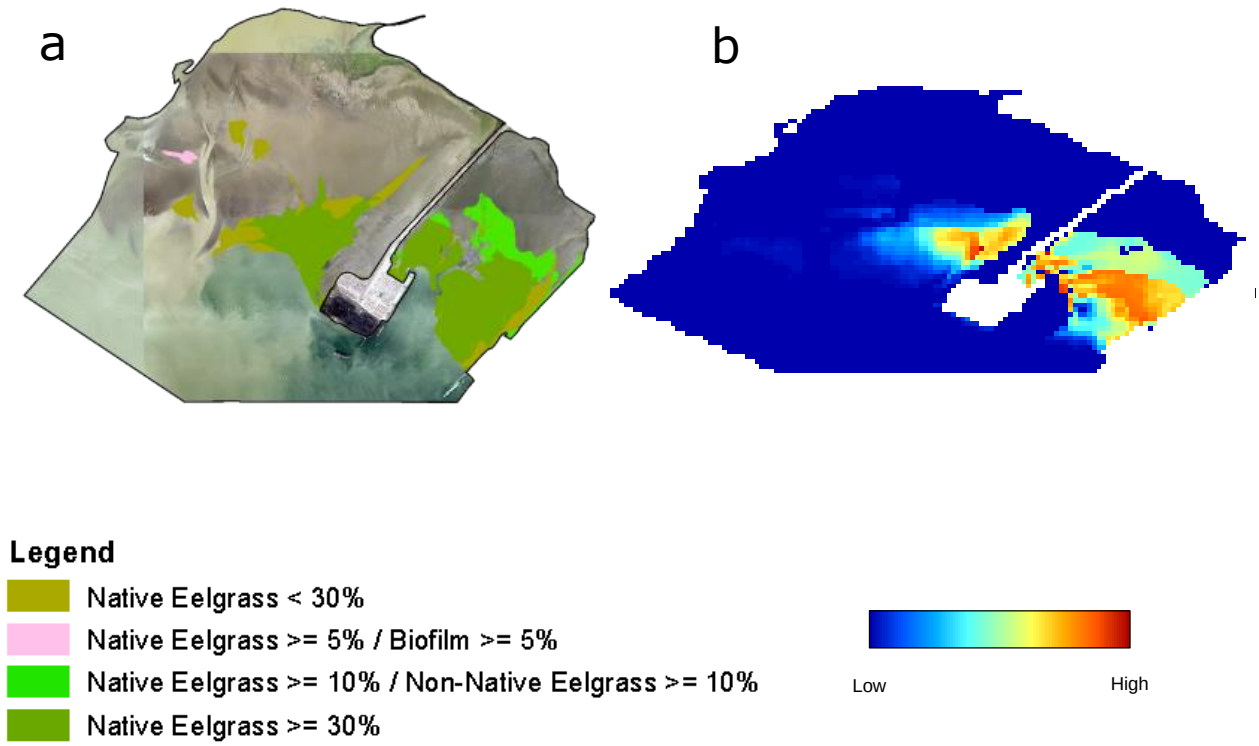
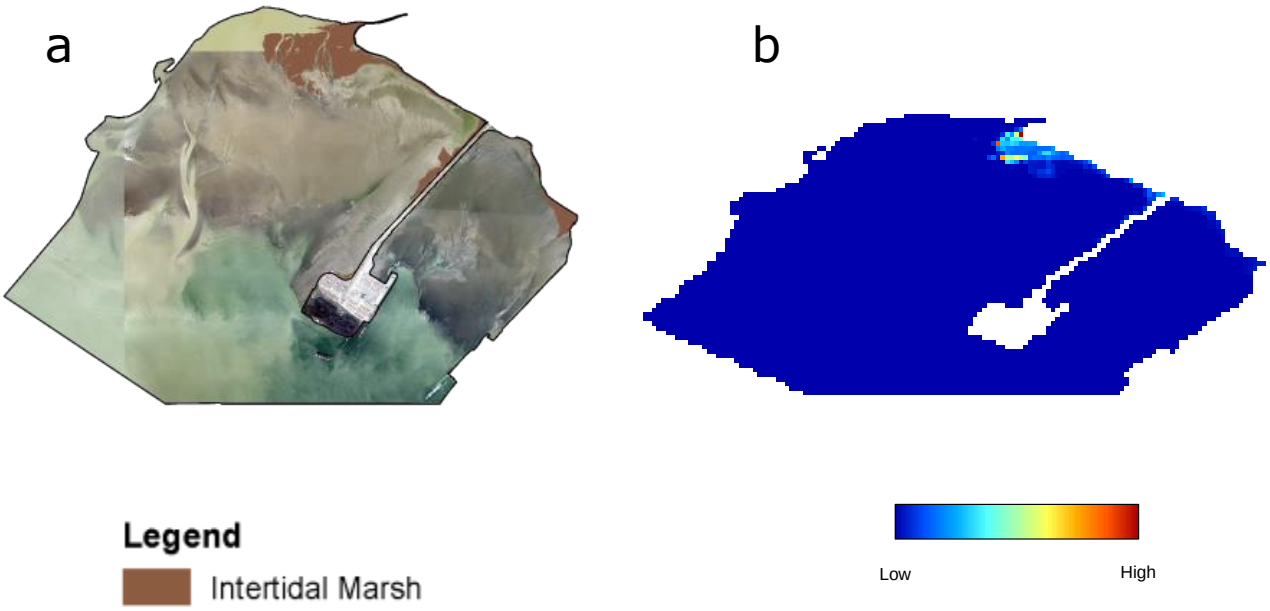


Figure 3-8 Tidal Marsh Distribution (a) Based on 2012-2014 Field Studies, Beside (b) Forecasted Without Project Conditions in Model



3.5 MODEL RESULTS FOR MARINE MAMMALS

Two marine mammal focal species identified by the PC-TAG (i.e., southern resident killer whales and transient killer whales), were included as two of the marine mammal functional groups in the Roberts Bank ecosystem model.

Marine mammals are an integral part of the marine ecosystem at Roberts Bank and play important roles in maintaining the ecosystem, especially through their role as top predators. The ecosystem model was not built to provide direct information on RBT2 effects on marine mammals because important variables to assess the effects, such as underwater noise and contaminants were not considered in the model. In addition, the study area for the ecosystem model is at a small scale compared to their habitat. Other models at the individual- and population-level will be used to assess the effects of the Project on Southern resident killer whales (SRKW) and other marine mammals (**Section 14.0 Marine Mammals**). Marine mammals were, however, included in the ecosystem model for their important role as top predators.

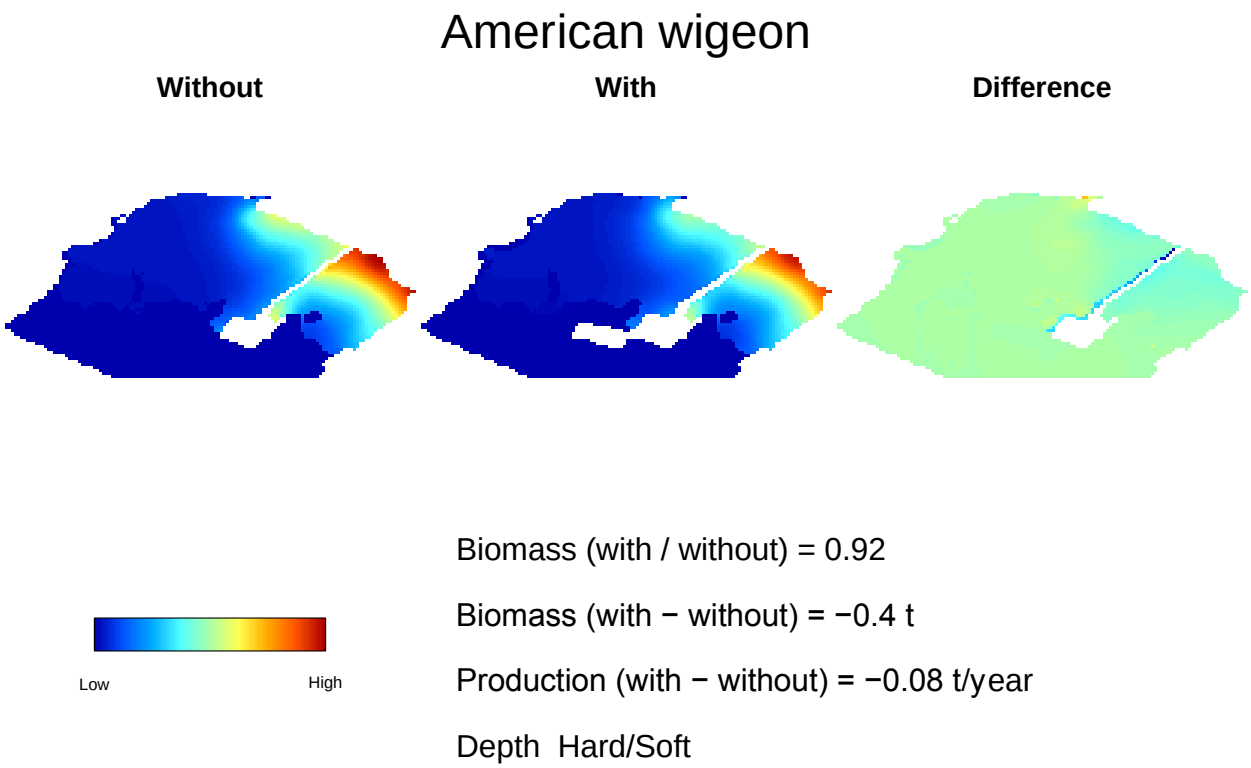
3.6 MODEL RESULTS FOR BIRDS

This section presents results forecasted by the Roberts Bank ecosystem model for birds identified as focal species at Roberts Bank by the PC-TAG, and used as functional groups in the model. Results for the remaining bird functional groups are included in **Appendix 1**.

The model forecasts changes in the production of bird functional groups as a result of the proposed Project assuming bird biomass is distributed as a function of suitable habitat and prey productivity (also affected by the proposed Project). The model should not be used to validate where birds were encountered during sampling in the study area.

3.6.1 *American Wigeon*

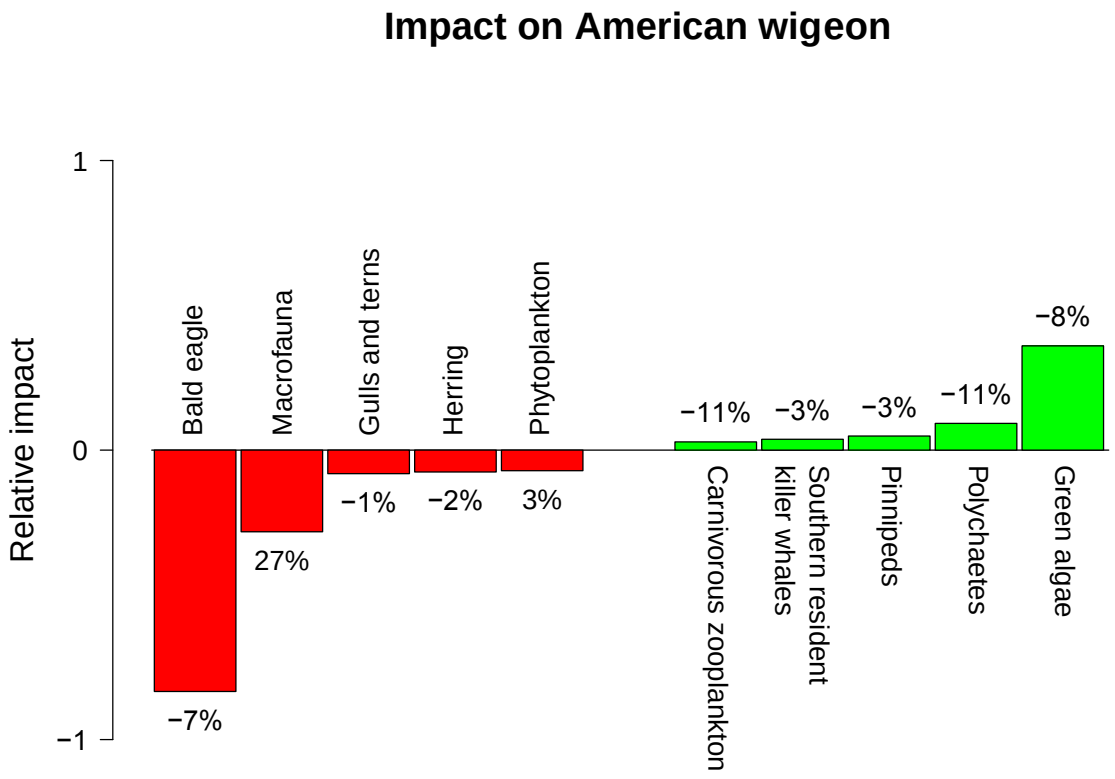
Figure 3-9 Forecasted Biomass Distribution for American Wigeon, Without the Project, With the Project, and the Difference (With - Without)



Note: American wigeon are distributed based on depth, and soft substrate. The colour scale indicates values from low (blue) to high (red)

The model forecasts a decrease of 8% in the biomass of American wigeon, particularly adjacent to the causeway and existing terminal (**Figure 3-9**). This decrease in American wigeon productive potential likely corresponds to biomass decreases of green algae which American wigeon feed on (see positive impact of green algae for American wigeon in (**Figure 3-10**). Green algae production is forecast to decrease by 8% in the same locations (see **Figure 3-54**). Further, macrofauna is forecast to increase 27% and this group has an indirect negative impact on American wigeon (**Figure 3-10**).

Figure 3-10 Mixed Trophic Impacts for Groups that have strongest relative Impact on American Wigeon



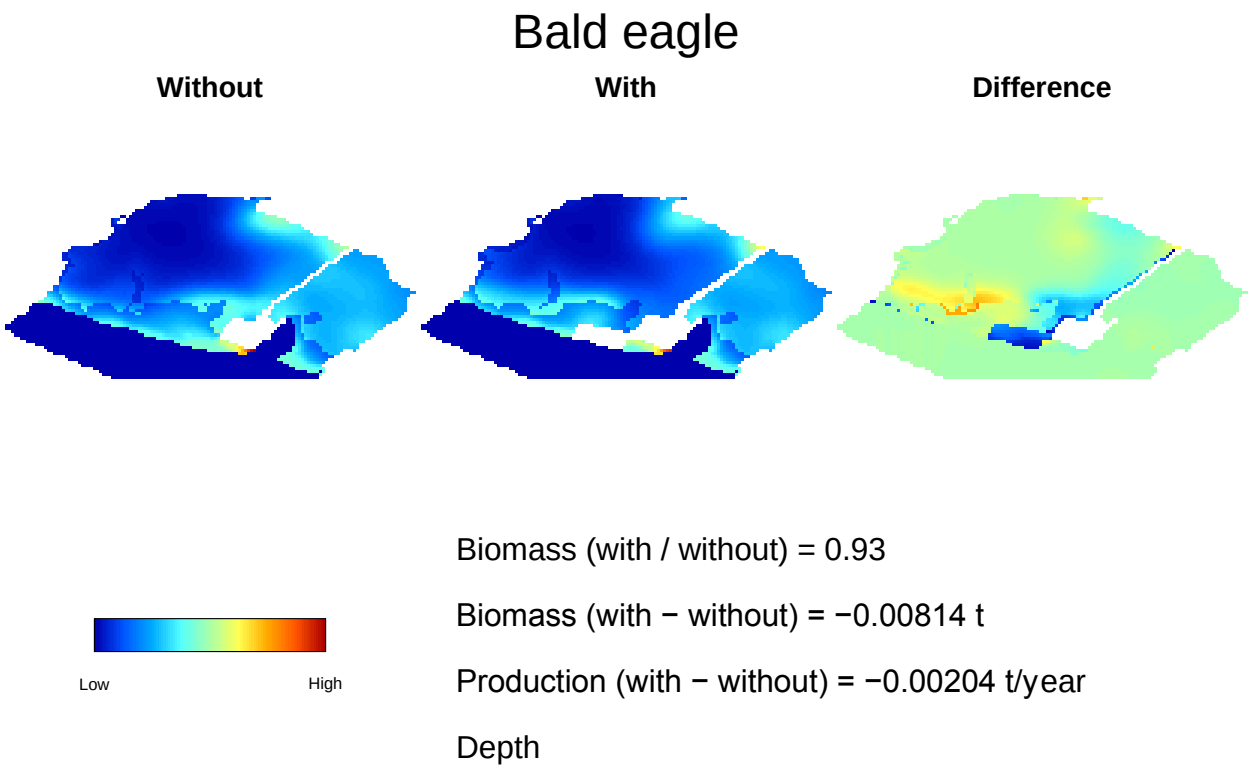
Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

In addition to the increased competition from macrofauna, (which benefits other groups that compete with the species), the American wigeon is impacted negatively by the reduced productive potential that is forecasted for all of the five most important groups that have a positive impact on it.

3.6.2 *Bald Eagle*

Bald eagle biomass is forecast to decrease by 7% as a result of the Project (**Figure 3-11**). Biomass is predicted to increase in the intertidal zone northwest of the Roberts Bank causeway, but not sufficiently to offset the forecasted losses in the area immediately north of the existing terminal and on the footprint of the proposed Project.

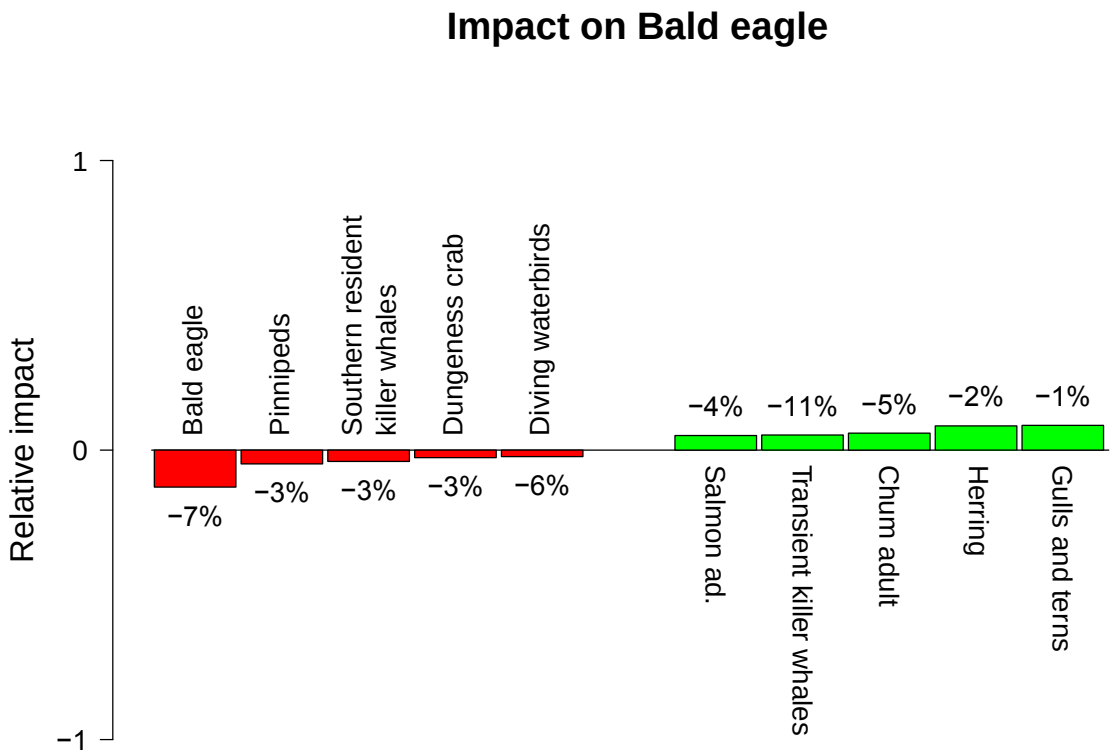
Figure 3-11 Forecasted Biomass Distribution for Bald Eagle, Without the Project, With the Project, and the Difference (With - Without)



Note: Bald eagle is distributed based on depth. The colour scale indicates values from low (blue) to high (red)

The groups that have most positive impact on bald eagle (**Figure 3-12**) are all forecast to have reduced productive potential, and this is not out-weighed by the decrease in negative impacts by the groups that compete with bald eagle.

Figure 3-12 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Bald Eagle

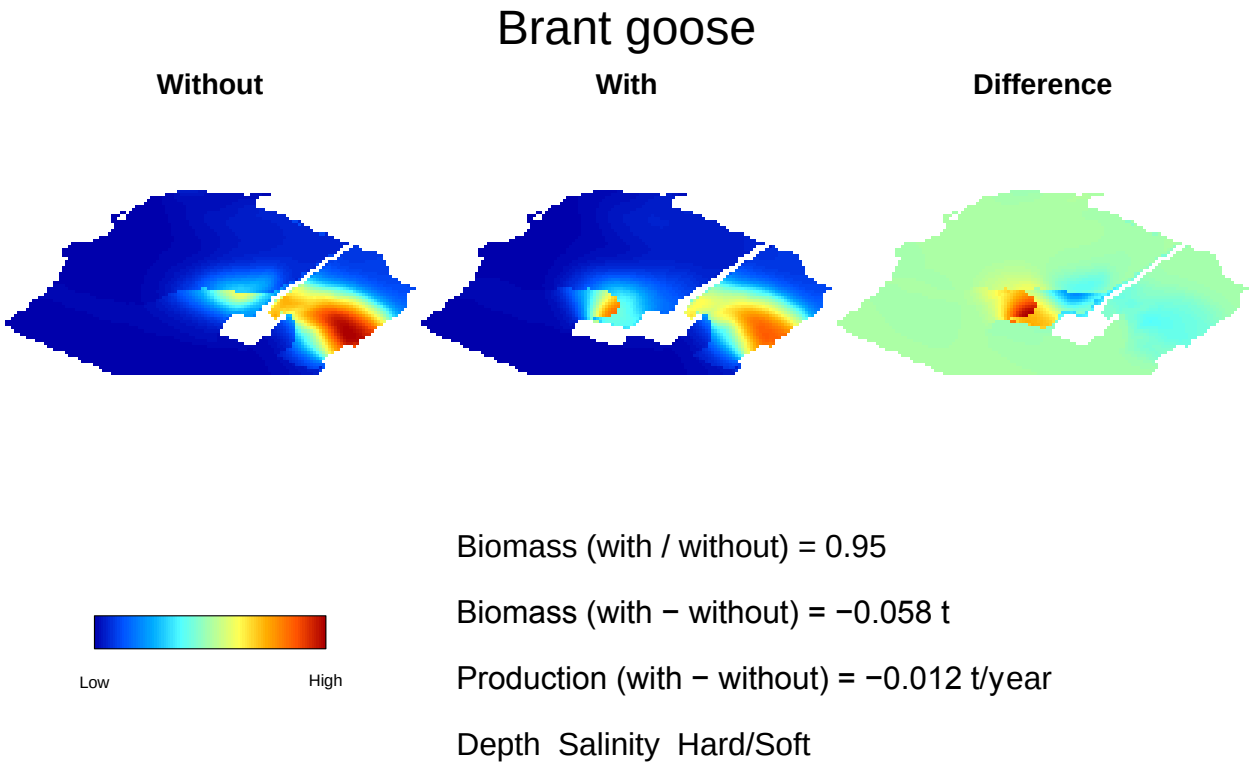


Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.6.3 *Brant Goose*

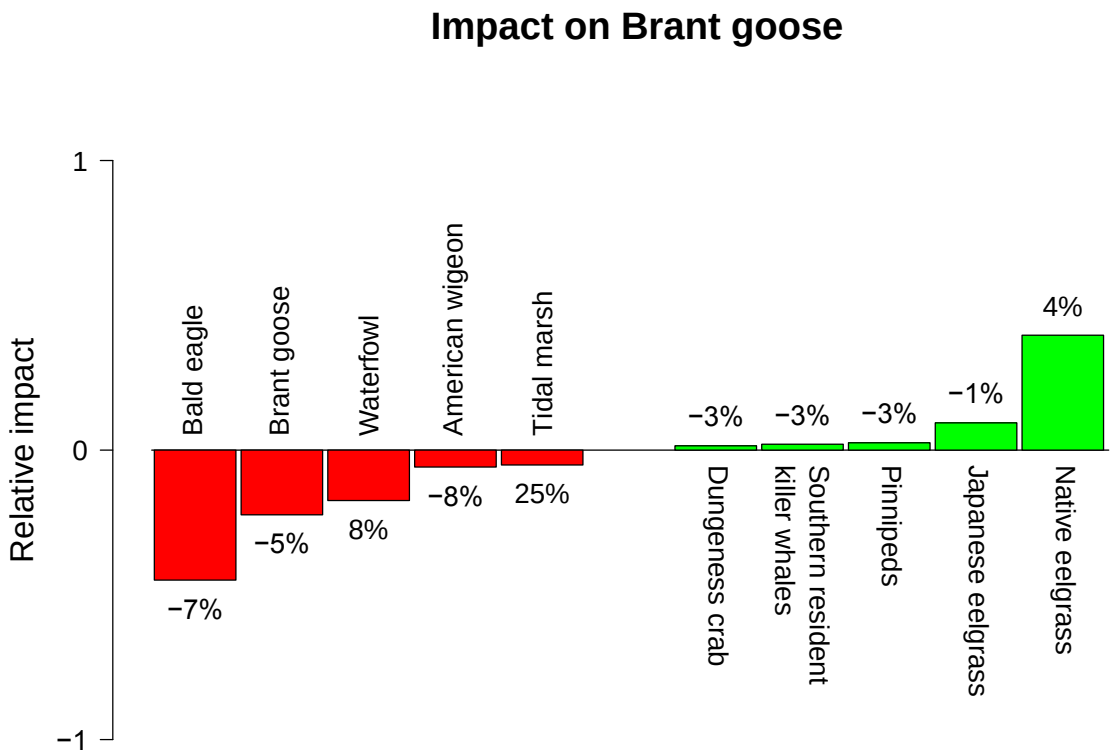
Brant goose biomass is forecast to decrease by 6% (**Figure 3-13**). Production increases near the Project and decreases immediately adjacent to the existing terminal and to the north, which more than offset these increases. Areas of increased and decreased Brant biomass correspond closely with areas of increased and decreased native eelgrass biomass, respectively (see **Figure 3-52**), underscoring the close tie between Brant and eelgrass. This is also clear form the impacts graph (**Figure 3-14**).

Figure 3-13 Forecasted Biomass Distribution for Brant Goose, Without the Project, With the Project, and the Difference (With - Without)



Note: Brant geese are distributed based on depth, salinity, and soft substrate. The colour scale indicates values from low (blue) to high (red)

Figure 3-14 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Brant Goose

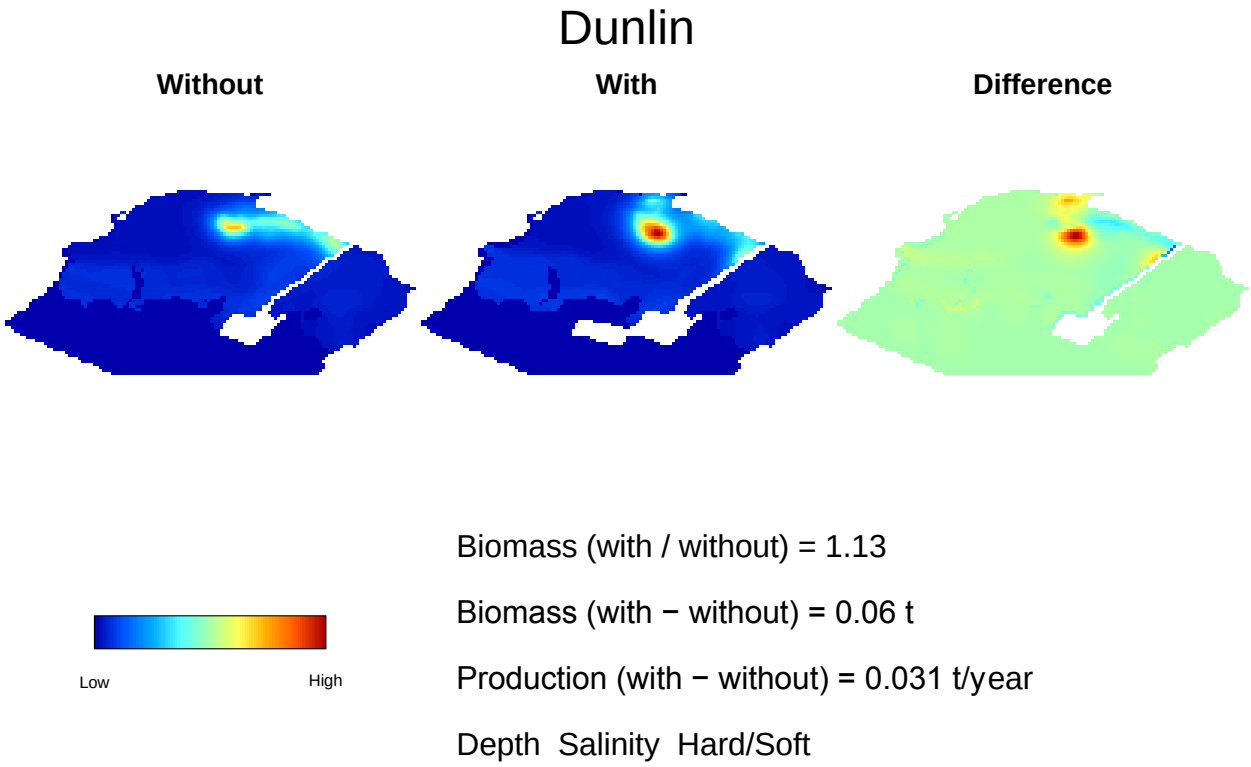


Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.6.4 *Dunlin*

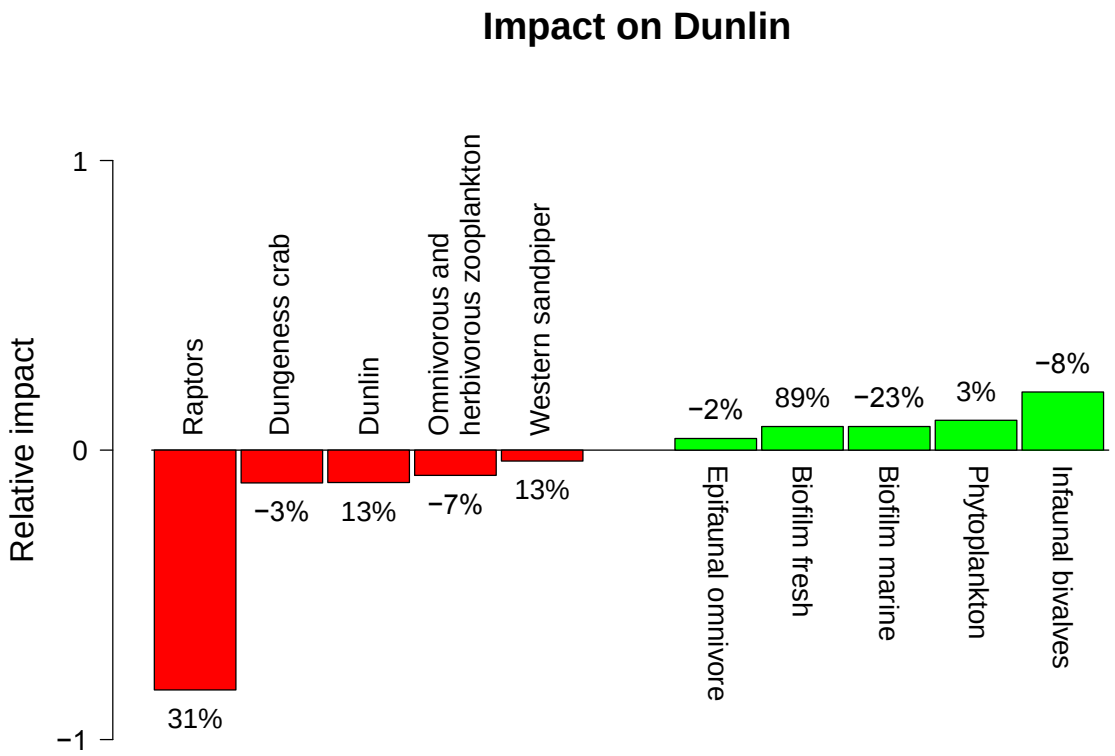
Dunlin production is forecasted to increase by 13% (**Figure 3-15**) likely as a result of an increase in prey productivity on the tidal flats northeast of RBT2. Although infaunal bivalves (which have a strong positive impact on dunlin, **Figure 3-16**) are forecasted to decrease, other major prey of dunlin such as macrofauna (**Figure 3-43**), meiofauna (**Figure A1.39**), and freshwater biofilm (**Figure 3-49**), are forecasted to increase, resulting in an overall net gain in productivity of dunlin prey.

Figure 3-15 Forecasted Biomass Distribution for Dunlin, Without the Project, With the Project, and the Difference (With - Without)



Note: Dunlin are distributed based on depth, salinity, and soft substrate. The colour scale indicates values from low (blue) to high (red)

Figure 3-16 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Dunlin

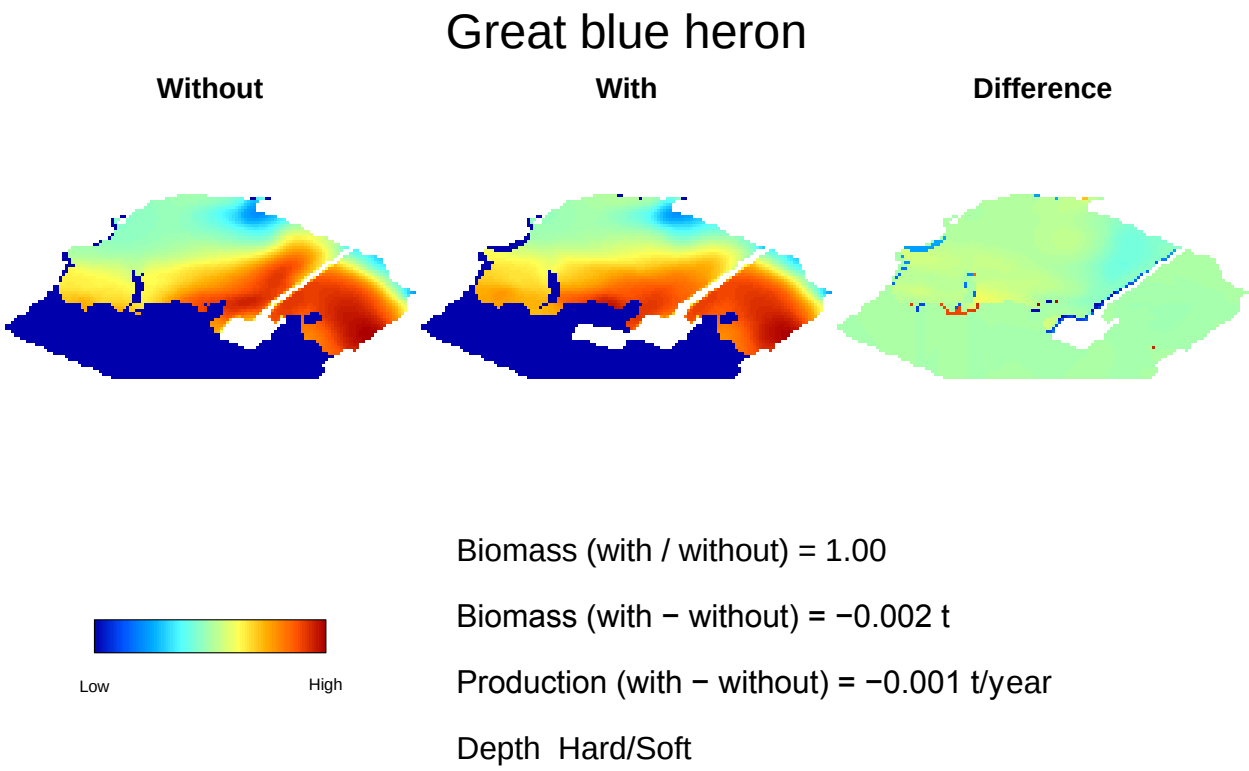


Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.6.5 *Great Blue Heron*

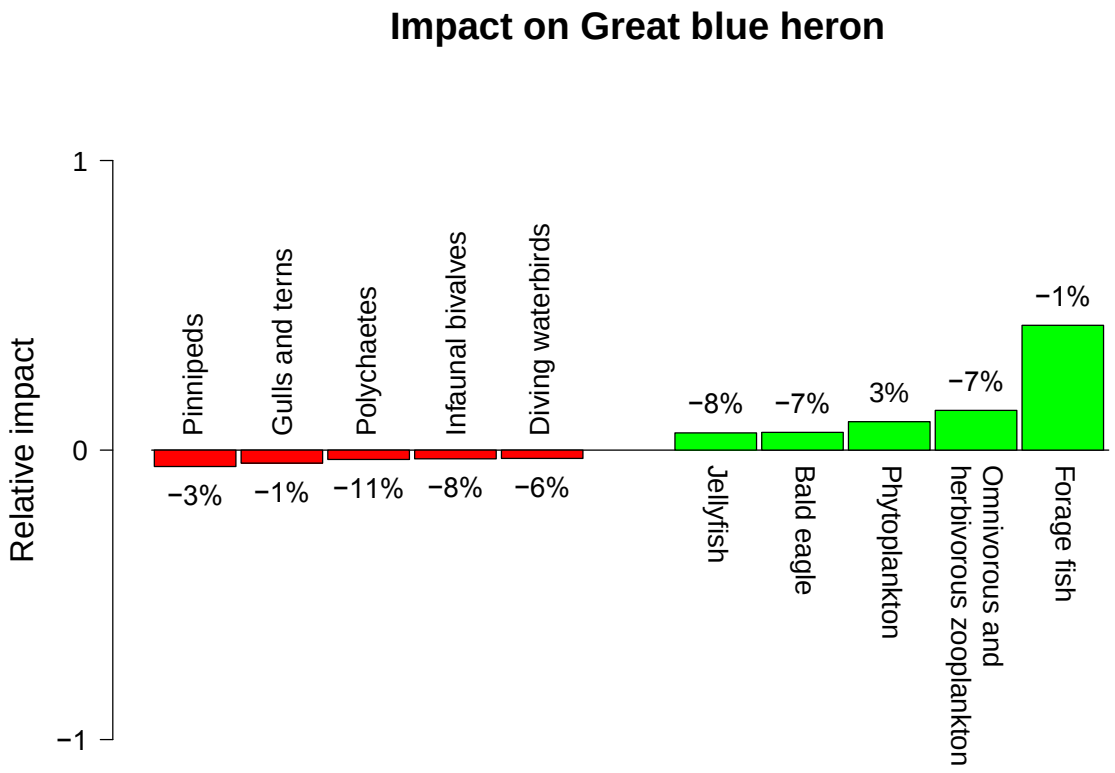
Great blue heron biomass is forecast to remain effectively unchanged (**Figure 3-17**). Slightly greater biomass in the inter-causeway area will be offset by decreased biomass along the north side of the causeway and existing terminal.

Figure 3-17 Forecasted Biomass Distribution for Great Blue Heron, Without the Project, With the Project, and the Difference (With - Without)



Note: Great blue heron are distributed based on depth, and soft substrate. The colour scale indicates values from low (blue) to high (red)

Figure 3-18 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Great Blue Heron

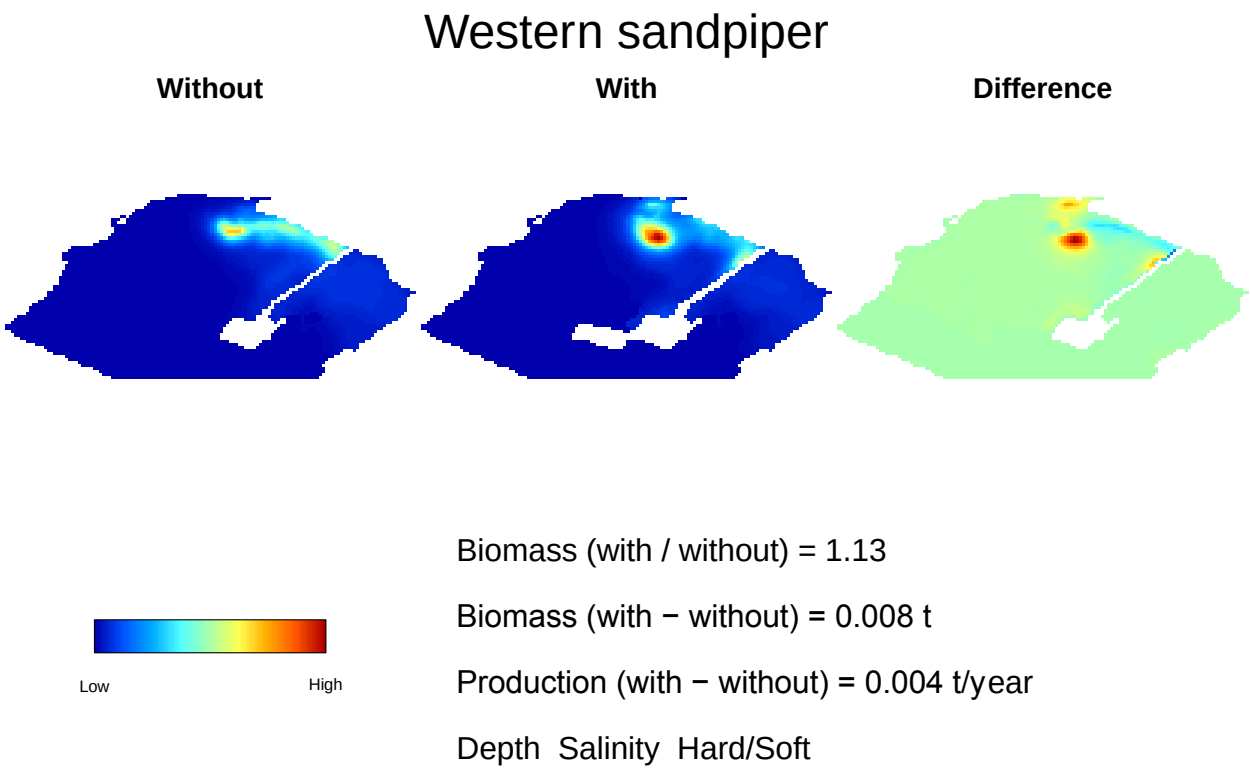


Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.6.6 *Western Sandpiper*

The productive potential of Western sandpiper is forecast to increase by 13% (**Figure 3-19**), likely as a result of an increase in prey production on the tidal flat northwest of the Roberts Bank causeway and north of RBT2. The increase should be interpreted as a forecast that the study area may be able to support more shorebirds with the Project, if, however, the productive potential in the study area is not a limiting factor for shorebirds, the forecasted increase may not be realized. Main prey in the diet of western sandpiper include macrofauna (**Figure 3-43**), meiofauna (**Figure A1.39**), and marine and freshwater biofilm (**Figure 3-47** and **Figure 3-49**) (Hemmera 2014).

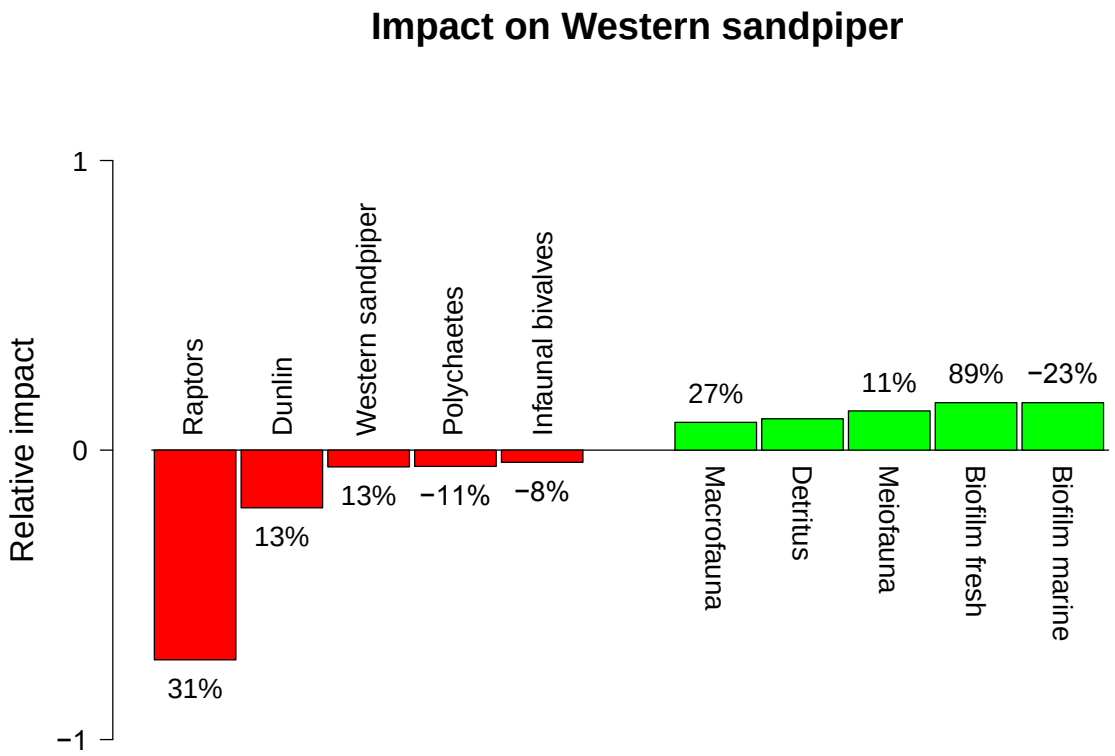
Figure 3-19 Forecasted Biomass Distribution for Western Sandpiper, Without the Project, With the Project, and the Difference (With - Without)



Note: Western sandpiper are distributed based on depth, salinity, and soft substrate. The colour scale indicates values from low (blue) to high (red)

The increase in Western sandpiper is associated with the major increase that is predicted for freshwater biofilm, a group with a strong positive impact on it (**Figure 3-20)**. The increase in freshwater biofilm, thus outweighs the forecast decline in marine biofilm, which also has a strong positive impact on the species.

Figure 3-20 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Western Sandpiper



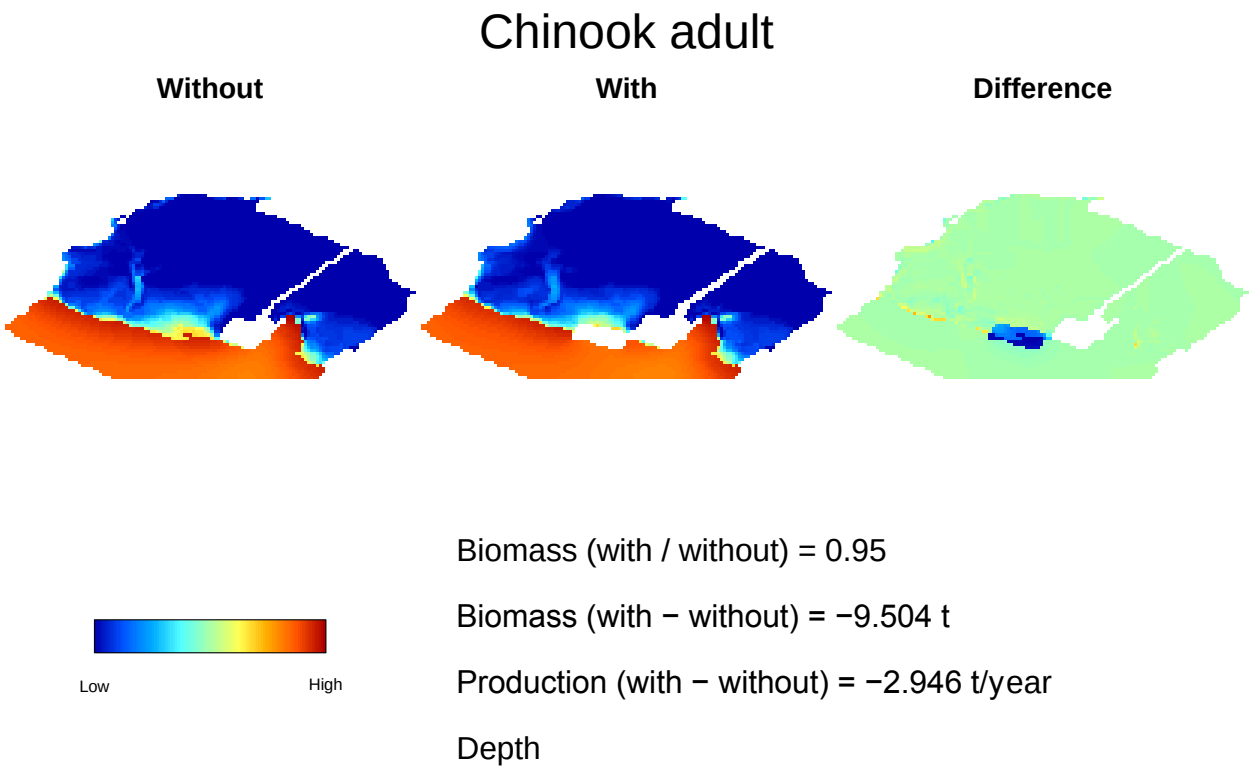
Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.7 MODEL RESULTS FOR FISH

3.7.1 *Chinook Salmon Adult*

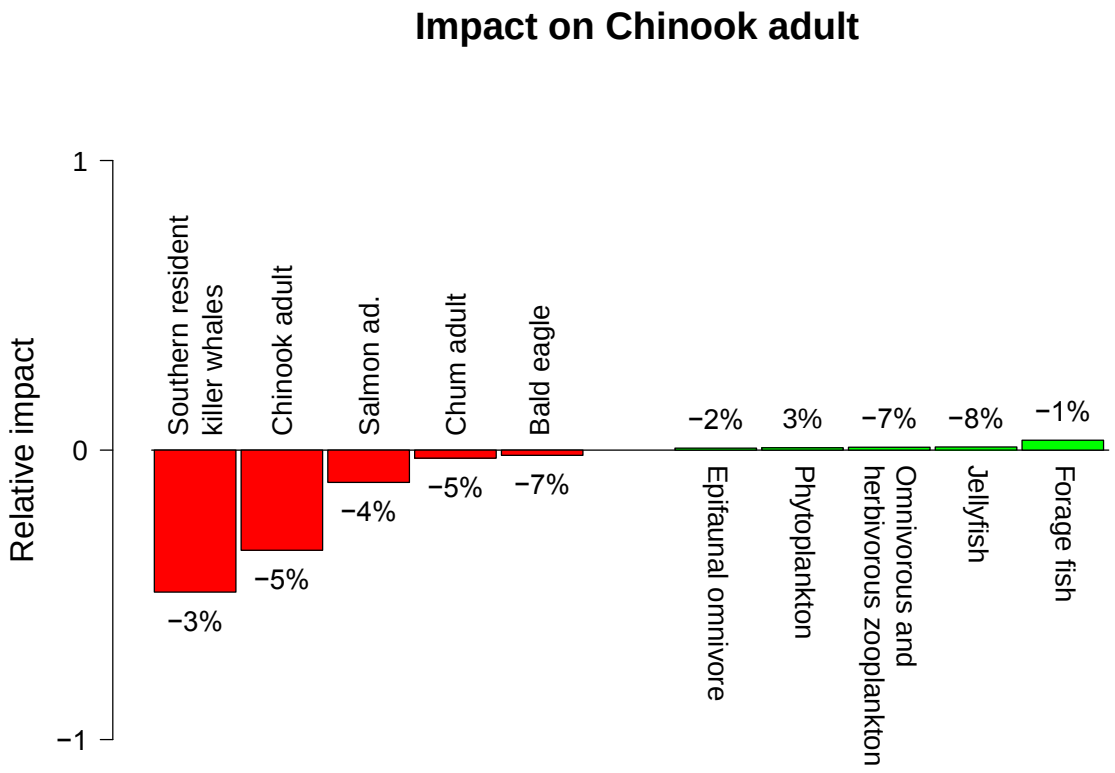
Adult chinook salmon biomass is forecast to decrease by 5% (**Figure 3-21**), which corresponds to production of 2.79 t year^{-1}. The most productive areas for adult chinook salmon are forecasted to be in the subtidal zone of Roberts Bank along the foreslope, with some increased production forecasted with the Project. However, increased production along the edge of the foreslope will be counterbalanced by losses due to the footprint of RBT2.

Figure 3-21 Forecasted Biomass Distribution for Adult Chinook Salmon, Without the Project, With the Project, and the Difference (With - Without)



Note: Adult chinook salmon are distributed based on depth. The colour scale indicates values from low (blue) to high (red)

Figure 3-22 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Adult Chinook Salmon



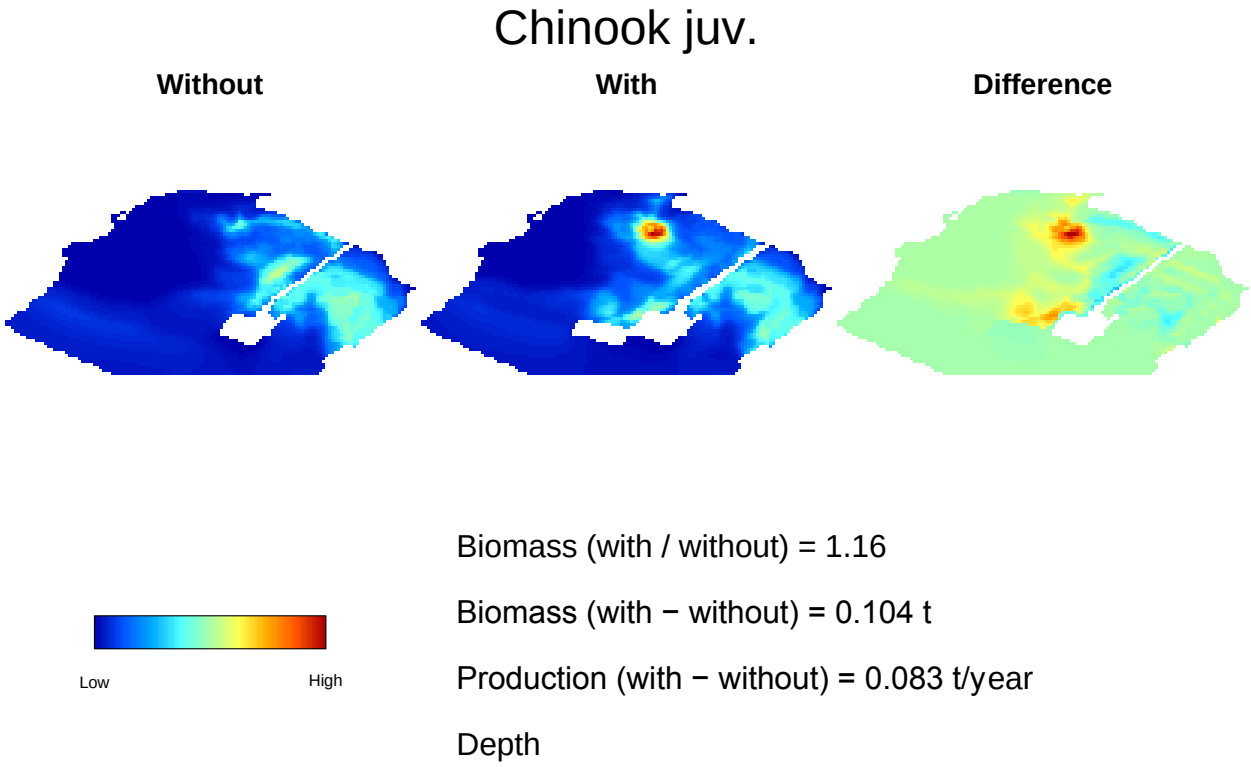
Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

The groups that have strongest negative impact on adult chinook salmon (**Figure 3-22**) are all forecast to decrease, but the reduced negative impact this may have on the species is not enough to outweigh the declines by the main groups that have positive impact on the chinook salmon.

3.7.2 *Chinook Salmon Juvenile*

Juvenile chinook salmon production is forecast to increase by 16% (**Figure 3-23**). Most productive locations within the study area are forecasted to be on the tidal flats northwest of the Roberts Bank causeway, and these outweigh losses as a result of terminal placement and causeway widening.

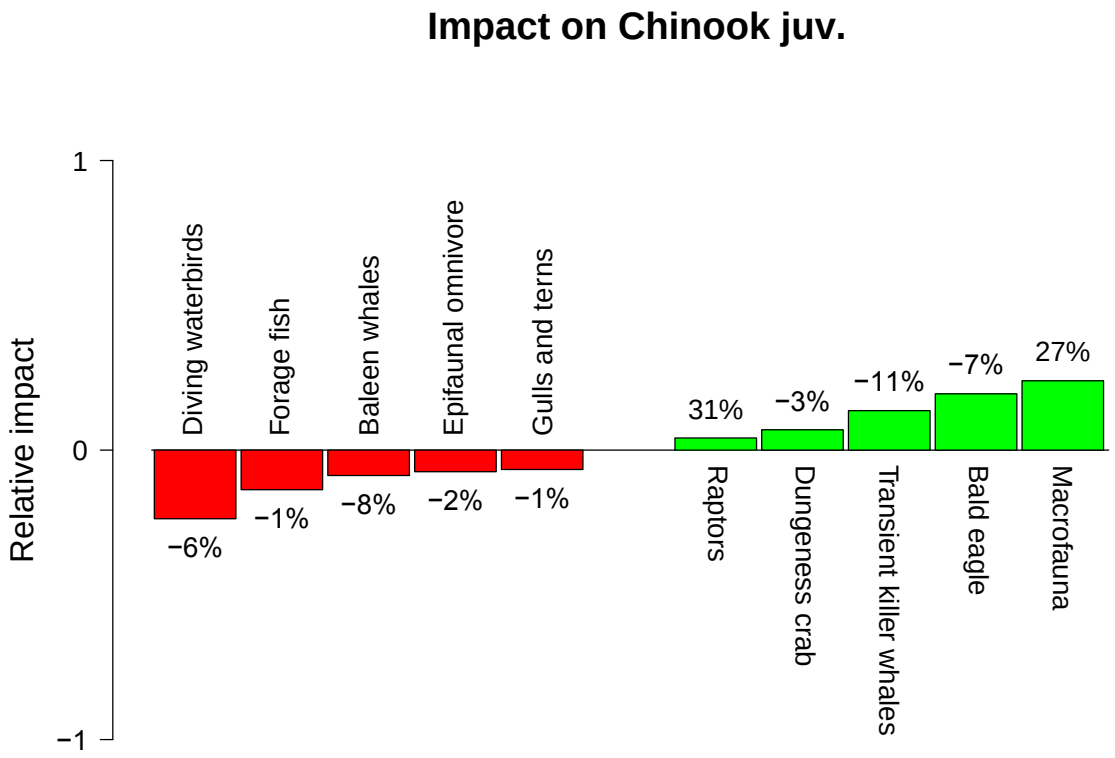
Figure 3-23 Forecasted Biomass Distribution for Juvenile Chinook Salmon, Without the Project, With the Project, and the Difference (With - Without)



Note: Juvenile chinook salmon are distributed based on depth. The colour scale indicates values from low (blue) to high (red)

The mixed trophic impact analysis (**Figure 3-24**) shows that all the groups with major negative food web impact on the juvenile chinook salmon are forecast to see reduced productive potential. The group with the strongest positive impact (macrofauna) is, however, predicted to increase considerably (27%).

Figure 3-24 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Juvenile Chinook Salmon

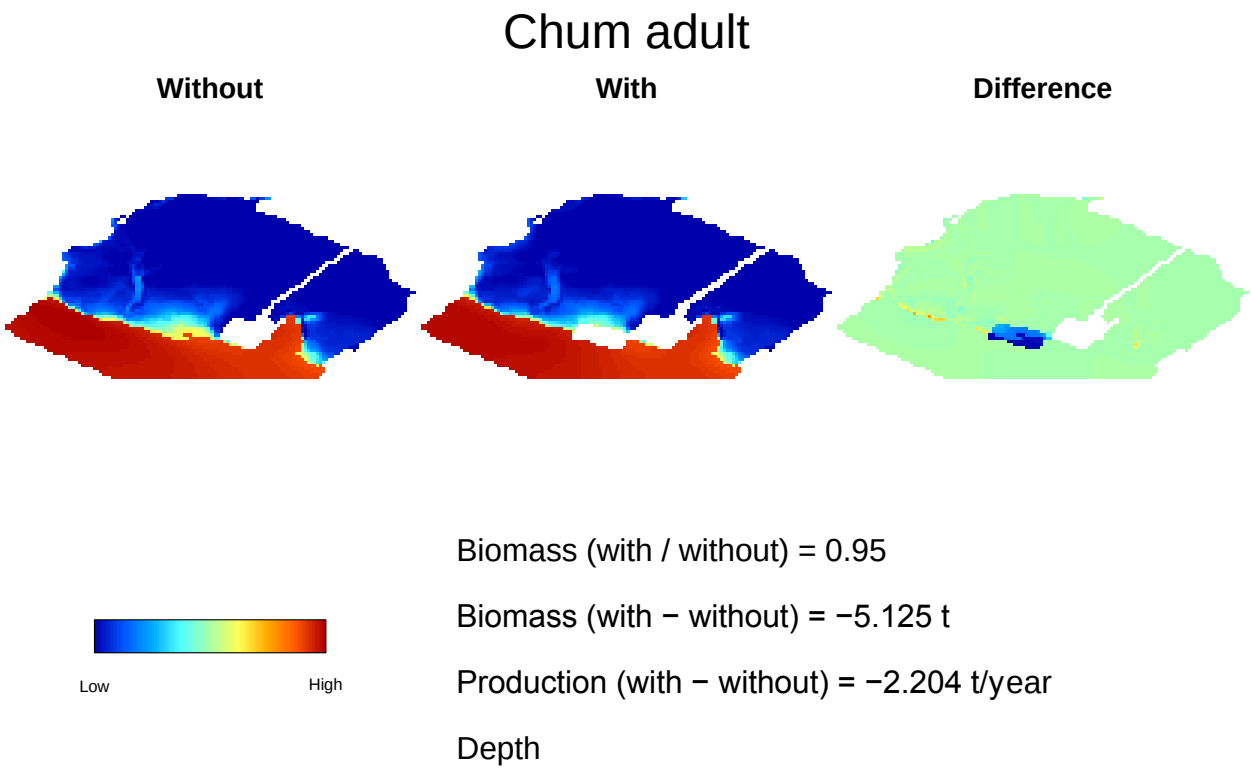


Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.7.3 *Chum Salmon Adult*

Adult chum salmon production is forecasted to decrease by 4% (**Figure 3-25**). The most productive areas for adult chum are forecasted in the subtidal zone of Roberts Bank along the foreslope. In contrast, the tidal flats northwest of the Roberts Bank causeway and the inter-causeway area are the least productive. Some of the decrease in production is likely the result of loss of wetted area as a result of terminal placement and causeway widening.

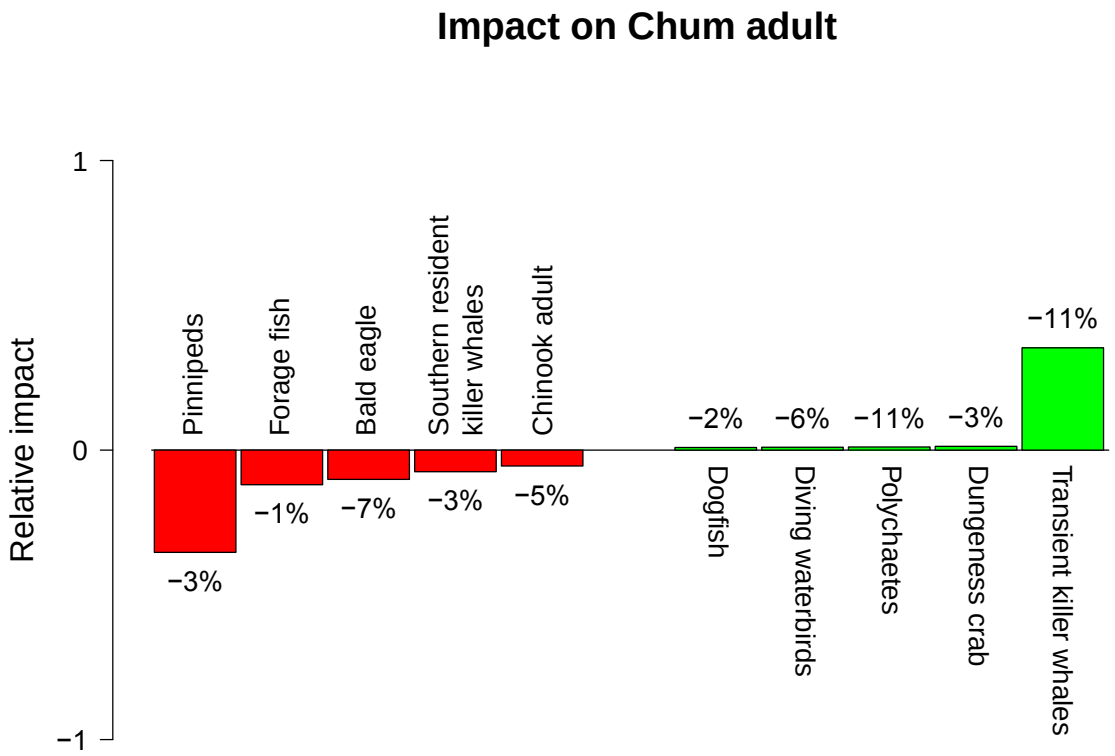
Figure 3-25 Forecasted Biomass Distribution for Adult Chum Salmon, Without the Project, With the Project, and the Difference (With - Without)



Note: Adult chum salmon are distributed based on depth. The colour scale indicates values from low (blue) to high (red)

The trophic impacts on adult chum salmon (**Figure 3-26**) show that the groups with most negative impact all are forecast to decline, but so are the groups with the strongest positive impacts, and the balance is that the change corresponds to the lost habitat area.

Figure 3-26 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Adult Chum Salmon

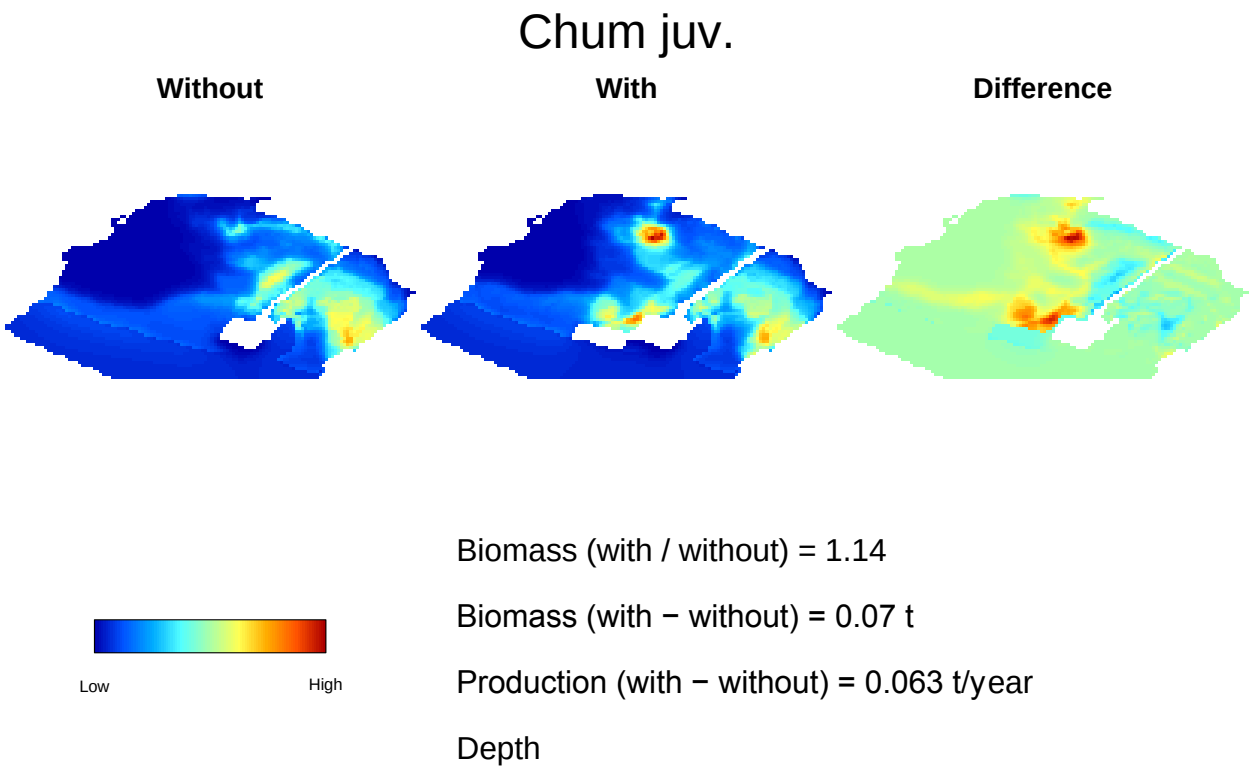


Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.7.4 *Chum Salmon Juvenile*

Juvenile chum salmon biomass is forecast to increase by 14% (**Figure 3-27**). The most productive areas for juvenile chum are forecast to be on the tidal flats northwest of the Roberts Bank causeway. Increased production is forecasted northwest of the existing terminal (behind the RBT2), and on the tidal flats northwest of the Roberts Bank causeway, which counterbalances the loss of production as a result of RBT2 placement.

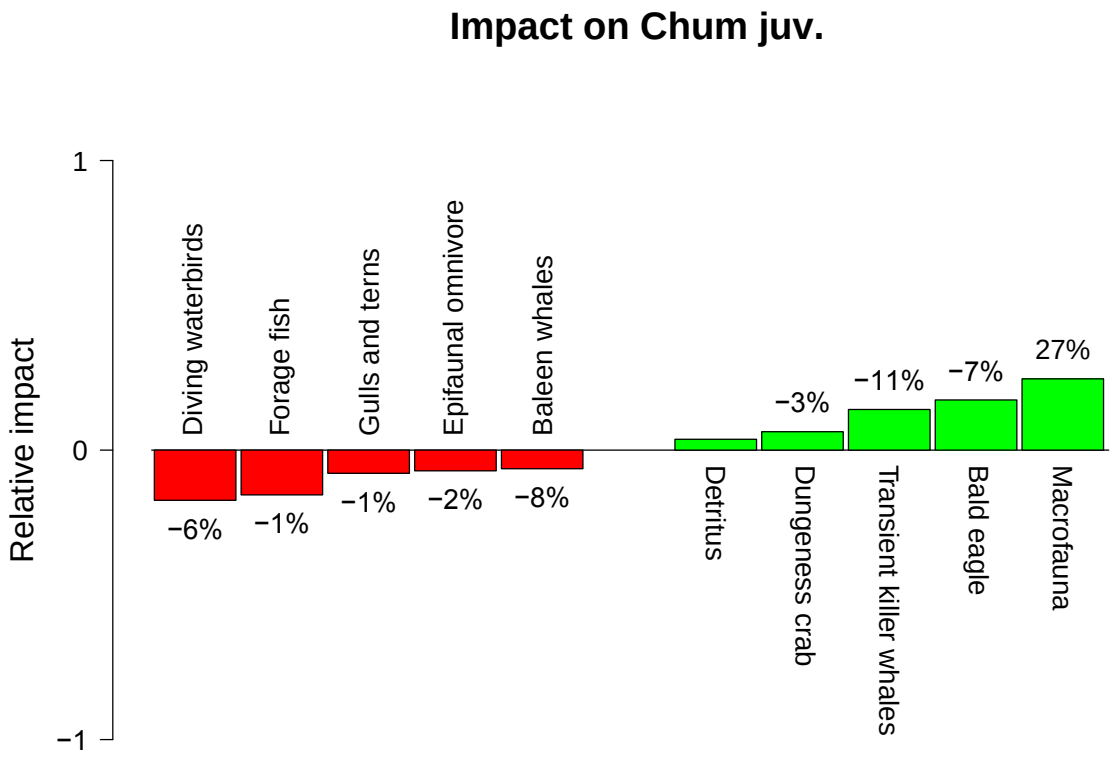
Figure 3-27 Forecasted Biomass Distribution for Juvenile Chum Salmon, Without the Project, With the Project, and the Difference (With - Without)



Note: Juvenile chum salmon are distributed based on depth. The colour scale indicates values from low (blue) to high (red)

The forecast increase is likely due to a combination of decreased predation pressure and increased prey production. The groups with the strongest negative impact on juvenile chum salmon are all predicted to decrease (**Figure 3-28**), while the group with the strongest positive impact, i.e. macrofauna, (which is also the major prey for the juvenile chum salmon) is predicted to increase 27%. Overall, this likely has a strong impact on the results for the juvenile chum salmon.

Figure 3-28 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Juvenile Chum Salmon

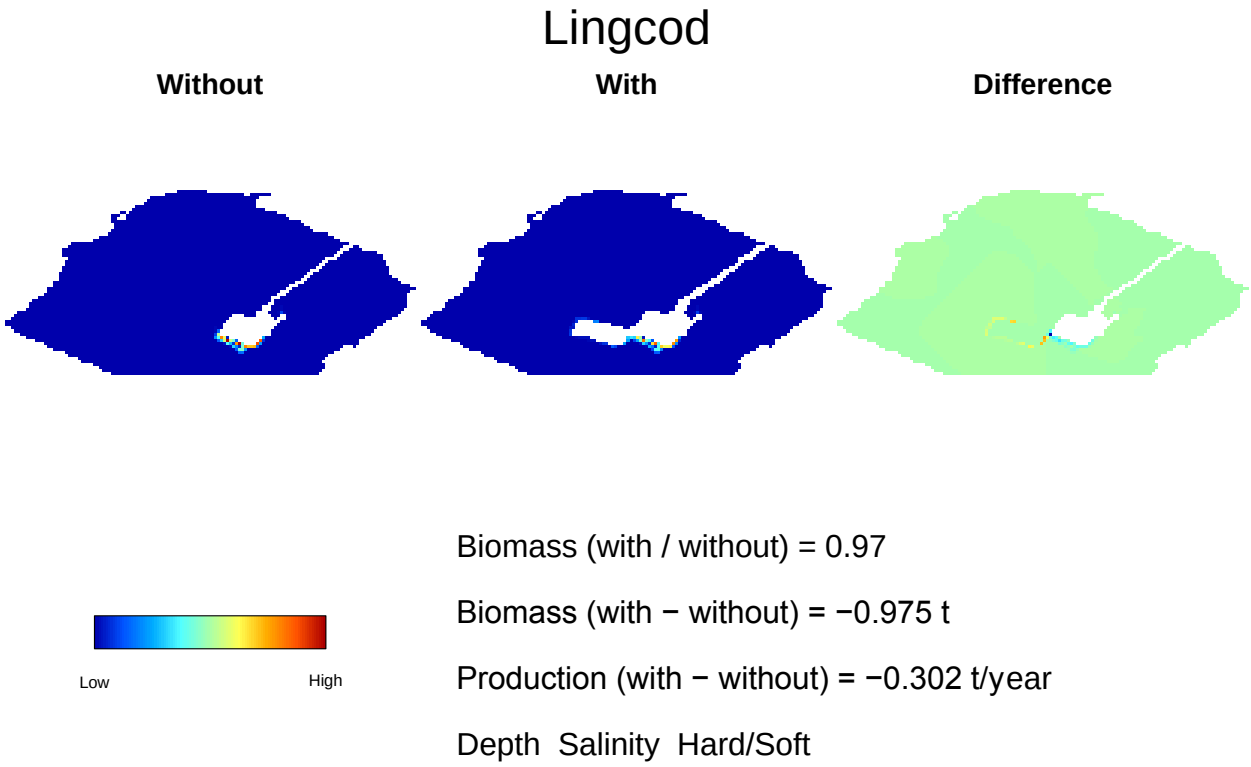


Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.7.5 *Lingcod*

Lingcod production is forecast to decrease by 3% (**Figure 3-29**). The most productive habitat for lingcod is hard substrate, which is distributed around the Roberts Bank terminal, the proposed new terminal, and along the causeway.

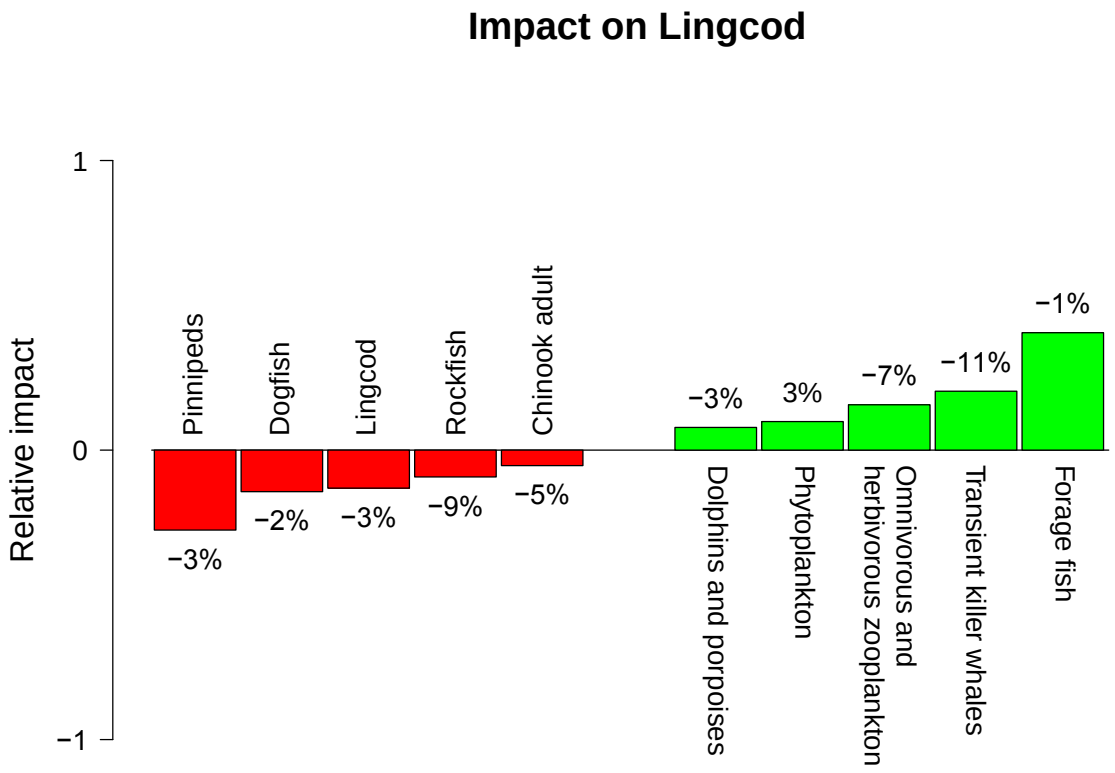
Figure 3-29 Forecasted Biomass Distribution for Lingcod, Without the Project, With the Project, and the Difference (With - Without)



Note: Lingcod are distributed based on depth, salinity, and hard substrate. The colour scale indicates values from low (blue) to high (red)

The results for lingcod are closely tied to what happens with hard substrate, and as such influenced positively with the addition of more of this habitat type as is considered in connection with the proposed RBT2. The lingcod benefit from decreased predation and competition from all of the groups with strongest negative impact on lingcod (**Figure 3-30**), but all the groups with positive impacts are also forecast to decrease, and the balance is that lingcod change only little (-3%).

Figure 3-30 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Lingcod

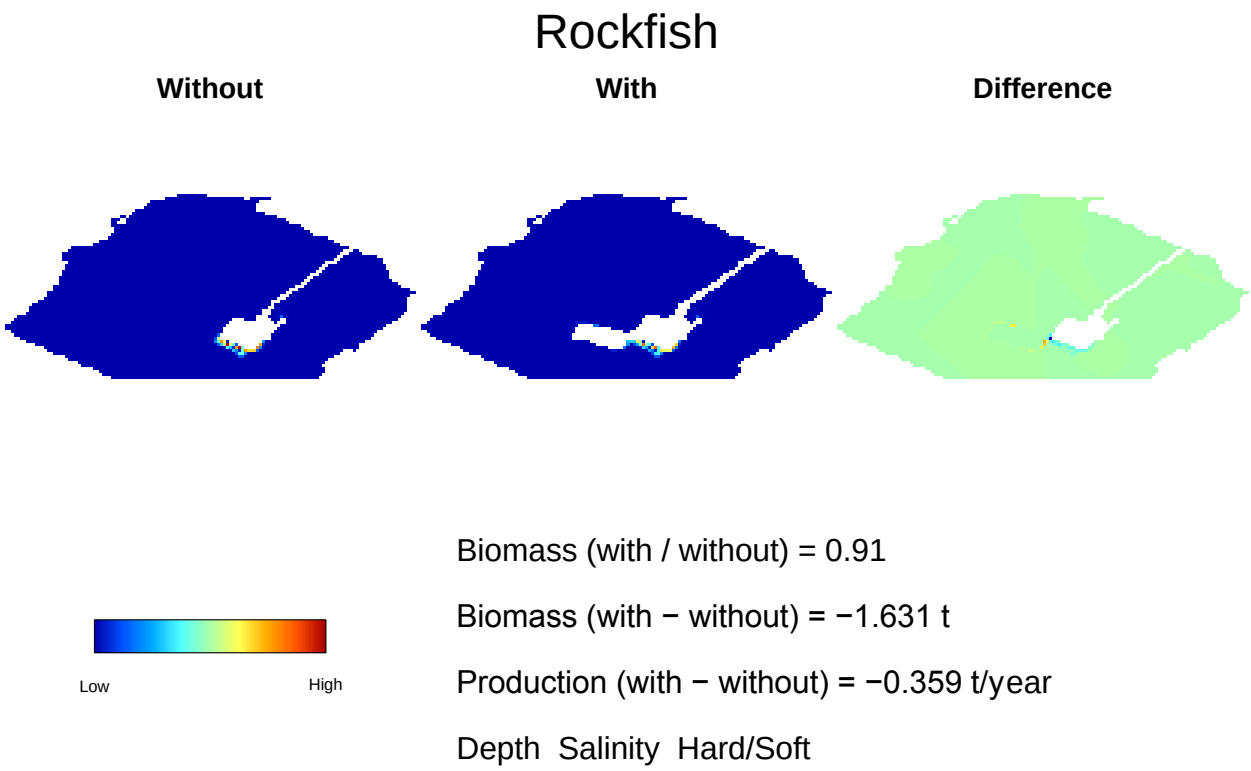


Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.7.6 *Rockfish*

Rockfish favour hard substrate and they are distributed in the Roberts Bank ecosystem model based on their preference for this layer as well as for depth and salinity (**Figure 3-31**). While the addition of hard substrate as support structures for the widened causeway and new terminal is proposed, production of rockfish is forecast to decrease by 9%.

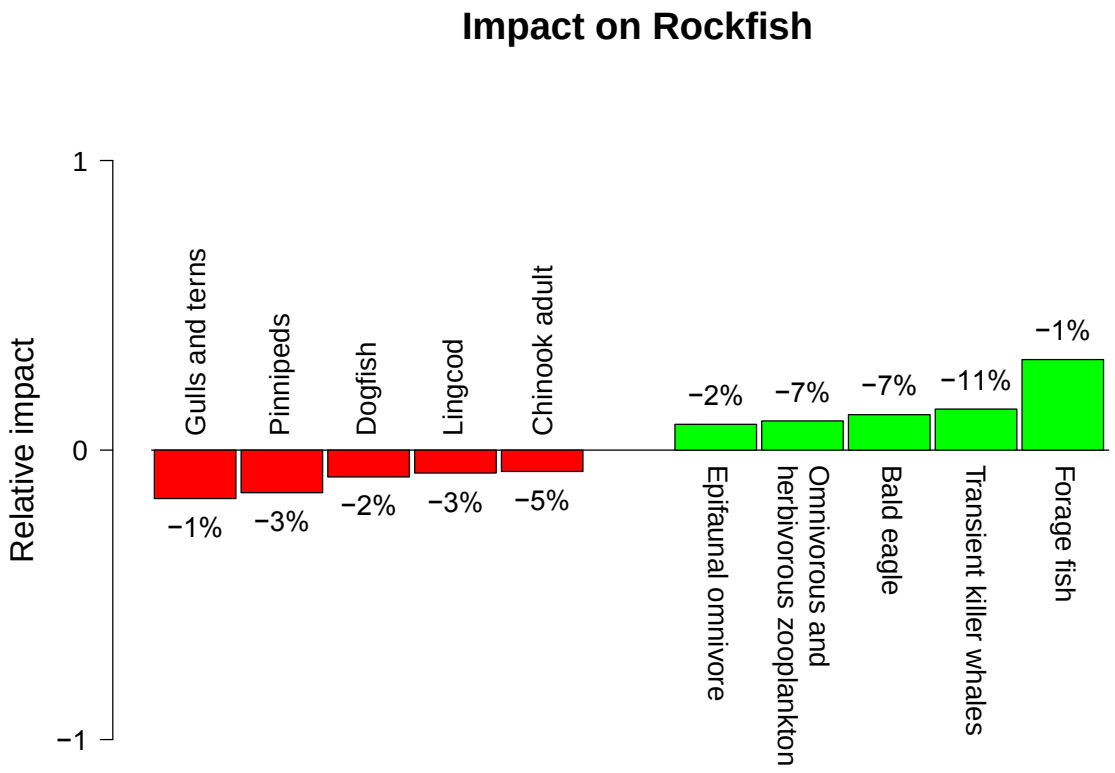
Figure 3-31 Forecasted Biomass Distribution for Rockfish, Without the Project, With the Project, and the Difference (With - Without)



Note: Rockfish are distributed based on depth, salinity, and hard substrate. The colour scale indicates values from low (blue) to high (red)

The mixed trophic impact routine (**Figure 3-32**) shows a slightly decreased predation and competition for rockfish from the groups with strongest negative impact, but this is more than outweighed by stronger forecast declines in all of the groups that have the strongest positive impact on rockfish. Indications are thus, that the forecast decline for rockfish is related to both direct and indirect food web effects.

Figure 3-32 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Rockfish

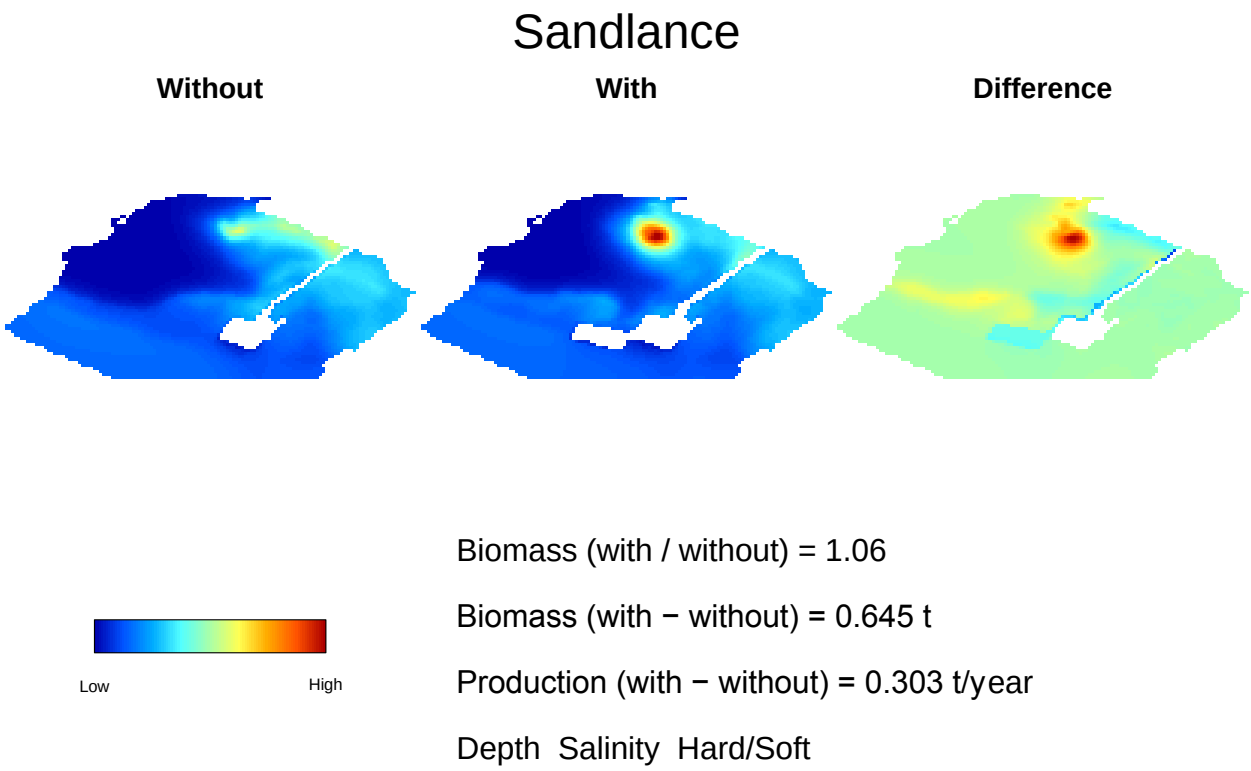


Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.7.7 *Sandlance*

Sandlance is an important prey source for marine mammals, birds, and fish in the Strait of Georgia. Sandlance biomass is forecast to increase by 6%, especially on the tidal flats north of the RBT2, likely due to improved conditions in the area south of Canoe Passage (**Figure 3-33**).

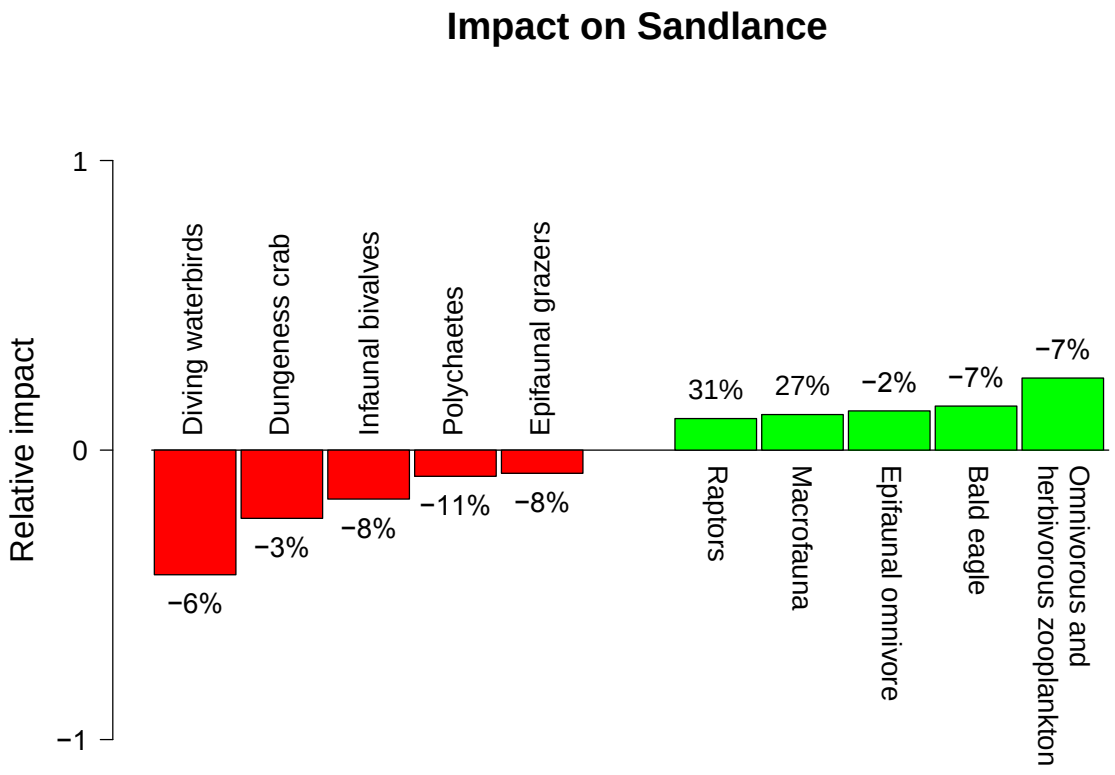
Figure 3-33 Forecasted Biomass Distribution for Sandlance, Without the Project, With the Project, and the Difference (With - Without)



Note: Sandlance are distributed based on depth, salinity, and soft substrate. The colour scale indicates values from low (blue) to high (red)

The trophic impacts for sandlance (**Figure 3-34**) shows that all of the groups with the strongest negative impacts on sandlance are forecast to decline, while especially macrofauna, which has a positive impact on sandlance, is predicted to increase considerably (27%). Overall, these impacts contribute to the forecast 6% increase for sandlance

Figure 3-34 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Sandlance

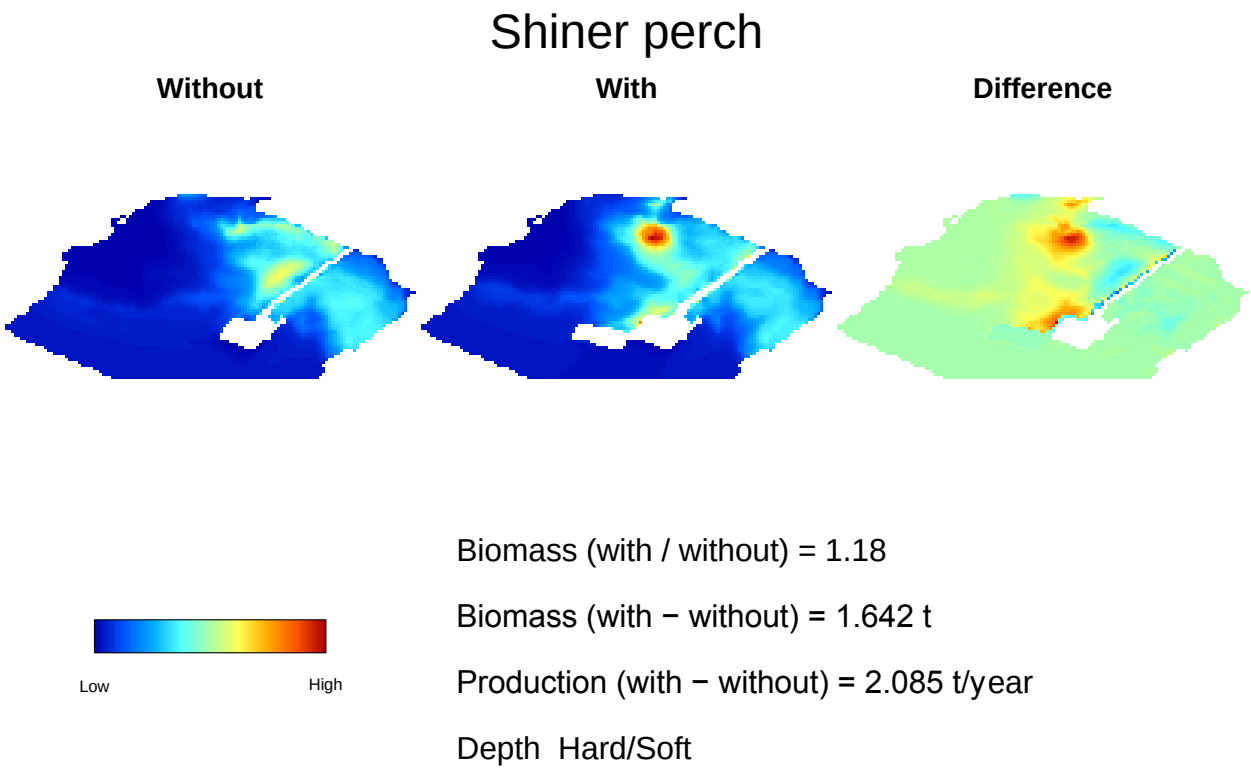


Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.7.8 *Shiner Perch*

Shiner perch biomass is forecast to increase by 18%, especially on the tidal flats to the west and northwest of the terminal site (**Figure 3-35**).

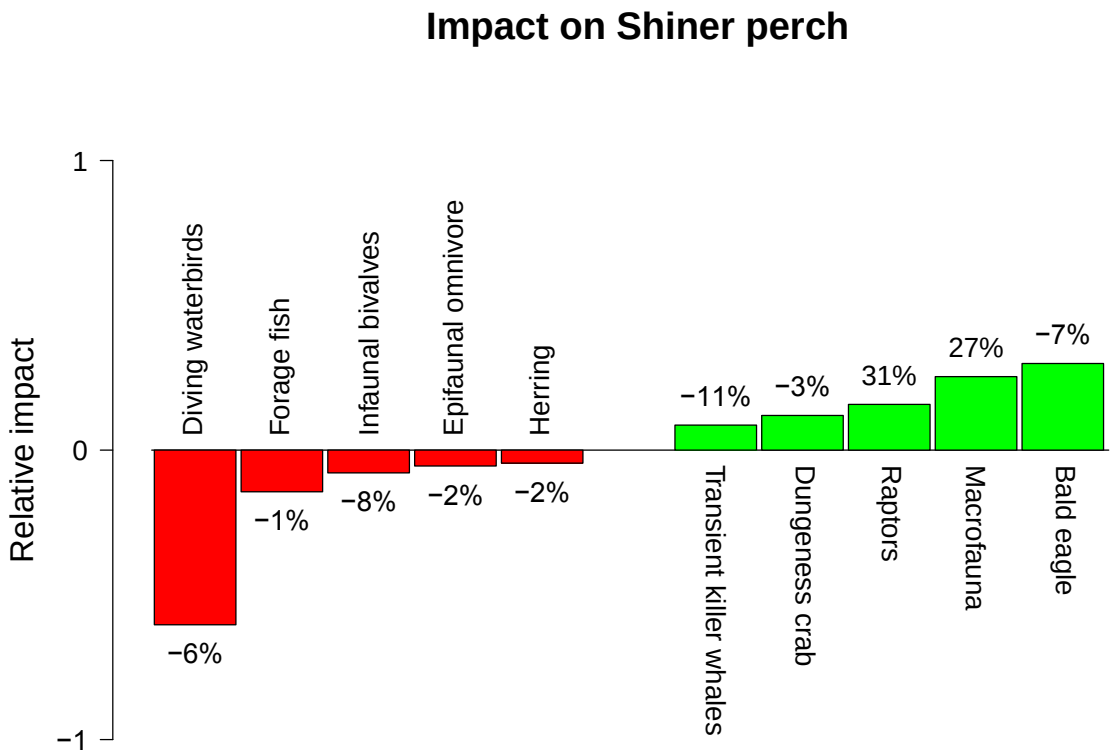
Figure 3-35 Forecasted Biomass Distribution for Shiner Perch, Without the Project, With the Project, and the Difference (With - Without)



Note: Shiner perch are distributed based on depth, and soft substrate. The colour scale indicates values from low (blue) to high (red)

The shiner perch benefits from reduced predation and competition from all the groups that have the strongest negative impact on the group (**Figure 3-36**), and the species also benefits from notably the increased production (27%) for a major prey, macrofauna, and for another group, (raptors, 31%) that have a negative impact on competitors and predators of shiner perch, and therefore a strong positive impact on the species. Combined, these factors all lead to an increase for the shiner perch.

Figure 3-36 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Shiner Perch

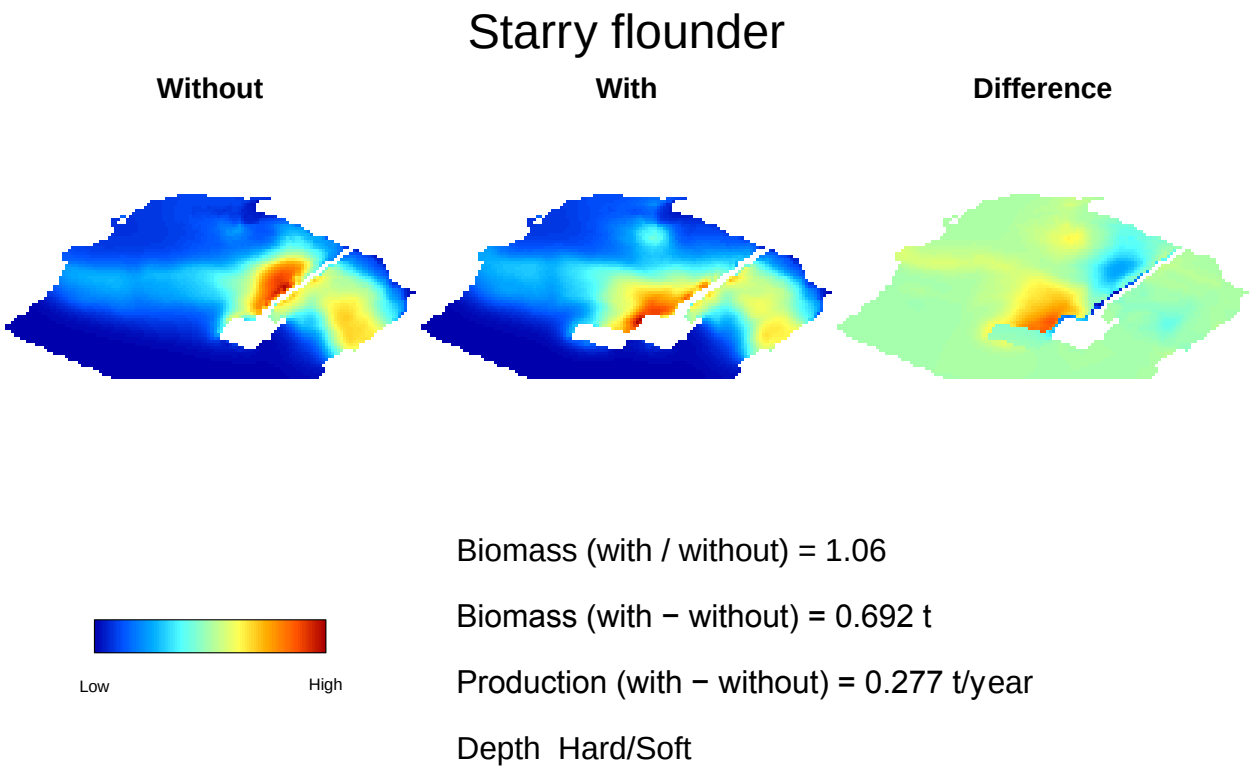


Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.7.9 *Starry Flounder*

Starry flounder biomass is forecast to increase by 6%, particularly in the lee of the Roberts Bank terminal and the tidal flats north of RBT2 (**Figure 3-37**). This is likely due to forecasted increases in the productivity of macrofauna (see **Figure 3-43**) in the same areas.

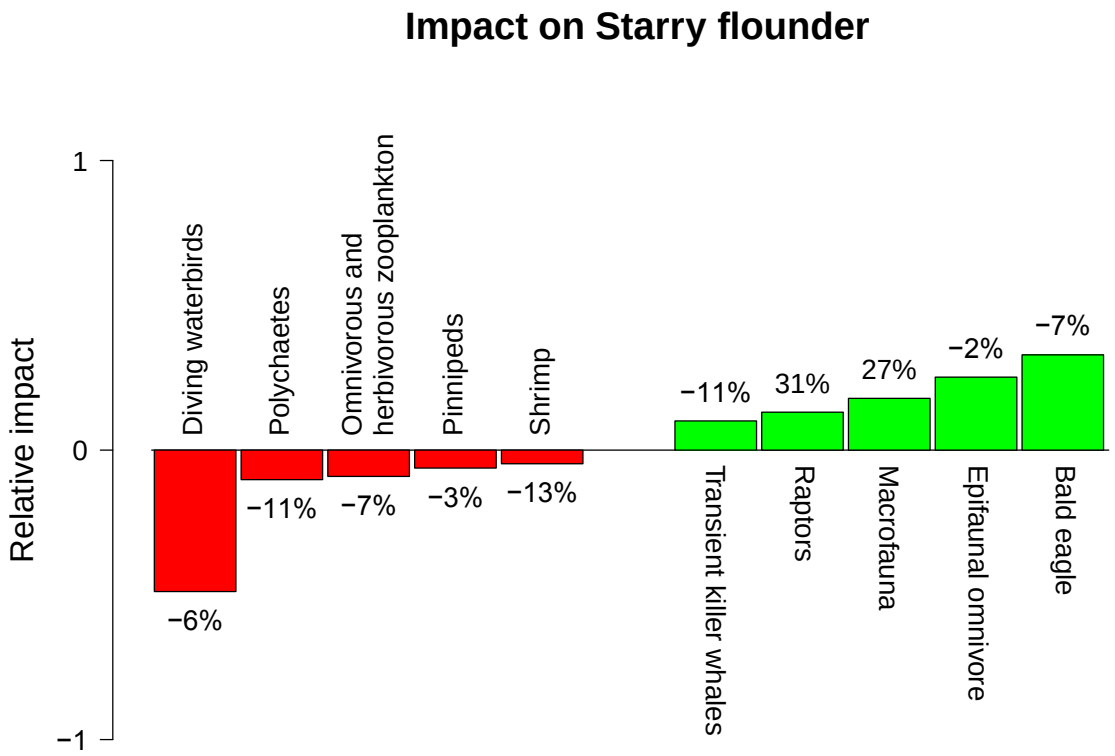
Figure 3-37 Forecasted Biomass Distribution for Starry Flounder, Without the Project, With the Project, and the Difference (With - Without)



Note: Starry flounder are distributed based on depth, and soft substrate. The colour scale indicates values from low (blue) to high (red)

The trophic impacts routine (**Figure 3-38**) shows that all the major groups with the strongest negative impacts on starry flounder are predicted to decrease, while two groups with positive impacts, an important prey, macrofauna, and a minor predator, raptors, are predicted to increase considerably (27% and 31%, respectively). The positive impact of raptors is a case of what is called "beneficial predation" where the negative direct impact a predator may have on a prey is outweighed by indirect positive impact.

Figure 3-38 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Starry Flounder



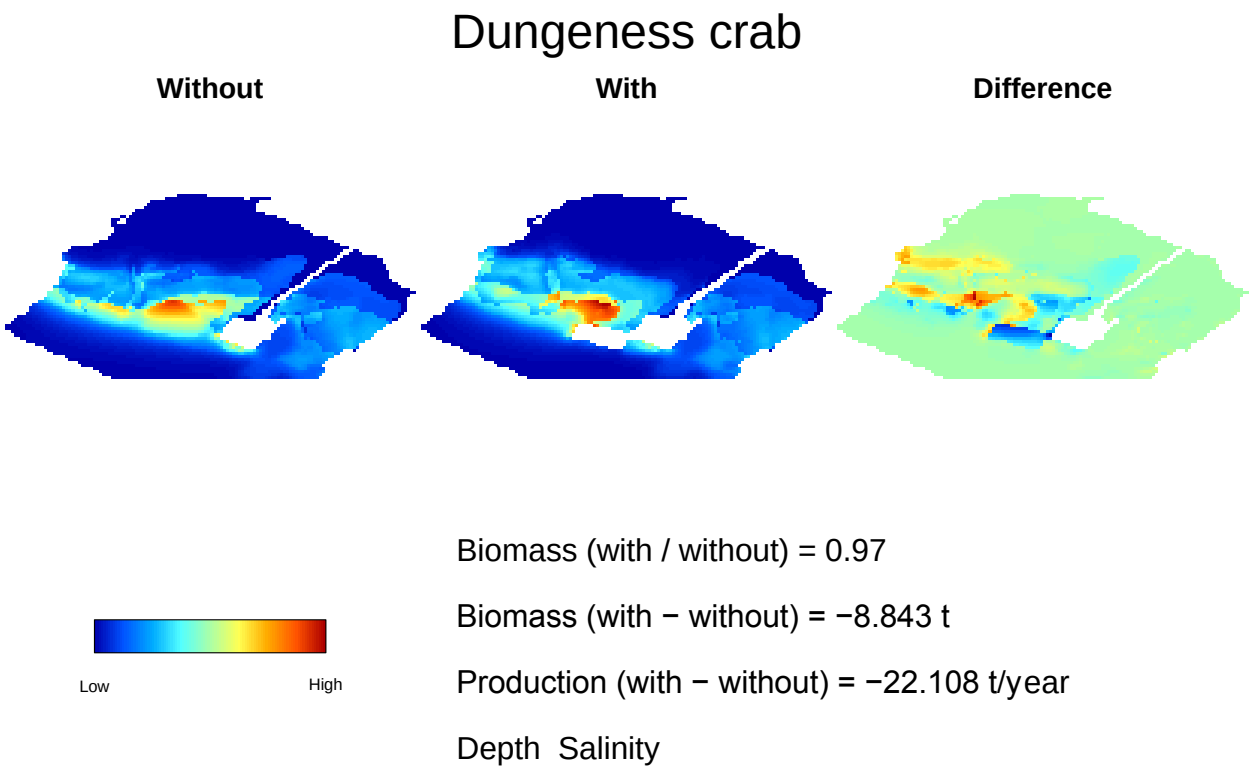
Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.8 Model Results for Invertebrates

3.8.1 *Dungeness Crab*

Dungeness crab production is forecast to decrease by 3%, corresponding to a net biomass loss of 8.8 t (**Figure 3-39**). Productive areas are forecasted to be northwest of. Net loss in Dungeness crab production is predicted in the lower saline area immediately to the west of the terminal and causeway.

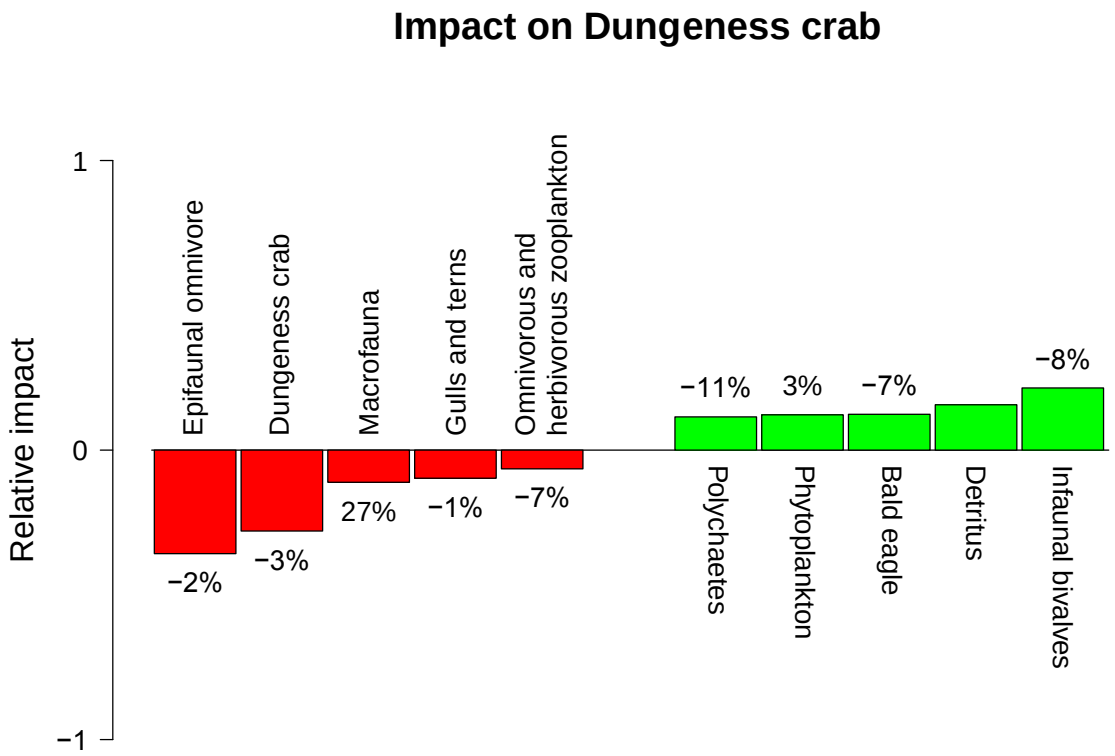
Figure 3-39 Forecasted Biomass Distribution for Dungeness Crab, Without the Project, With the Project, and the Difference (With - Without)



Note: Dungeness crab is distributed based on depth, and salinity. The colour scale indicates values from low (blue) to high (red)

The trophic impacts routine (**Figure 3-40**) shows a major increase for one of the groups with negative impact on Dungeness crab (macrofauna, 27%) but also decreases for most groups with a strong positive impact on the species. Overall, the forecast is for a 3% reduction for Dungeness crab, i.e. corresponding to the the areal loss due to the footprint area (2.9%).

Figure 3-40 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Dungeness Crab

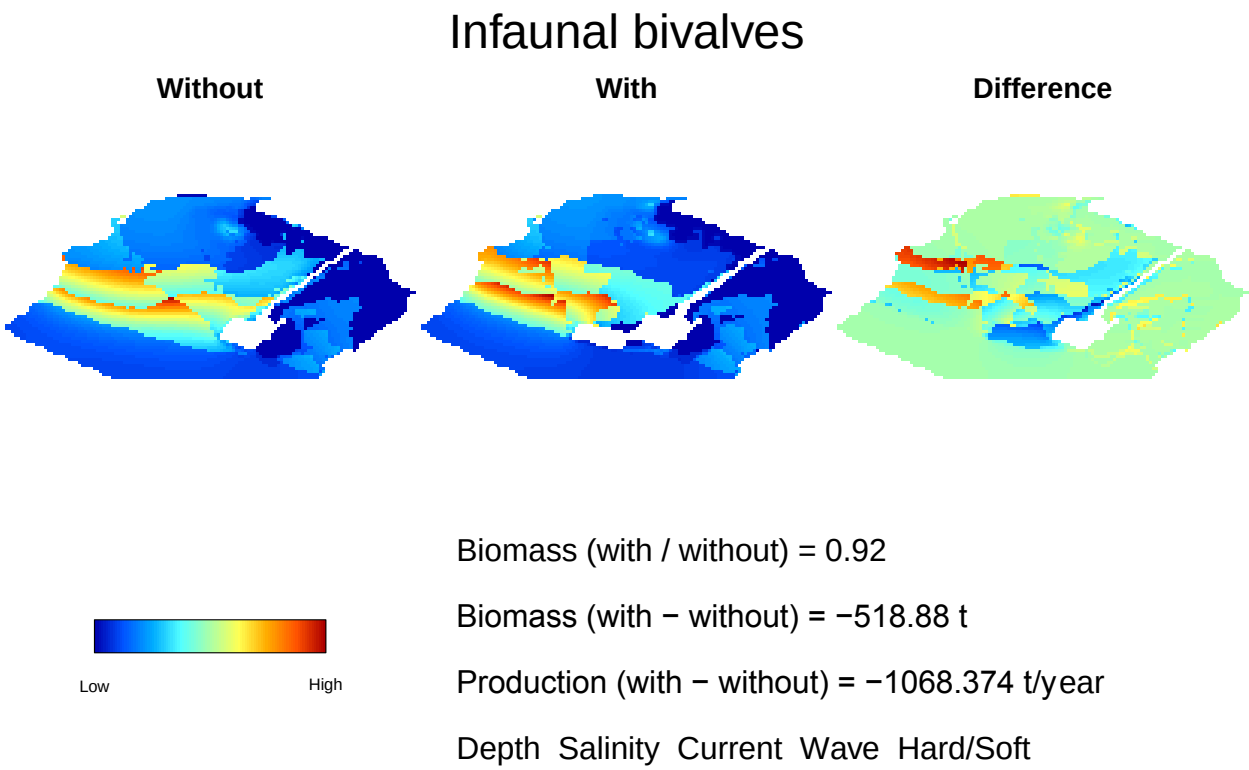


Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.8.2 *Infaunal Bivalve*

Infaunal bivalves are prey for many marine mammals, birds, fish and invertebrate species at Roberts Bank. They are planktivorous with a diet consisting primarily of phytoplankton and detritus. Infaunal bivalve production is forecast to decrease by 8%, corresponding to a net loss of 519 t (**Figure 3-41**). Net loss in production is forecast to occur at and in the lee of the proposed terminal and the tidal flats of Roberts Bank north of the causeway.

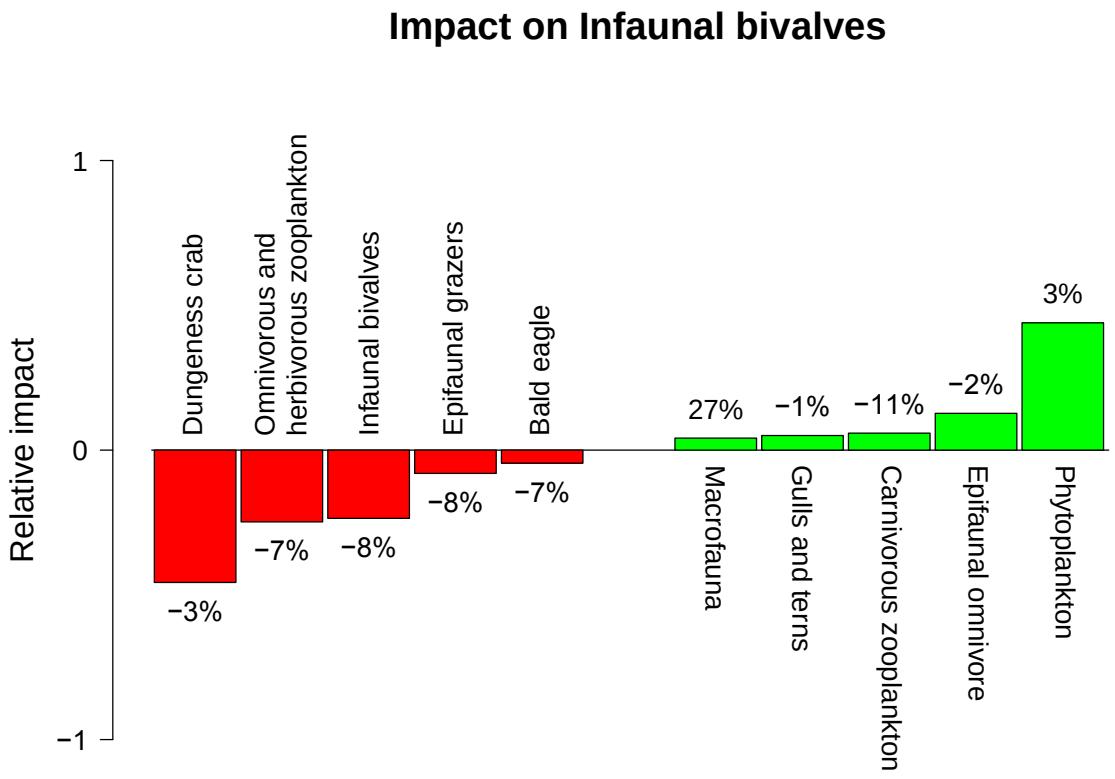
Figure 3-41 Forecasted Biomass Distribution for Infaunal Bivalves, Without the Project, With the Project, and the Difference (With - Without)



Note: Infaunal bivalves are distributed based on depth, salinity, bottom current, wave height, and soft substrate. The colour scale indicates values from low (blue) to high (red)

All of the groups that have the strongest negative impacts on infaunal bivalves (**Figure 3-42**), while the groups with the strongest positive impacts shows a mixture of increases and declines. Overall, this indicates that the food web effects should be positive or not much negative for the bivalves, and the 8% decline for the group is therefore likely to be impacted by environmental conditions, notably the decreased salinity along the causeway.

Figure 3-42 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Infaunal Bivalves

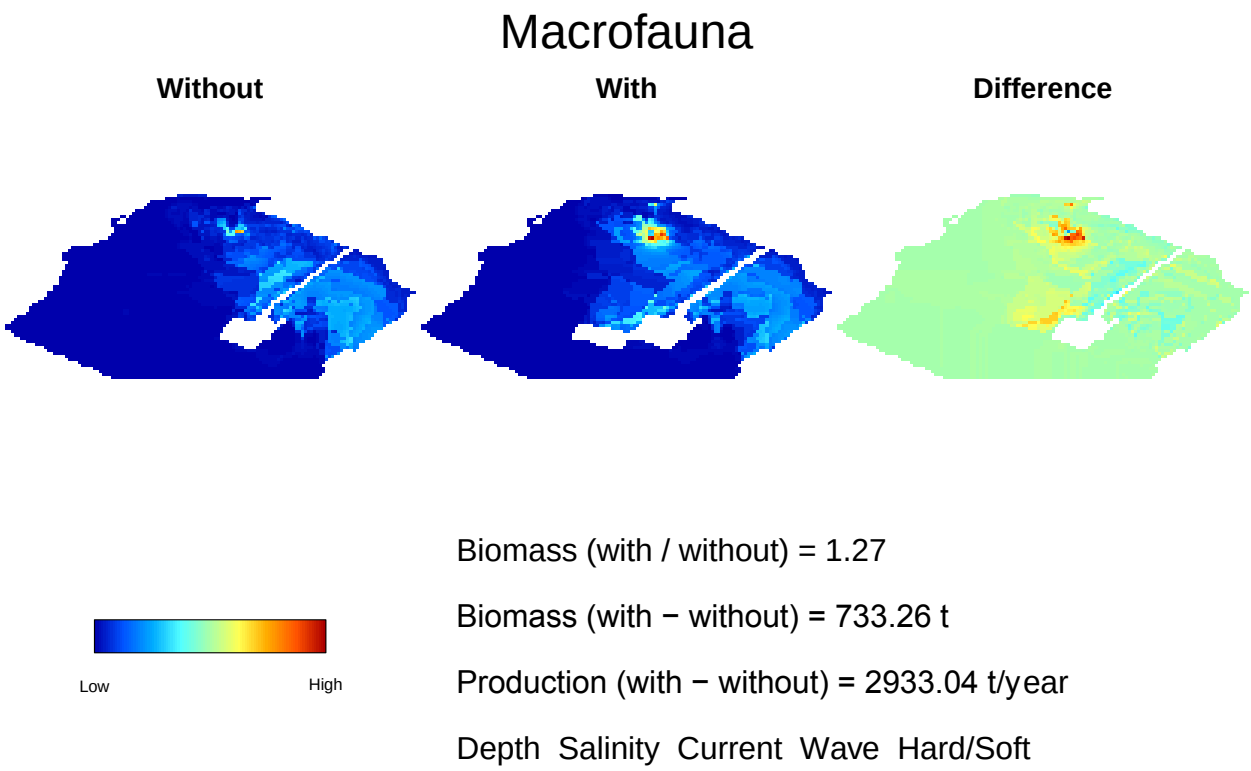


Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.8.3 *Macrofauna*

Spatial mapping using data collected during Roberts Bank sampling showed that macrofauna has a widespread distribution on the tidal flats of Roberts Bank. Macrofauna production is forecast to increase by 27% (**Figure 3-43**), corresponding to a net biomass increase of 733 t, likely as a result of a shift to environmental conditions favoured by macrofauna. A net increase in production is forecast predominantly on the tidal flats north of RBT2 and in the Canoe Passage area.

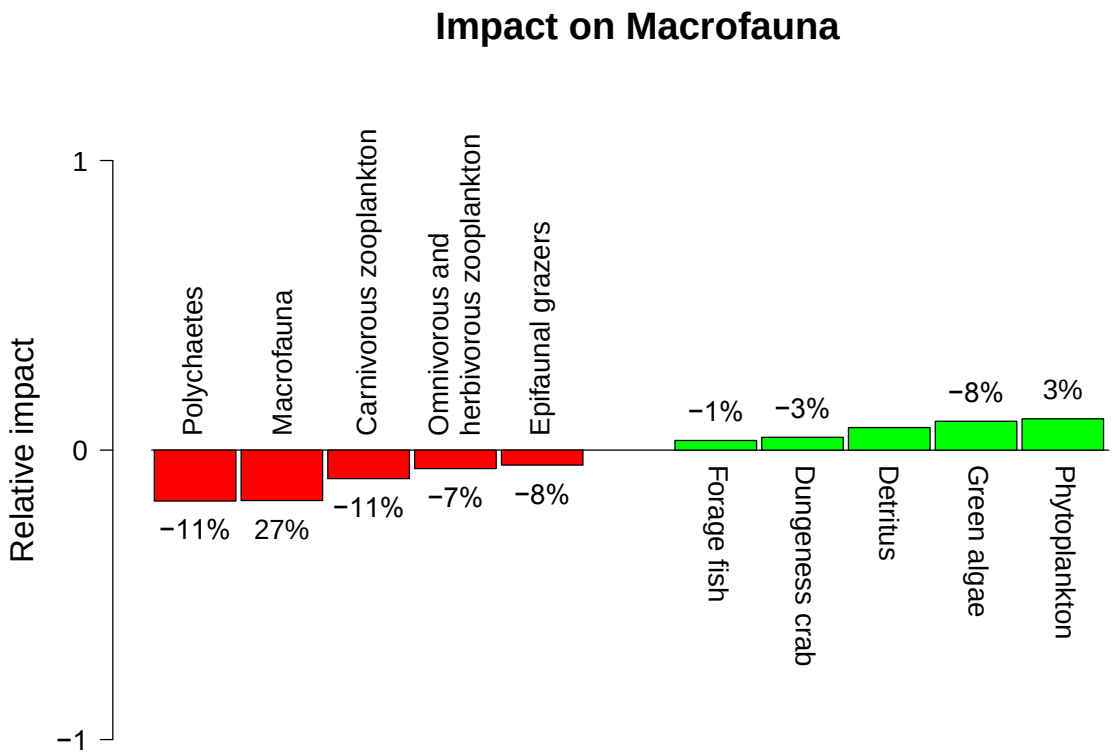
Figure 3-43 Forecasted Biomass Distribution for Macrofauna, Without the Project, With the Project, and the Difference (With - Without)



Note: Macrofauna are distributed based on depth, salinity, bottom current, wave height, and soft substrate. The colour scale indicates values from low (blue) to high (red)

The mixed trophic impacts analysis (**Figure 3-44**) shows that the groups with strongest negative impacts on macrofauna are predicted to decrease (apart from macrofauna itself), while the groups with the strongest positive impacts show less change and this in the form of both increases and decreases. Combined, the food web impacts point to increased productive potential for macrofauna, but not enough to explain the 27% increase. Indications are rather that the group benefits from improved environmental conditions on the tidal flats.

Figure 3-44 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Macrofauna

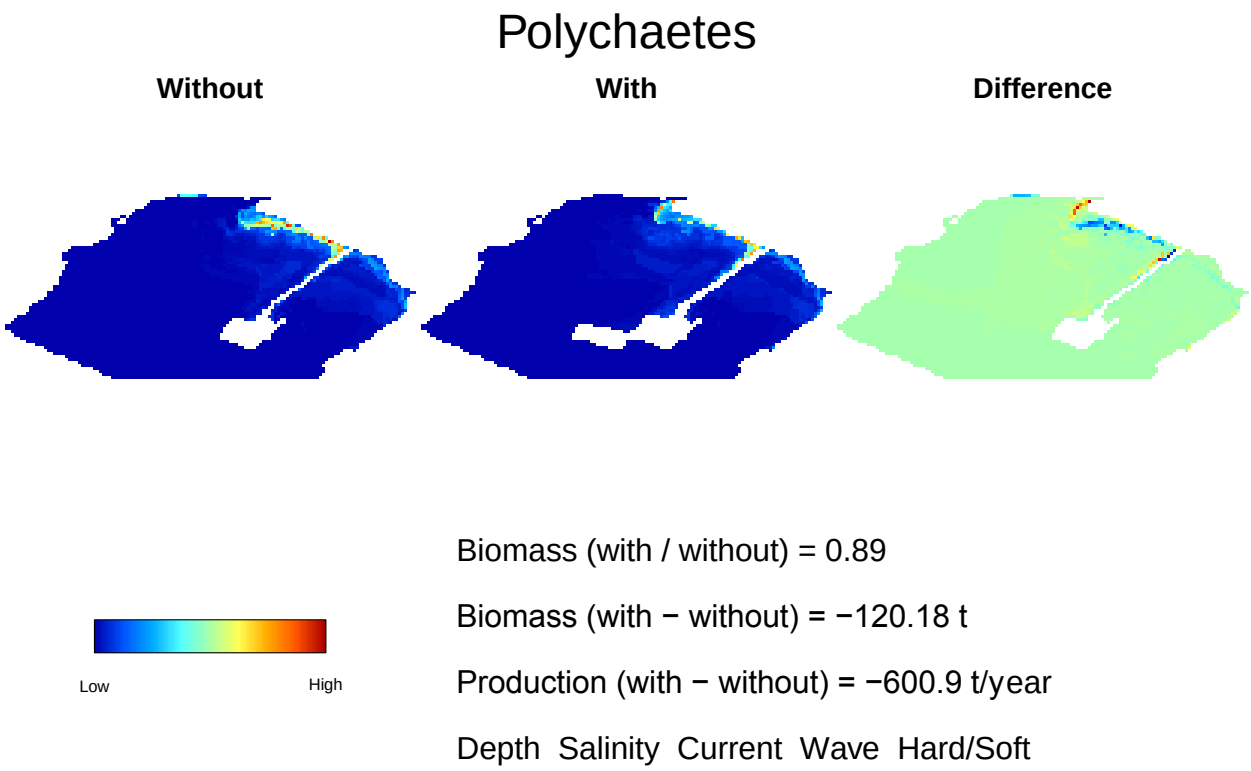


Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.8.4 *Polychaetes*

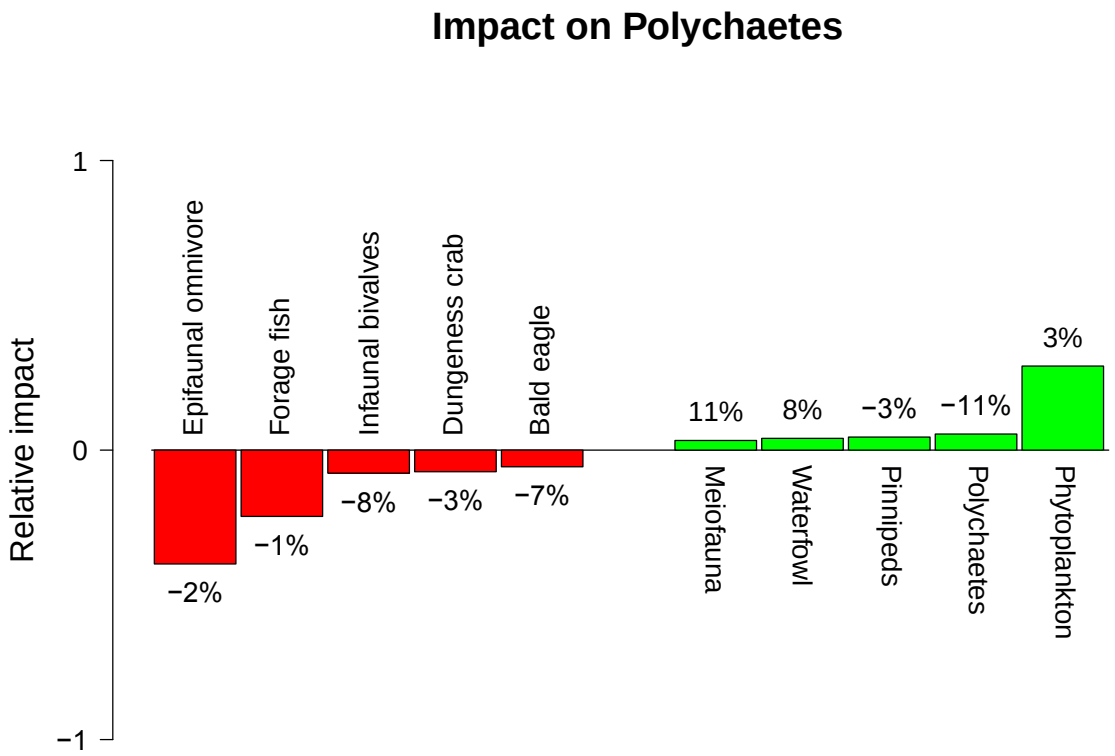
Production of polychaetes is forecast to decrease by 11%, corresponding to a biomass impact of 120 t, predominantly on the tidal flats between Canoe Passage and the causeway (**Figure 3-45**).

Figure 3-45 Forecasted Biomass Distribution for Polychaetes, Without the Project, With the Project, and the Difference (With - Without)



Note: Polychaetes are distributed based on depth, salinity, bottom current, wave height, and soft substrate. The colour scale indicates values from low (blue) to high (red)

Figure 3-46 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Polychaetes



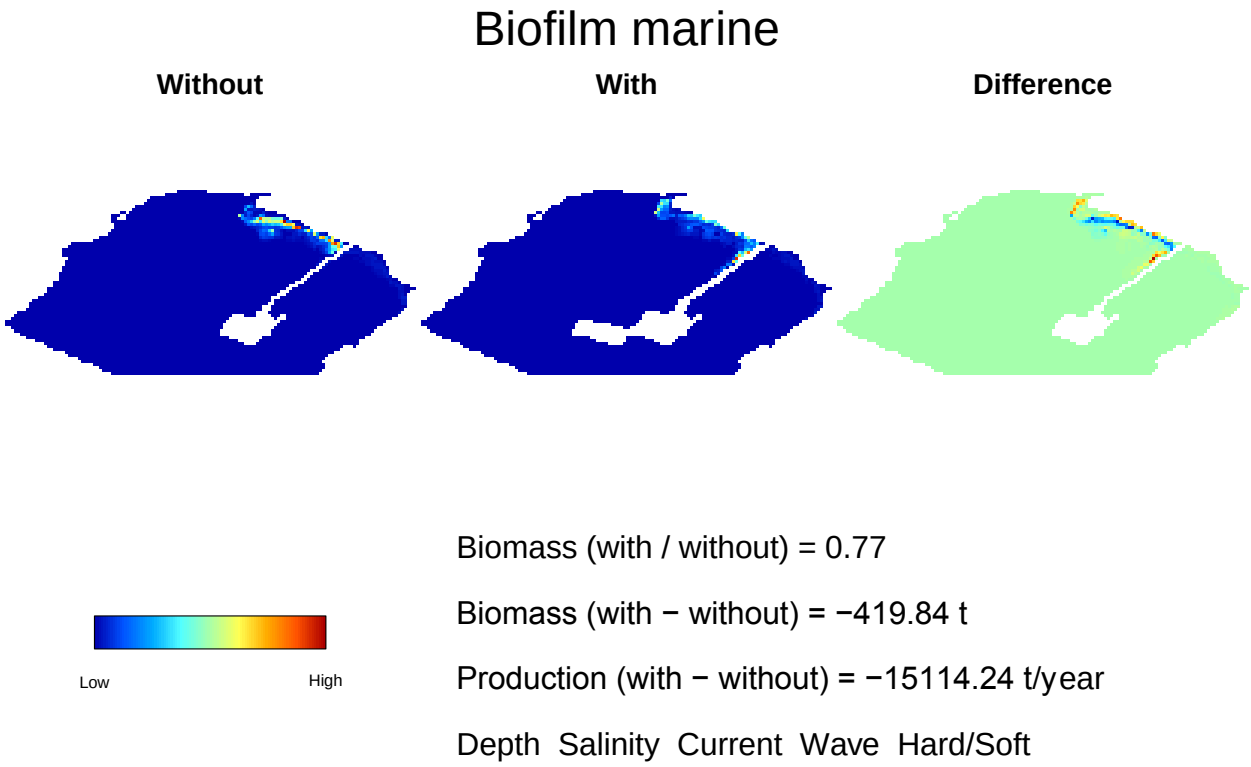
Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.9 Model Results for Primary Producers

3.9.1 *Freshwater and Marine Biofilm*

Marine biofilm production is forecast to decrease by 23% (a biomass change of 420 t), predominantly close to the shore between Canoe Passage and the causeway (**Figure 3-47**). A longer residence time for fresh water from the outlet of the Fraser River in this area, due to terminal placement, likely contributes to this result. On the other hand, freshwater biofilm production is forecasted to increase by 89% (with a biomass change of 1,468 t) (**Figure 3-49**), and most of this increase occurs in the Canoe Passage area, where freshwater from the Fraser River empties into the sea.

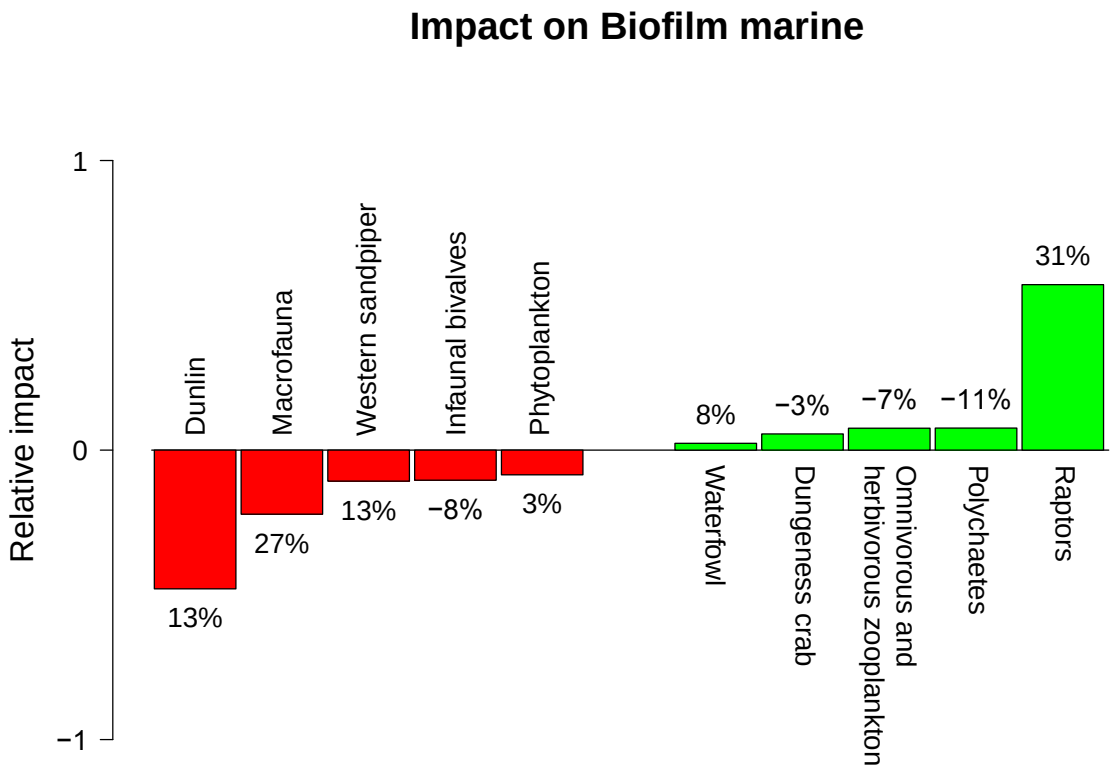
Figure 3-47 Forecasted Biomass Distribution for Marine Biofilm, Without the Project, With the Project, and the Difference (With - Without)



Note: Biofilm is distributed based on depth, salinity, bottom current, wave height, and soft substrate. The colour scale indicates values from low (blue) to high (red)

Marine biofilm is negatively impacted by forecast increases for the three groups that have the strongest negative food web impact on the group, i.e. dunlin (13%), macrofauna (27%), and Western sandpiper (13%), see **Figure 3-48**. Three of the five groups that have the strongest positive impacts on marine biofilm are further predicted to decrease, but one group, raptors, which have a strong positive impact on marine biofilm is predicted to increase substantially (31%). Overall, the food web impacts are likely to be negative, but the strong overall decline for the group (-23%) is probably mainly due to decreased salinity in their main distribution area.

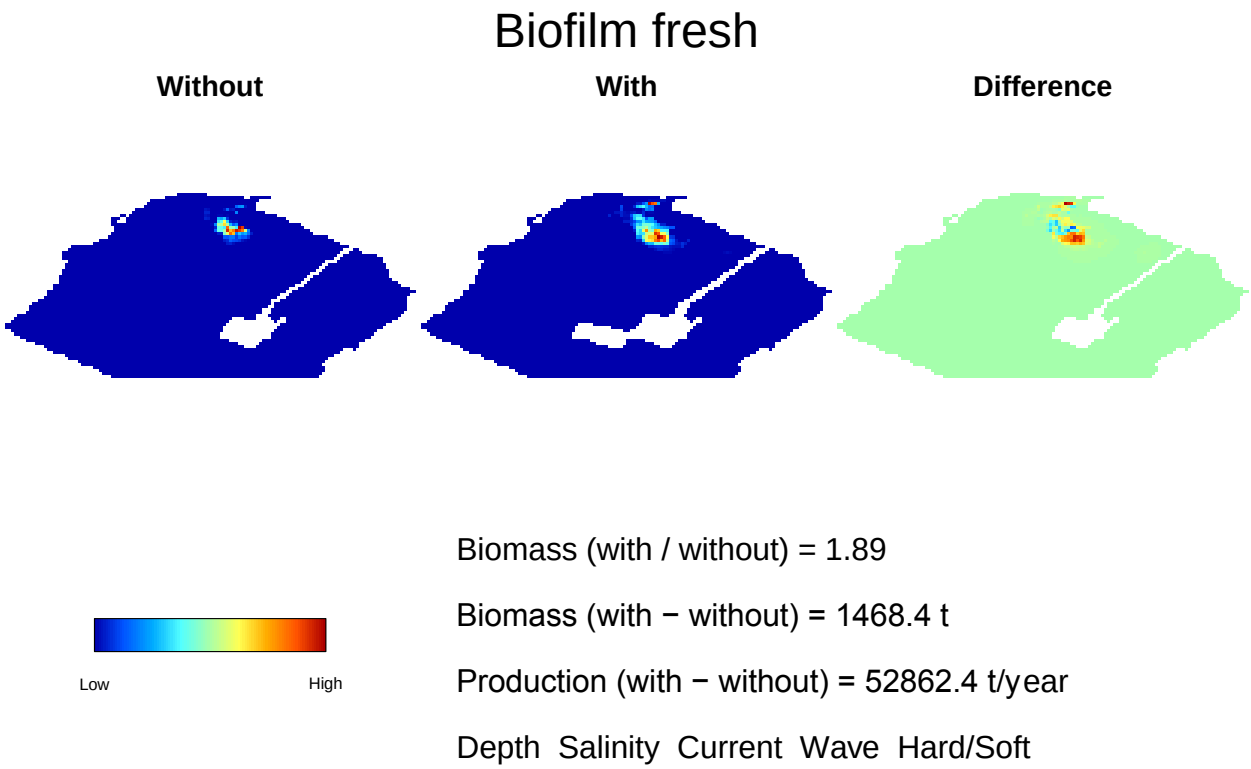
Figure 3-48 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Marine Biofilm. The Impacts are Identical for Freshwater Biofilm



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

Figure 3-48 also represents the mixed trophic impacts for freshwater biofilm – the groups have the same predators, and given that freshwater biofilm increases 89%, this illustrates that the changes are predominantly due to changes in environmental parameters, notably salinity.

Figure 3-49 Forecasted Biomass Distribution for Freshwater Biofilm, Without the Project, With the Project, and the Difference (With - Without)

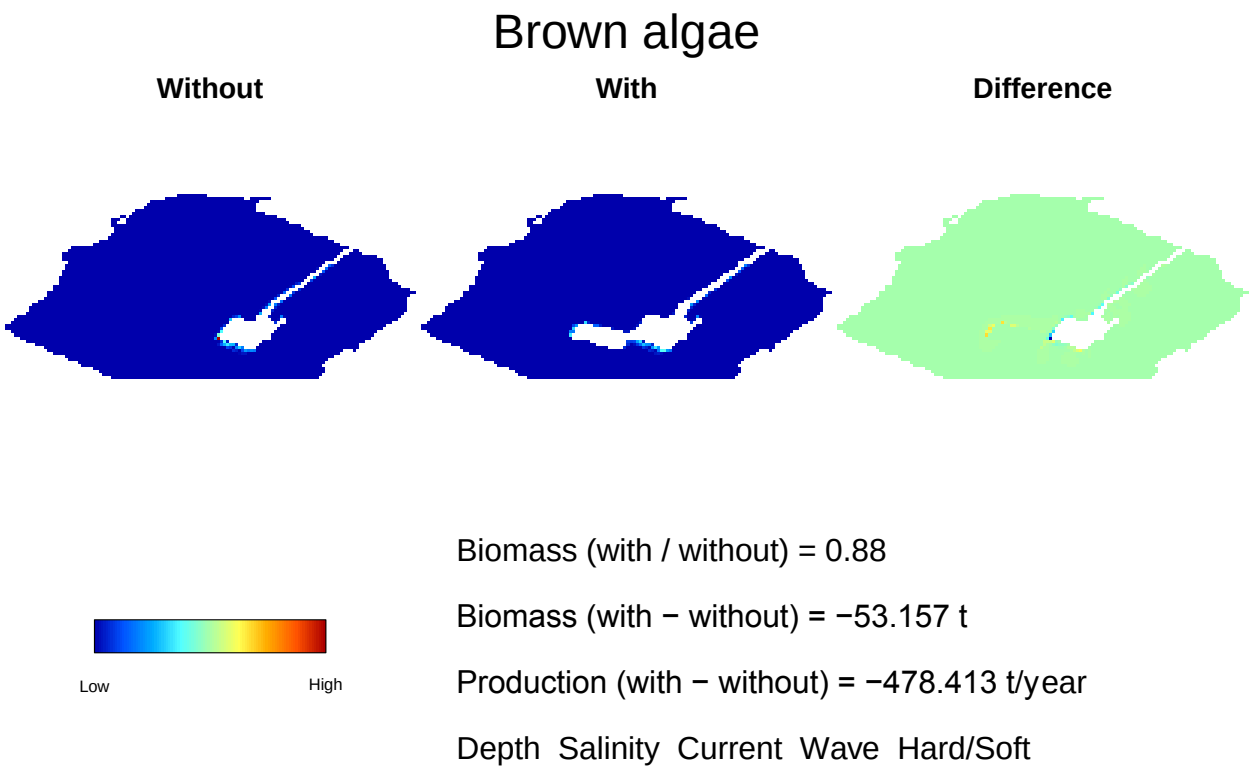


Note: Biofilm is distributed based on depth, salinity, bottom current, wave height, and soft substrate. The colour scale indicates values from low (blue) to high (red)

3.9.2 *Brown Algae*

Brown algae production is forecast to decrease by 12%, corresponding to a biomass change of 53 t (**Figure 3-50**). A net gain is forecasted around the RBT2, but this is more than offset by decreased production around the west and south of the existing terminal.

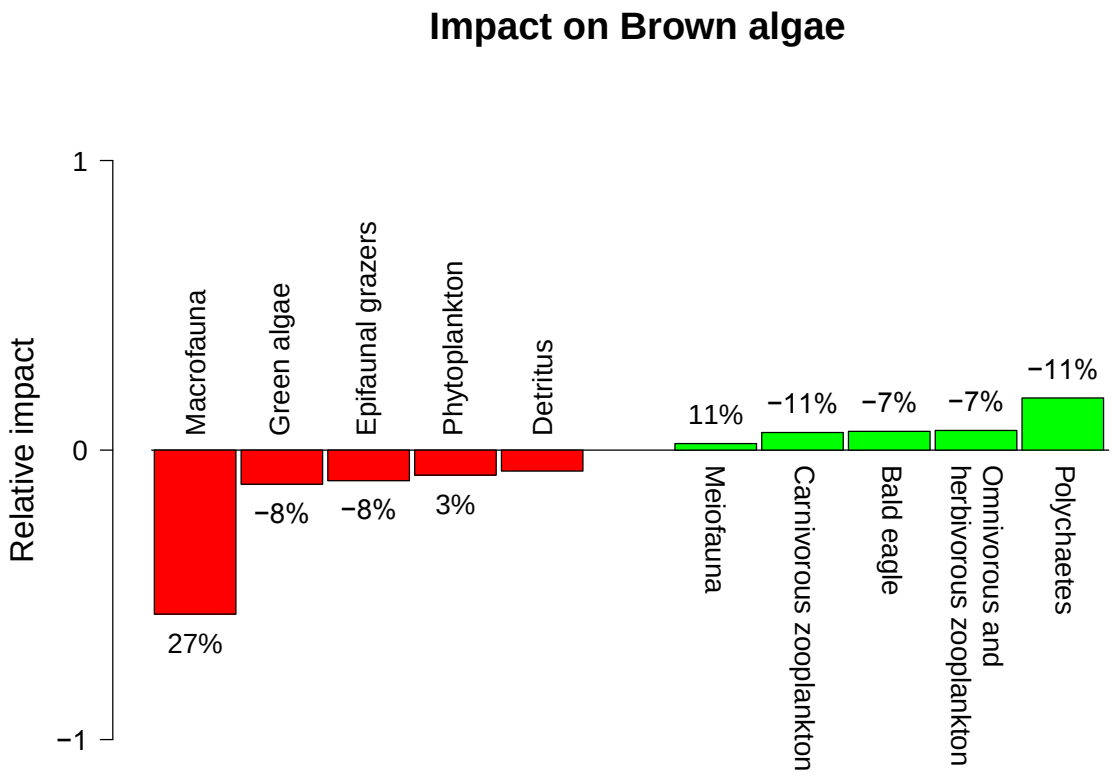
Figure 3-50 Forecasted Biomass Distribution for Brown Algae, Without the Project, With the Project, and the Difference (With - Without)



Note: Brown algae are distributed based on depth, salinity, bottom current, wave height, and hard substrate. The colour scale indicates values from low (blue) to high (red)

The group that has the strongest negative impact (see **Figure 3-51**) on brown algae, macrofauna is forecast to increase considerably (27%), while all of the five groups that have the strongest positive impact on brown algae all are forecast to decrease. Overall, this means that the food web conditions are declining for brown algae, and this is likely to be a key factor behind the decrease for the group.

Figure 3-51 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Brown Algae

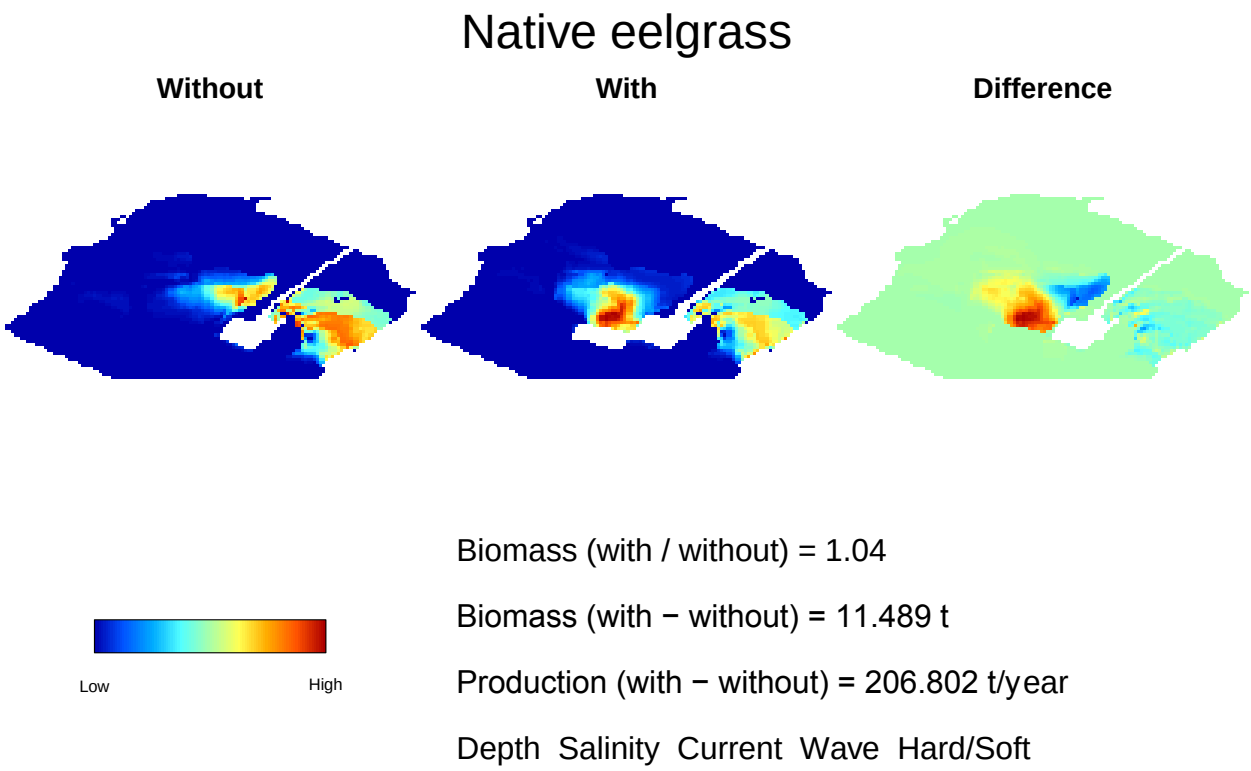


Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.9.3 *Native Eelgrass*

Native eelgrass production is forecast to increase by 4%, corresponding to a biomass change of 11 t (**Figure 3-52**). Production losses are forecast for the lee of the existing terminal and causeway, and in the inter-causeway area. However, eelgrass increases north of RBT2 as a decrease in waves and currents allows it to expand from its current distribution all the way to the north edge of RBT2. These gains are predicted to more than offset the losses in the current model distribution area.

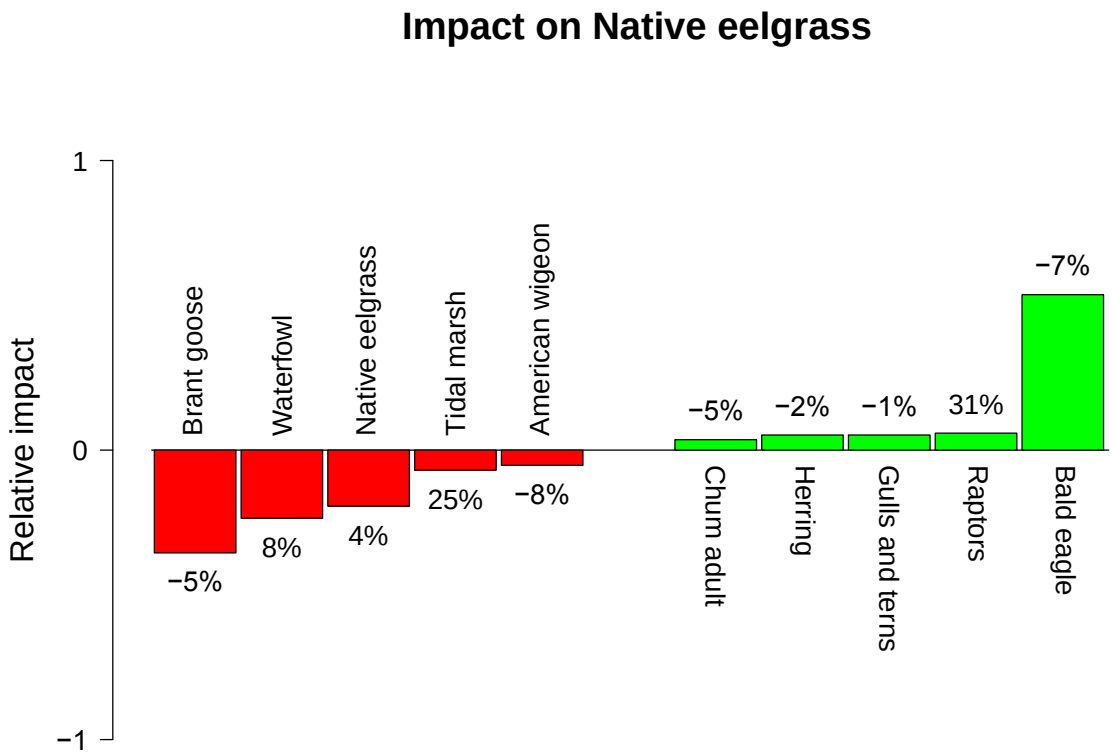
Figure 3-52 Forecasted Biomass Distribution for Native Eelgrass, Without the Project, With the Project, and the Difference (With - Without)



Note: Native eelgrass is distributed based on depth, salinity, bottom current, wave height, and soft substrate. The colour scale indicates values from low (blue) to high (red)

The food web impacts are overall rather balanced for native eelgrass (**Figure 3-53**) with a mixture of increases and decreases for the groups with the strongest impacts on native eelgrass. Overall this indicates that the changes for the groups mainly are driven by environmental conditions.

Figure 3-53 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Native Eelgrass

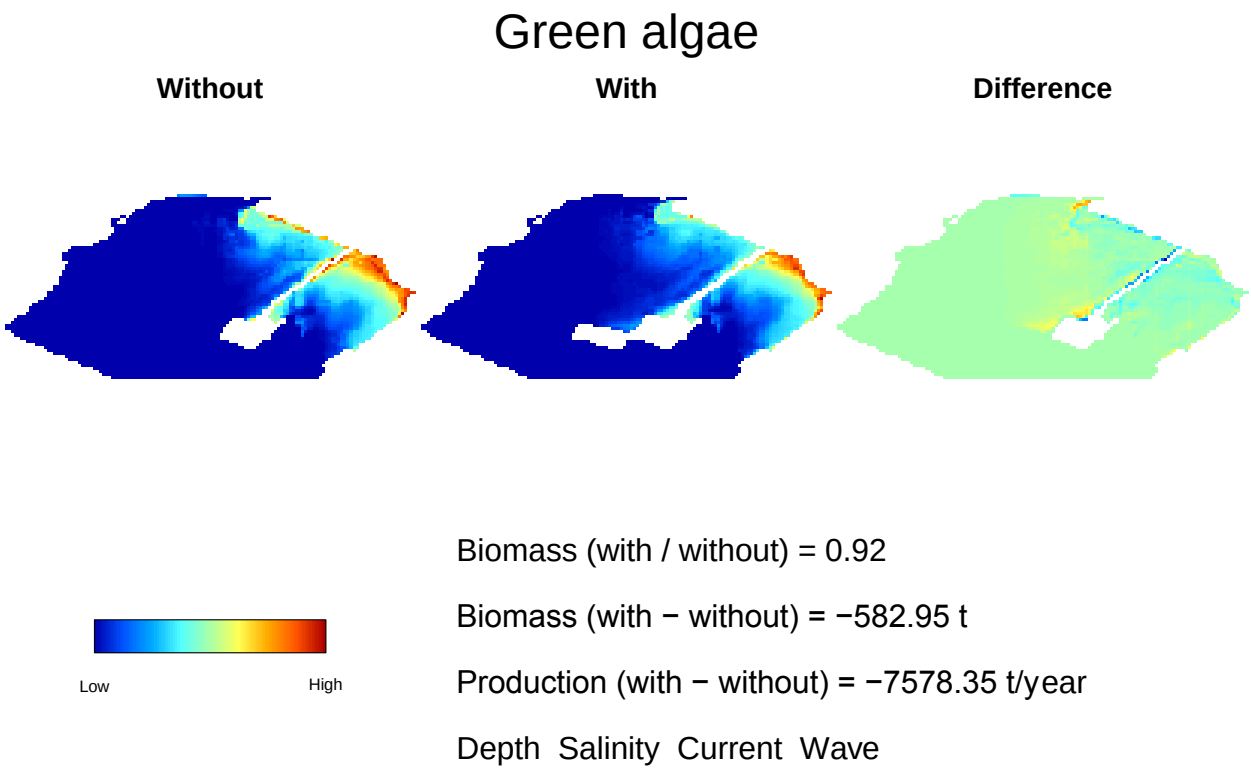


Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.9.4 *Green Algae*

Green algae production is forecast to decrease by 8%, corresponding to a biomass change of 583 t – which is the biggest absolute decline for any group (**Figure 3-54**). Losses are forecast along the north edge of the causeway, in the high intertidal north of RBT2 and south of Canoe Passage, and in the inter-causeway area. Small gains are expected in the lee of the existing terminal, but will be insufficient to offset the losses.

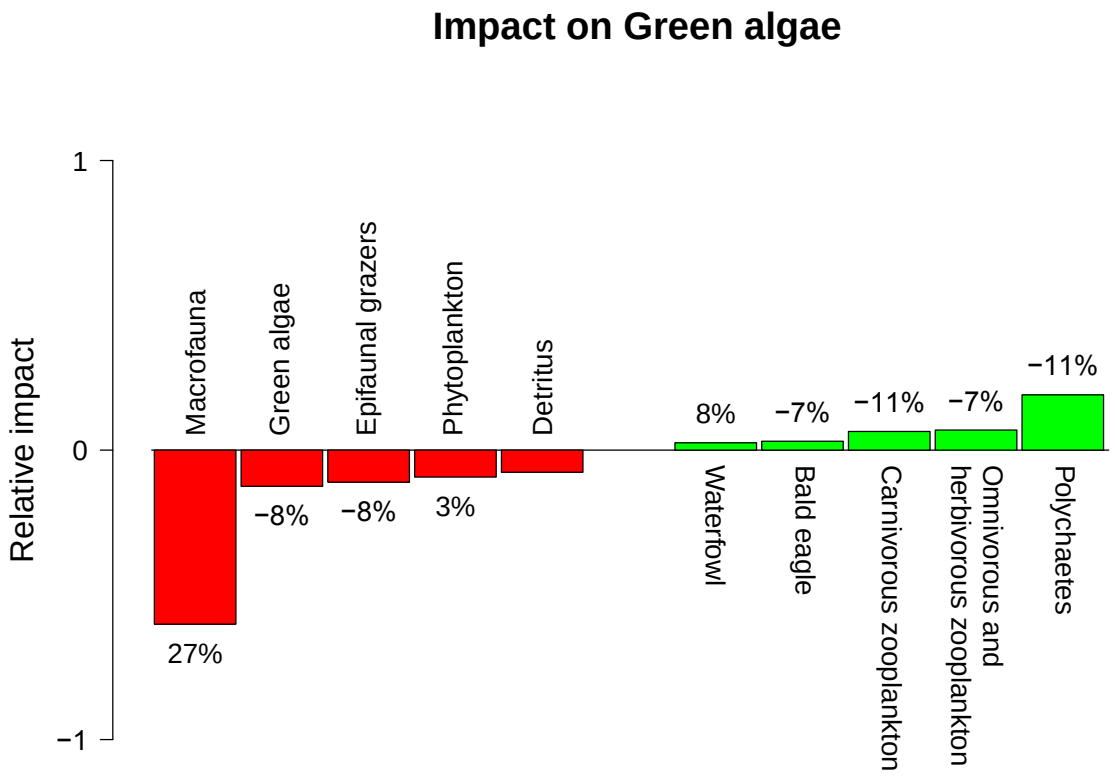
Figure 3-54 Forecasted Biomass Distribution for Green Algae, Without the Project, With the Project, and the Difference (With - Without)



Note: Green algae are distributed based on depth, salinity, bottom current, and wave height. The colour scale indicates values from low (blue) to high (red)

The results from the mixed trophic impact routine (**Figure 3-55**) point to overall negative food web impacts on green algae. This is mostly due to a considerable increase in the group with the strongest negative impact on green algae (i.e. macrofauna, 27%) along with declines for the four groups with the strongest positive impacts on green algae.

Figure 3-55 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Green Algae

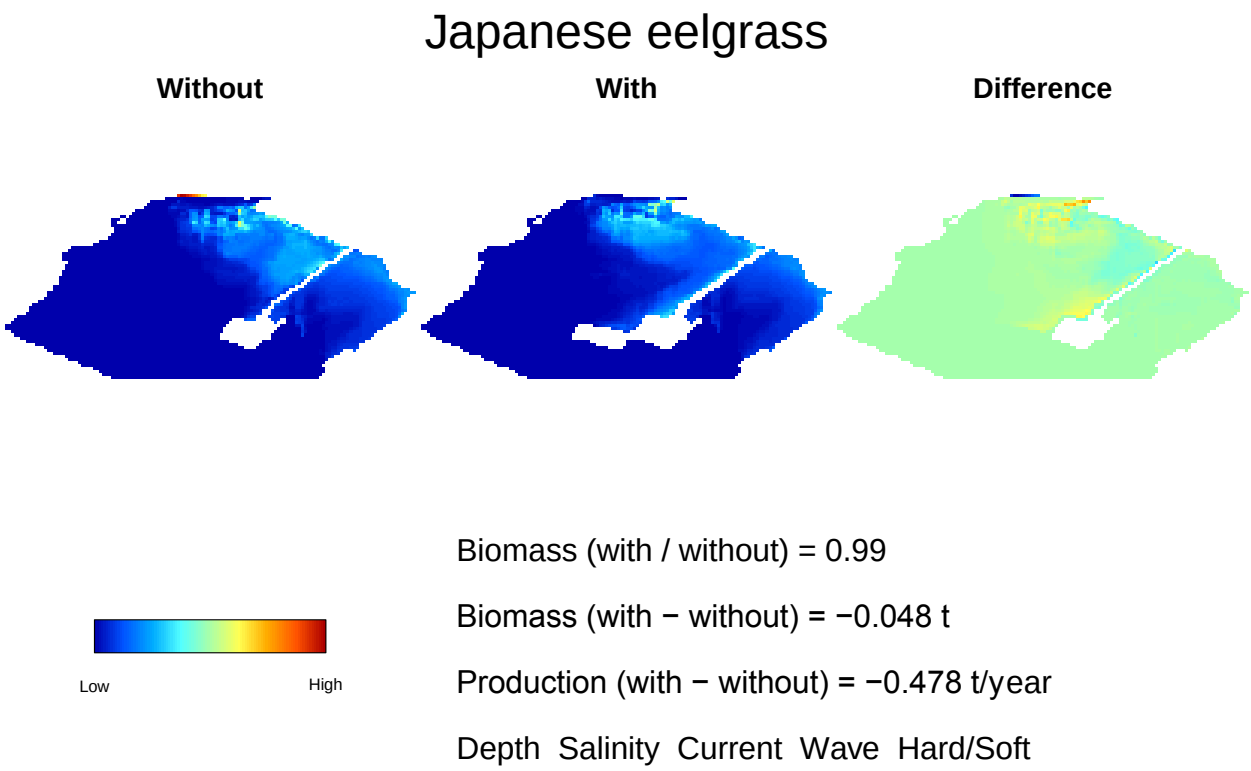


Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.9.5 *Japanese Eelgrass (Non-native)*

Japanese Eelgrass production is forecasted to remain essentially unchanged (a decrease of 1% is forecasted, corresponding to a biomass change of 0.05 t) (**Figure 3-56**).

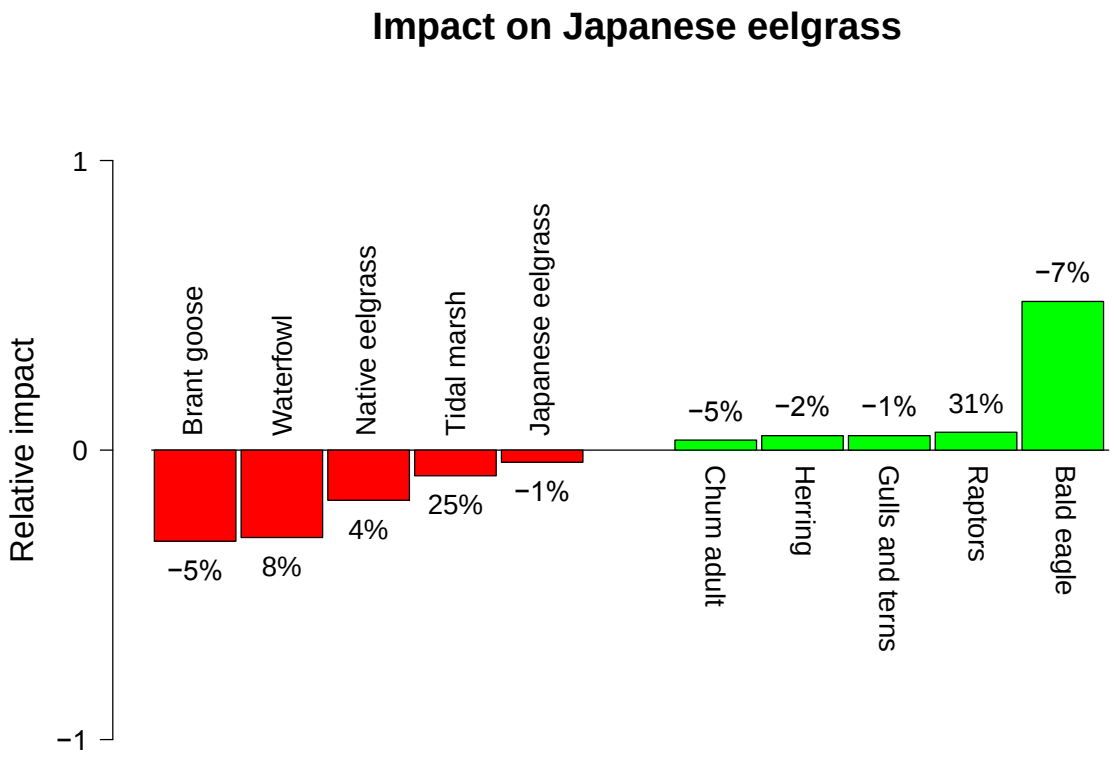
Figure 3-56 Forecasted Biomass Distribution for Japanese Eelgrass, Without the Project, With the Project, and the Difference (With - Without)



Note: Japanese eelgrass is distributed based on depth, salinity, bottom current, wave height, and soft substrate. The colour scale indicates values from low (blue) to high (red)

The food web impacts are overall neutral for Japanese eelgrass (**Figure 3-57**) with a mixture of increases and decreases across the groups that have the strongest negative and the groups with the strongest positive impacts on Japanese eelgrass.

Figure 3-57 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Japanese Eelgrass

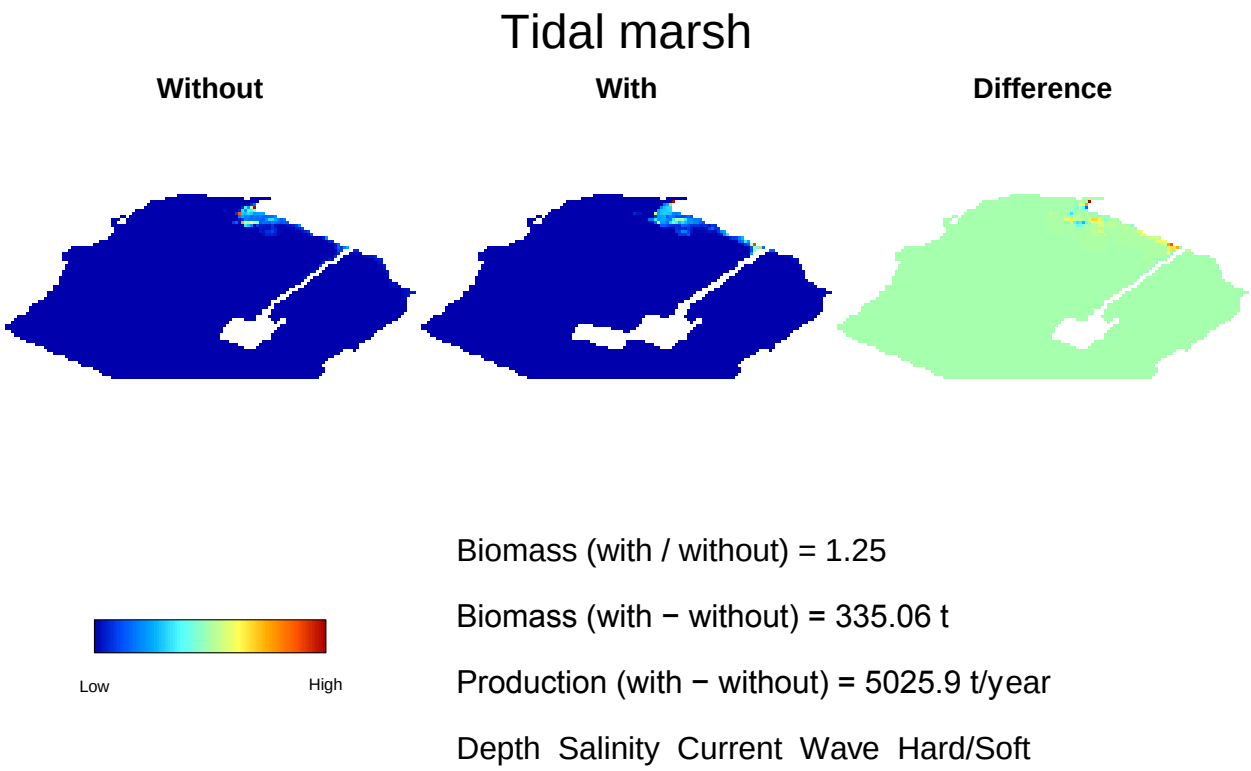


Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

3.9.6 *Tidal Marsh*

Tidal marsh production is forecast to increase by 25%, corresponding to a net biomass gain of 335 t (**Figure 3-58**). This net gain is most pronounced on the tidal flats northwest of the Roberts Bank causeway.

Figure 3-58 Forecasted Biomass Distribution for Tidal Marsh, Without the Project, With the Project, and the Difference (With - Without)

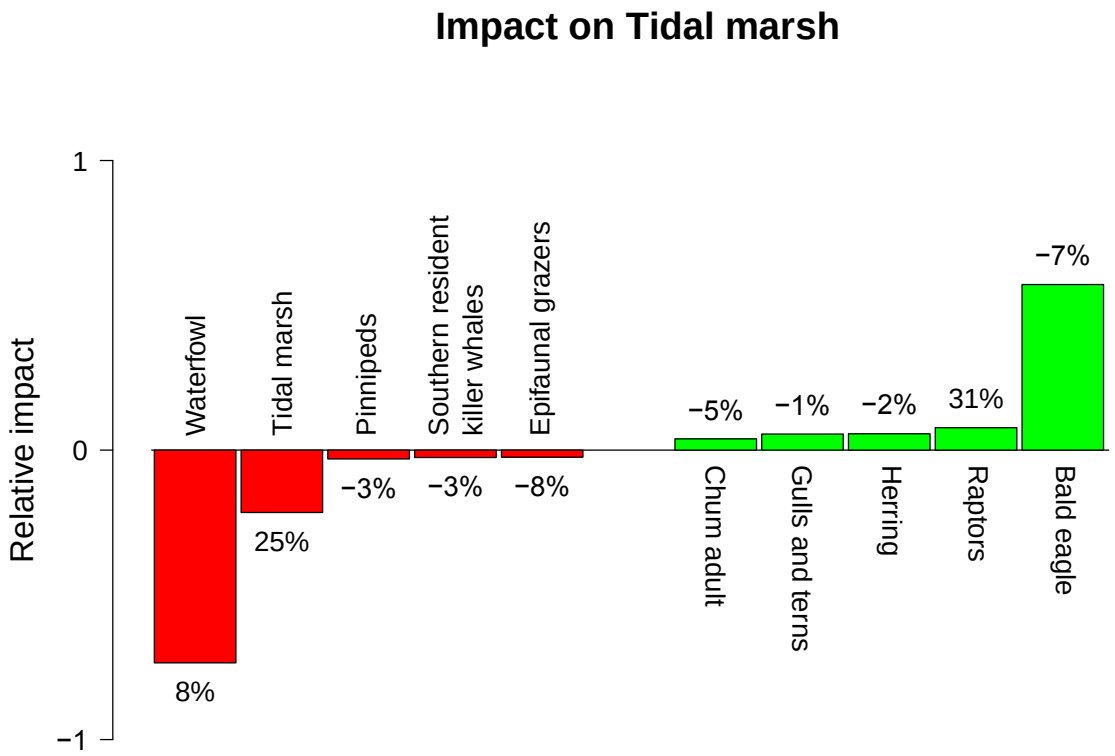


Note: Tidal marsh is distributed based on depth, salinity, bottom current, wave height, and soft substrate. The colour scale indicates values from low (blue) to high (red)

The food web impact routine (**Figure 3-59**) overall points to reduced food web conditions rather than improved. This is based on increases in the two groups that have the strongest negative impacts on tidal marsh, and a decline in four of the five groups that have the strongest positive impacts, including a 7% decrease for the group that have the strongest positive impact.

The increase in production indeed appears to be related to an improvement in growing conditions, likely resulting from a combination of reduced wave and current action, rather than an actual increase in areal distribution. Changes in salinity are not likely to effect tidal marsh as the group consists of both brackish and salt tolerant communities.

Figure 3-59 Mixed Trophic Impacts for Groups that have Strongest Relative Impact on Tidal Marsh



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

4.0 DISCUSSION

4.1 MODEL FINDINGS

This study forecast potential changes in the productivity of the Roberts Bank ecosystem and its functional groups, as a result of RBT2, specifically, proposed widening of the Roberts Bank causeway and terminal placement. Spatial changes in productivity (measured in terms of biomass and production) were forecasted assuming that:

(1) Distribution of functional groups in the study area is influenced by environmental conditions, and

(2) Changes to environmental conditions as a result of the Project, in combination with food-web dynamics (e.g., predator-prey interactions), will alter the functional groups' spatial distribution.

To evaluate the performance of environmental preference functions, distributions of habitat forming groups forecast by the Roberts Bank ecosystem model were compared to mapped distributions from field sampling. Environmental conditions described in the coastal geomorphology model adequately forecast distributions of these functional groups.

It is not expected that the environmental conditions in the inter-causeway area will change noticeably as a result of the Project. Still, there are groups for which there are forecasts of minor changes in productive potential in this area. Such changes are likely caused by predators that move from west of the RBT causeway to the inter-causeway area to seek comparatively better feeding conditions than they may be experiencing west of the causeway .

4.1.1 *Impact of Area Changes*

The proposed Project footprint associated with widening of the Roberts Bank causeway and terminal placement is 160 ha (i.e., 1.60 km^2), corresponding to 2.9% of the study area. Although one might erroneously infer that footprint effects would directly translate into 2.9% loss in productive potential of functional groups using habitats within the Project footprint, model results indicate that changes in productive potential for the various groups will likely be less than that. In particular, overall productivity in the study area is forecasted to increase by 2.7% for birds and by 2.2% for primary producers, but decrease by 2.1% for fish and 3.2% for invertebrates. The small changes in the productive potential of primary and secondary consumers at Roberts Bank is likely influenced by the small changes in primary production. Previous studies have shown that changes in primary production can cause non-linear changes up through the food web (Guénette et al. 2006; e.g., Christensen and Walters 2011).

4.2 MODEL LIMITATIONS

Limitations associated with the model are provided in the sections below. Although this report does not consider seasonal changes, these are discussed further in an accompanying memo (ESSA 2014, Appendix 4).

4.2.1 *The Mass Balance Model*

The Roberts Bank ecosystem model used for the key run is a representation of the Roberts Bank food web. Other potential food web representations, and associated model outcomes, are addressed in the accompanying Roberts Bank Ecosystem Model Sensitivity Analyses

Report, including re-sampling procedures using varying pedigree values to quantify parameter uncertainty and evaluate model robustness (ESSA 2014).

4.2.2 *Density Dependence*

Time series (i.e. trend) data are not available for Roberts Bank, therefore historic simulations using Ecosim were not conducted. As a result, the Roberts Bank ecosystem model could not be used to generate vulnerability estimates. Simulations of future conditions; therefore rely on default density dependence (vulnerability) values (see **Section 2.8**). The default settings assume that any given predator group is relatively close to its carrying capacity but that it can exert moderate changes in its prey's mortality if its biomass changes. The use of default vulnerability values in the Roberts Bank ecosystem model is likely of minor consequence to the habitat groups. However, varying vulnerability may have a greater effect to the magnitude of change in the production of higher trophic level functional groups. Vulnerability assumptions are evaluated in detail in the accompanying Roberts Bank Ecosystem Model Sensitivity Analyses Report (ESSA 2014).

4.2.3 *Model Drivers and Environmental Preference Functions*

Ecospace results are limited by the environmental variables considered and the response of functional groups to environmental conditions these variables measure. Firstly, environmental conditions are described in the Roberts Bank ecosystem model using only those environmental drivers that are quantified for Roberts Bank in the coastal geomorphology model (i.e., depth, salinity, bottom current, and wave height) (NHC 2014) as well as a hard/soft bottom layer (without and with the Project) that was derived independently of the coastal geomorphology model. Secondly, environmental preference functions for the functional groups in the Roberts Bank ecosystem model are informed by field sampling in the study area that targeted only habitat groups. For other groups it was necessary to rely on information from the literature.

4.2.4 *Habitat Capacity*

The habitat capacity model used for this study is a relatively new addition to the EwE modelling framework. While the methodology has been peer-reviewed (Christensen et al. 2014), it has only been applied once, though several other studies using this methodology are underway (Christensen et al., 2015; Ramirez et al., 2015). Studies in progress include modelling of the Mediterranean Sea by the Joint Research Centre (JRC) of the European Commission, of the Catalan Sea by the Institute of Research for Development (IRD) in

France, and of Bratia Bay, by Louisiana State University (LSU) in the U.S. (Chiara Piroddi, JRC, pers. comm.; Marta Coll, IRD, pers. comm.; Kristy Lewis, LSU, pers. comm.)

4.2.5 *Model Formulation Impact on Forecasts*

The estimates in **Table 3.2** and **Table 3.3** should not be considered direct predictions of how biomass and production will change if the proposed Project were to go ahead. Productivity changes are likely driven by factors of larger geographic and temporal scale, which are likely beyond the influence of the proposed Project and their assessment was also beyond the scope of this study.

The forecasts made in the present report about how the productive potential of the study area may change with the Project are not expected to be realized where the limiting factors for a group or species are outside of the study area. If, for instance, the limiting factor for a migrating bird species is on its summer breeding grounds in the North, then it may have little impact if conditions for it improve in the study area. Conversely, forecasts of reductions in productive potential, e.g., for marine mammals should not be taken as forecasts that these groups will decline in the Strait of Georgia, where the study area plays but a minor role for their overall conditions.

Many organisms at Roberts Bank indeed, particularly those at higher trophic levels and migratory species, spend much of their life cycle outside the study area (e.g., in the Strait of Georgia) and these influences would not be reflected in the ecosystem model. Climate change may cause fluctuations in water levels and temperature that may in turn positively or negatively affect productivity of fish populations that extend beyond Roberts Bank (Cheung et al. 2012). Shorebird populations may be influenced by factors such as may occur on their breeding grounds, elsewhere on their migration, or in overwintering sites.

The present study did not consider local impacts of fishing pressure even though that there is fishing activities in the study area, e.g., for Dungeness crab. This was partly due to very incomplete information about fishing pressure and catch rates in the study area, but even more importantly because the focus of the study was on how the proposed Project might change the productivity patterns in the study area, and for this it is not important if fishing is considered explicitly or not.

This study has sought to evaluate how the local productivity of the focal species, in particular, might be impacted by the proposed Project. This was evaluated using "model drivers" that forecast how the area may change because of the proposed Project. Such

drivers were obtained from the coastal geomorphology model forecasts, which were derived based on state-of-the-art modelling techniques using local information and experience (NHC 2014).

The coastal geomorphology model provided drivers for the ecological modelling, with a limited scope: depth, salinity, wave height, and bottom current. Additional hard-bottom layers (without and with RBT2) were derived independently of the coastal geomorphology model, and these layers were also used in the ecological model. Combined, the environmental layers were deemed sufficient to inform the ecological model and support the forecasts of how the proposed Project might impact local ecological productivity.

The distribution of functional groups at Roberts Bank can be adequately described based on their preference for depth, salinity, wave height, bottom current, and hard or soft substrate. However, other factors can influence species distributions and may warrant further consideration. One such factor may be turbidity. For example, eelgrass may be more dependent on low turbidity conditions than on salinity. Salinity and turbidity are negatively correlated, so that low salinity waters are characterised by high turbidity (e.g., Marshall and Elliott 1998). Salinity was forecasted to decrease as a result of the Project along the north side of the Roberts Bank causeway, while terminal placement is predicted to reduce wave height and bottom currents (NHC 2014). The present study was designed to evaluate the impact of such secondary construction effect, and it is potentially a limiting factor that the Roberts Bank ecosystem model used only environmental drivers for which it was possible to obtain quantitative forecasts, and hence did not consider notably turbidity.

Another factor that influences species distribution but was not considered is sediment grain size. The coastal geomorphology model estimated erosion and accretion assuming a single, dominant sediment size across the study area. Therefore, it was not deemed credible to predict sediment grain size distribution for use in the Roberts Bank ecosystem model. Instead, sediment grain size was considered indirectly as it was strongly positively correlated with wave height and bottom current. Potential effects of the changes in sediment grain size as a result of the Project are discussed in the Roberts Bank Ecosystem Model Sensitivity Analyses Report (ESSA 2014).

Food webs are complicated structures, and the study area presents no exception in this regard. Yet, it has been possible to develop a food web model that is strongly rooted in local data, to correlate the spatial distributions of notably the key habitat forming groups in the area with environmental conditions, and use forecasts for how the environmental conditions

may change with the Project in order to estimate how the productive potential for the various species and groups may be impacted. The changes in productive potential are, with a few exceptions forecasted to be relatively small, and it is important to stress that the modelling approach is transparent when it comes to evaluating why the changes are predicted to occur. Both this and the uncertainty that is associated with the forecasts has been evaluated in detail as described in the accompanying Roberts Bank Ecosystem Model Sensitivity Analyses Report (ESSA 2014).

5.0 CLOSURE

We appreciate the opportunity to conduct this study of ecosystem productivity for Roberts Bank, and invite questions to be addressed to us by email to villy.christensen@gmail.com.

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7.0 STATEMENT OF LIMITATIONS

This report was prepared by ESSA Technologies Ltd., based on information supplied by Hemmera and Northwest Hydraulic Consultants, for the sole benefit and exclusive use of PMV. The material in it reflects the best judgment by ESSA Technologies and its sub-contractors in light of information available to it at the time of preparing this report. Any use that a third party makes of this report, or any reliance on or decision made based on it, is the responsibility of such third parties. ESSA Technologies and its sub-contractors accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on this Report.

ESSA Technologies and its sub-contractors have performed the work as described above and made the findings and conclusions set out in this report in a manner consistent with the level of care and skill normally exercised by members of the environmental science profession practicing under similar conditions at the time the work was performed.

This report represents a reasonable analysis based on the information and methodologies available to ESSA Technologies and its sub-contractors within the established Scope, work schedule and budgetary constraints. It is possible that there are effects that have not considered in this report because of lack of information, and hence currently unrecognised factors. No warranty, expressed or implied, is given concerning the impact of unrecognised factors, expect as specifically noted in this report.

The conclusions and recommendations contained in the report were based on applicable legislation existing at the time the report was drafted. Any changes in the legislation may alter the conclusions and/or recommendations contained in this report. Regulatory implications discussed in this report were based on the applicable legislation existing at the time this report was written.

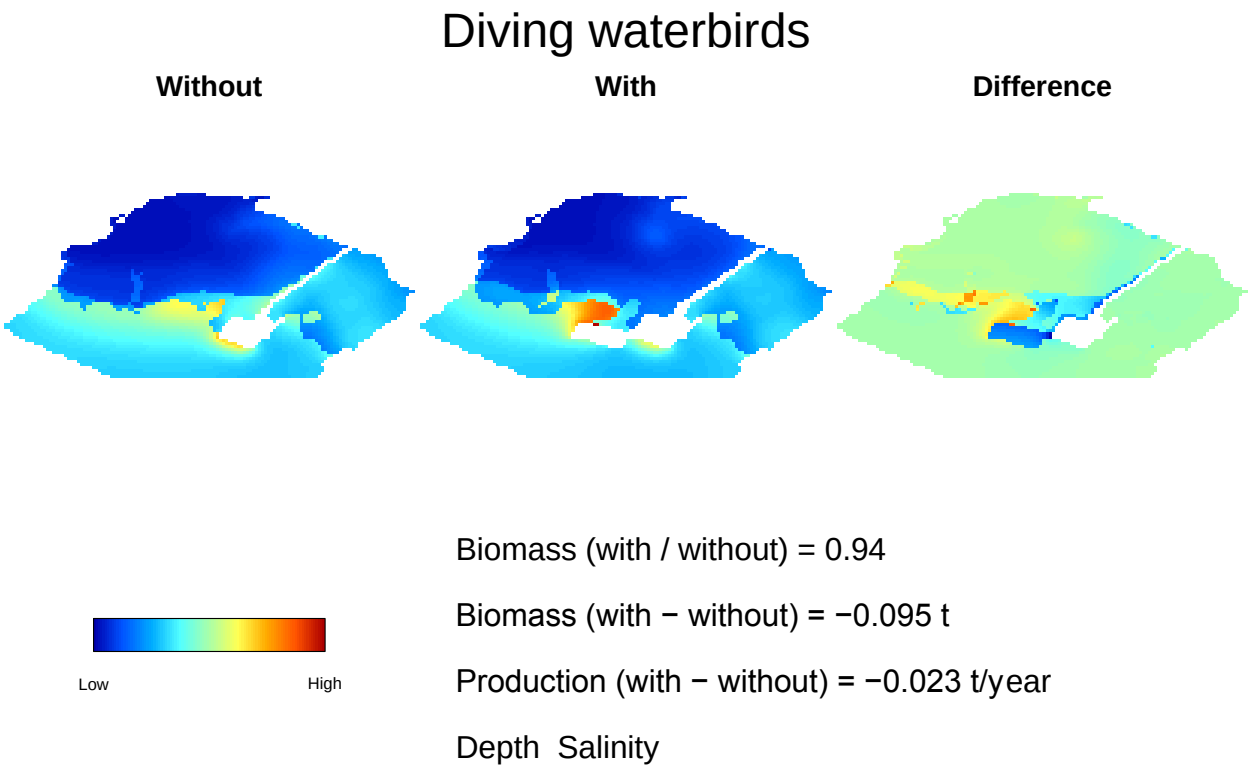
In preparing this report, ESSA Technologies and its sub-contractors have relied in good faith on information provided by others as noted in this report, and have assumed that the information provided by those individuals and organizations is both factual and accurate. ESSA Technologies and its sub-contractors accept no responsibility for any deficiency, misstatement or inaccuracy in the report resulting from the information provided by those individuals or organizations.

The liability of ESSA Technologies to Port Metro Vancouver shall be limited to injury or loss caused by the negligent acts of ESSA Technologies. The total aggregate liability of ESSA Technologies related to this agreement shall not exceed the lesser of the actual damages incurred, or the total fee of ESSA Technologies for services rendered on the project.

APPENDIX 1: SUMMARY RESULTS FOR NON-FOCAL SPECIES

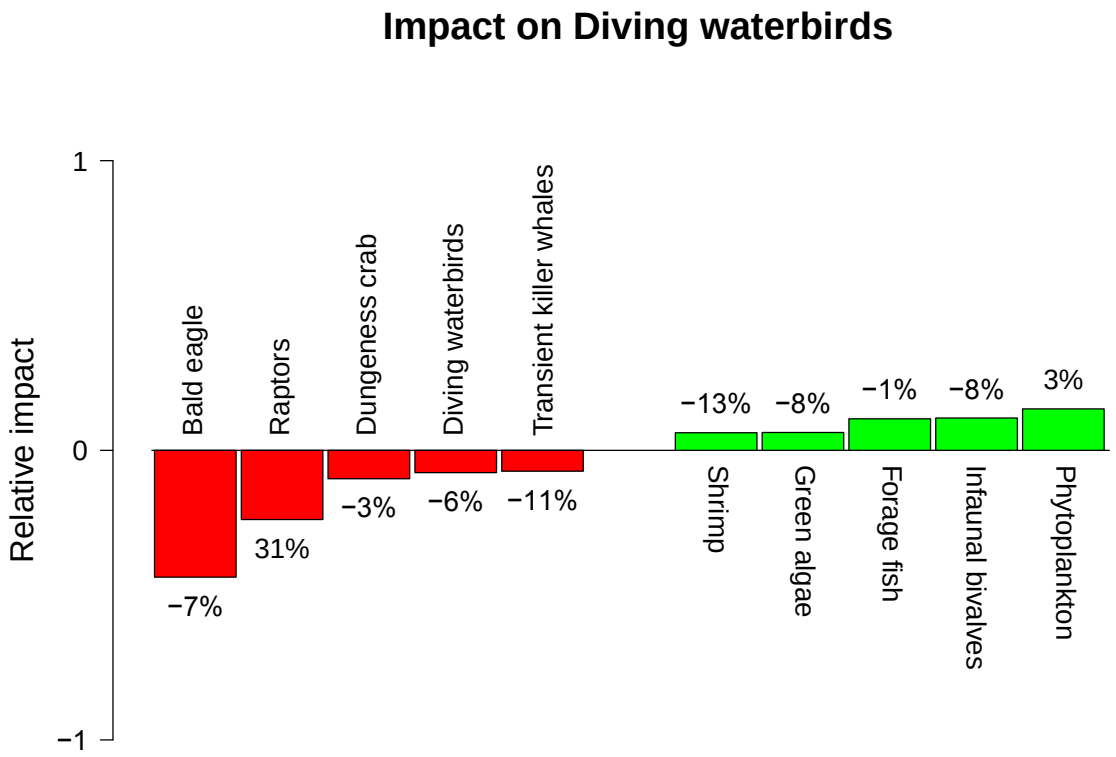
Diving Waterbirds

Figure A1.1 Forecasted Biomass Distribution for Diving Waterbirds, Without the Project, With the Project, and the Difference (With - Without)



Note: Diving waterbirds are distributed based on depth, and salinity. The colour scale indicates values from low (blue) to high (red)

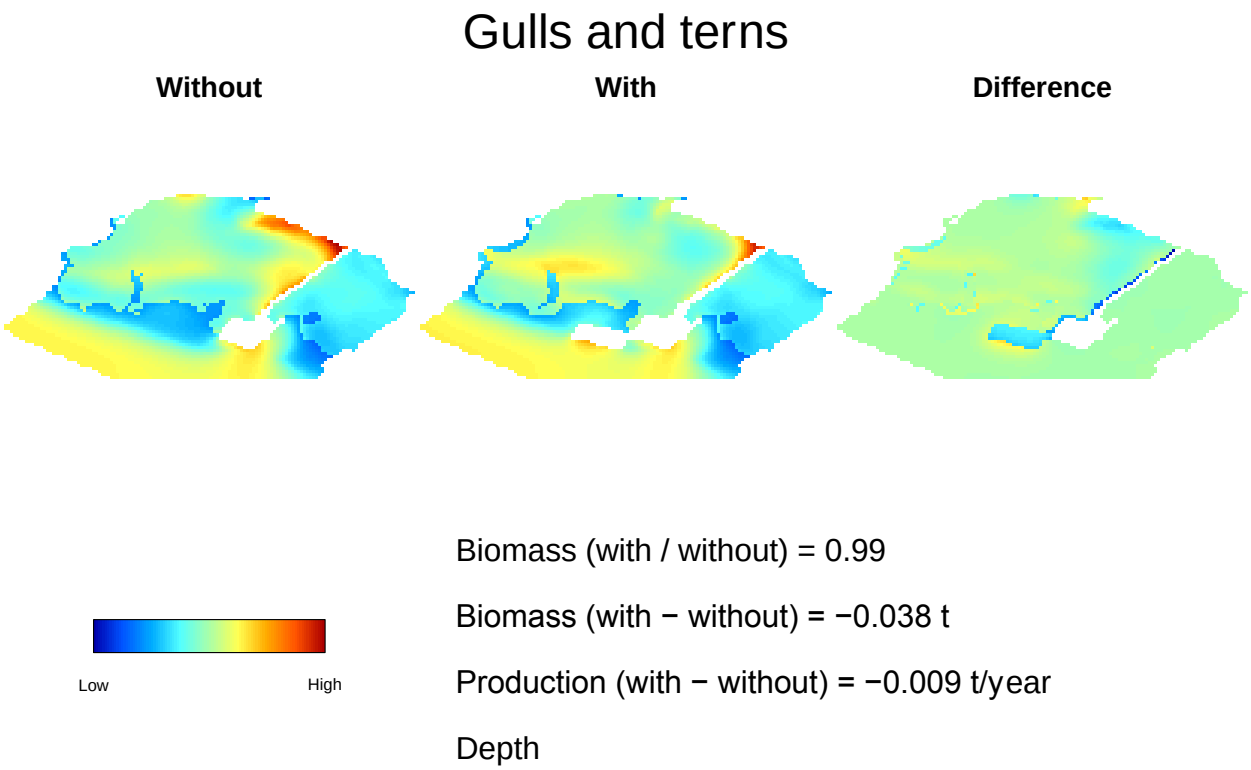
Figure A1.2 Mixed Trophic Impacts for Groups that have strongest relative Impact on Diving Waterbirds



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

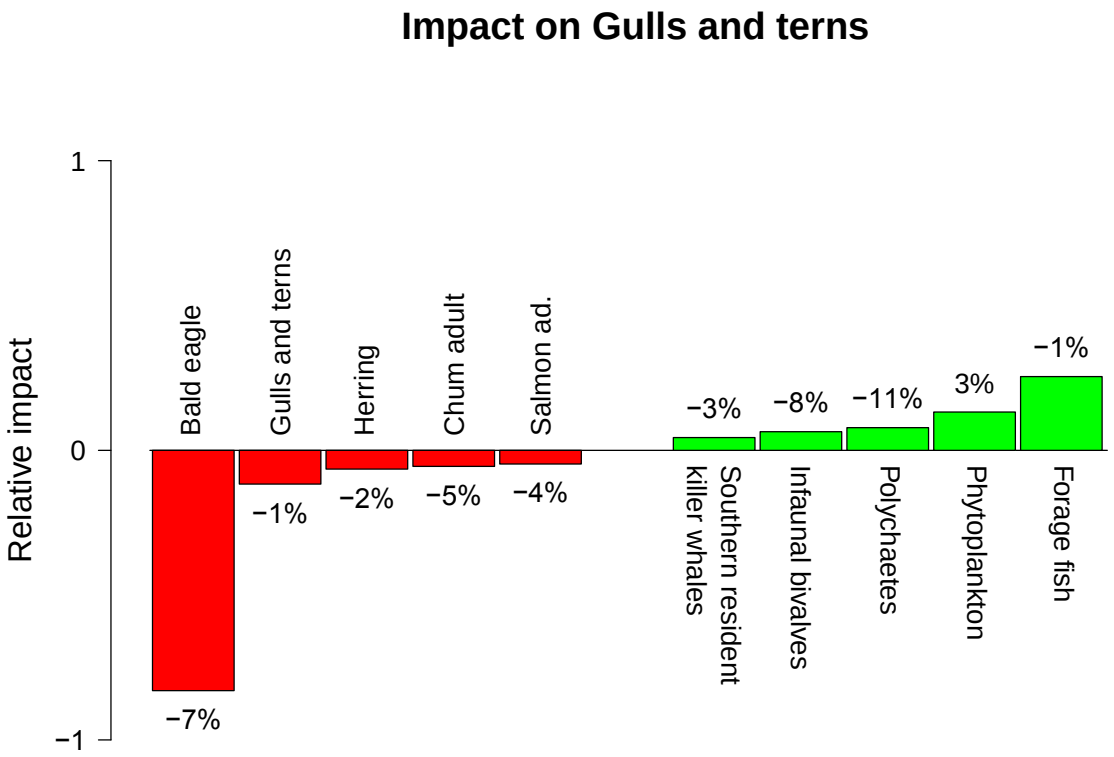
Gulls and Terns

Figure A1.3 Forecasted Biomass Distribution for Gulls and Terns, Without the Project, With the Project, and the Difference (With - Without)



Note: Gulls and terns are distributed based on depth. The colour scale indicates values from low (blue) to high (red)

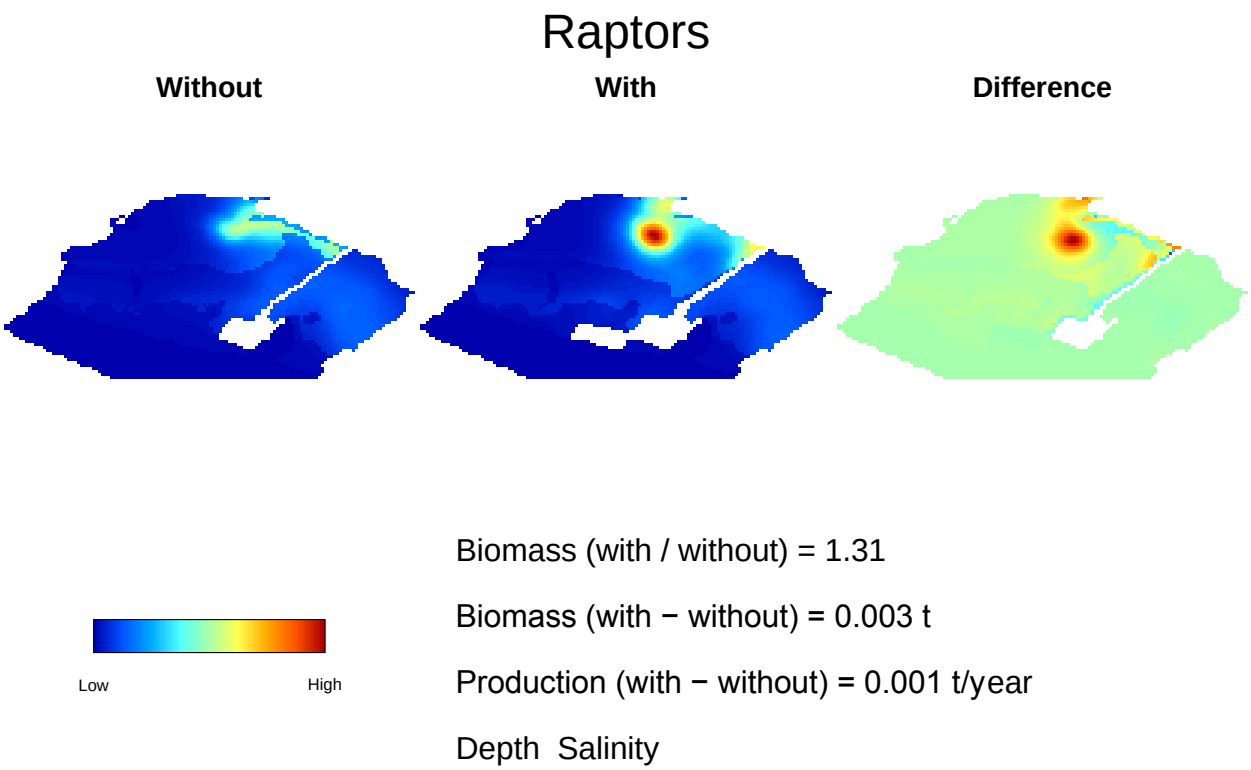
Figure A1.4 Mixed Trophic Impacts for Groups that have strongest relative Impact on Gulls and Terns



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

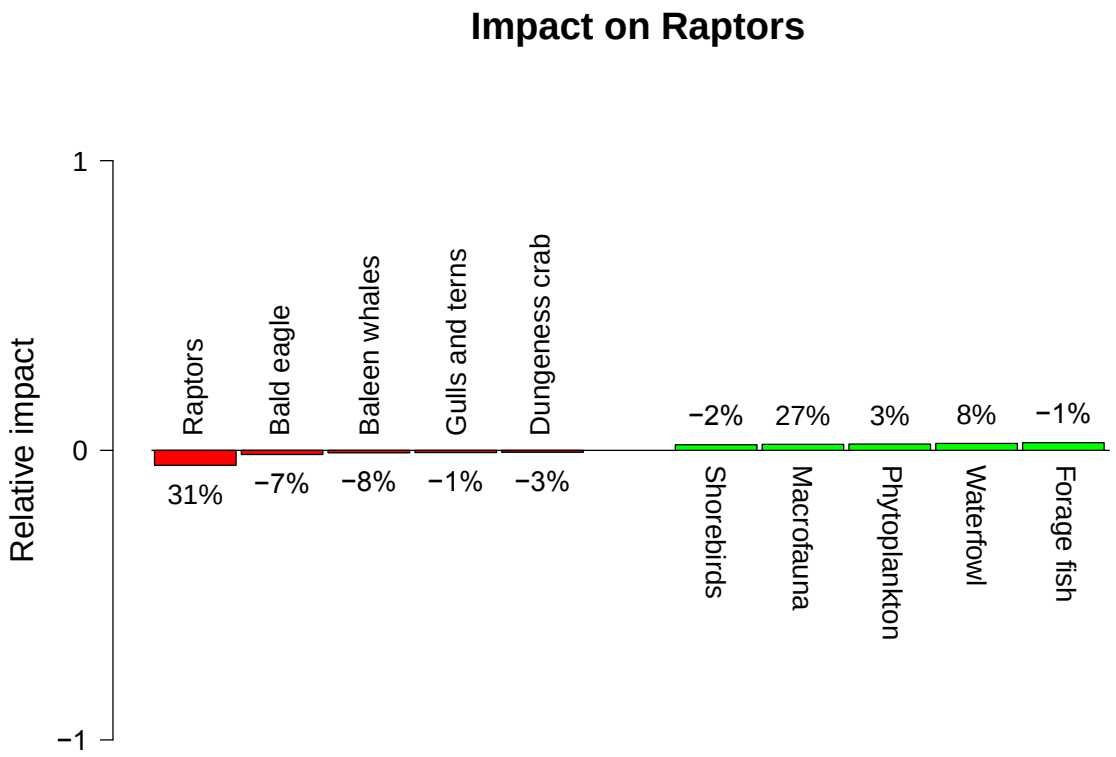
Raptors

Figure A1.5 Forecasted Biomass Distribution for Raptors, Without the Project, With the Project, and the Difference (With - Without)



Note: Raptors are distributed based on depth, and salinity. The colour scale indicates values from low (blue) to high (red)

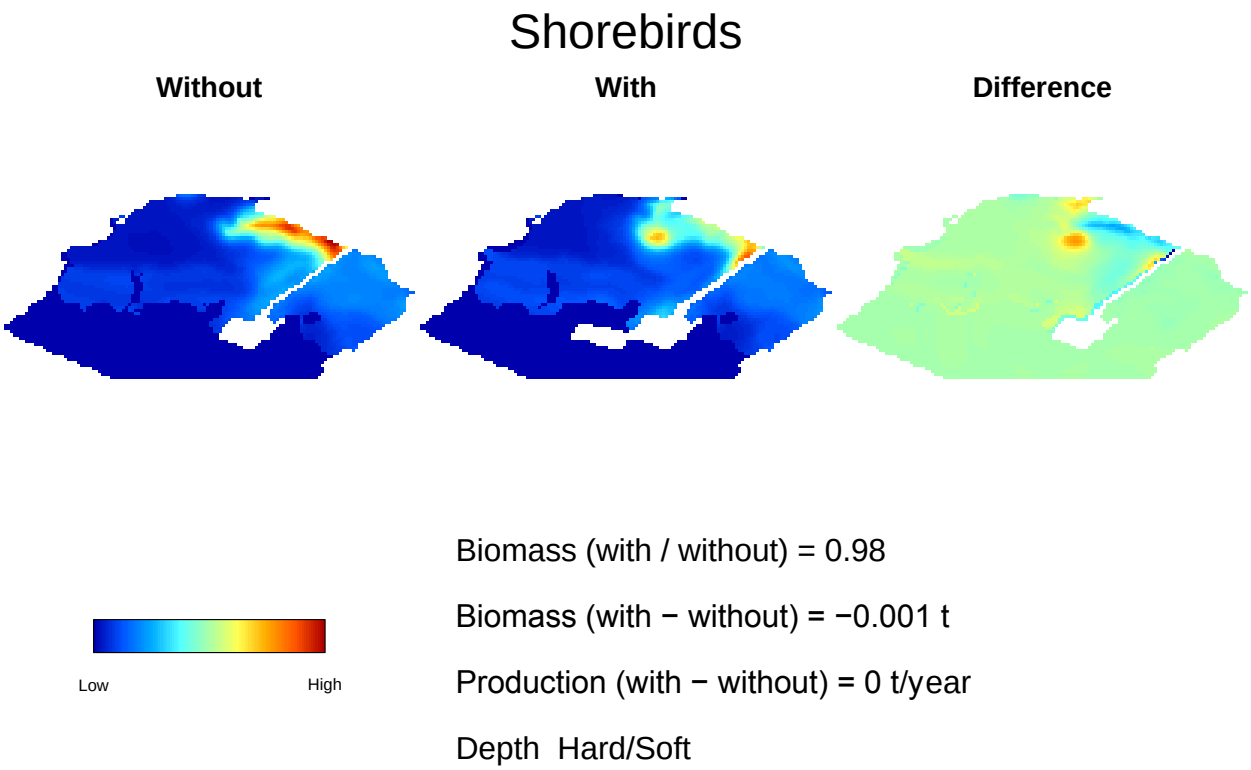
Figure A1.6 Mixed Trophic Impacts for Groups that have strongest relative Impact on Raptors



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

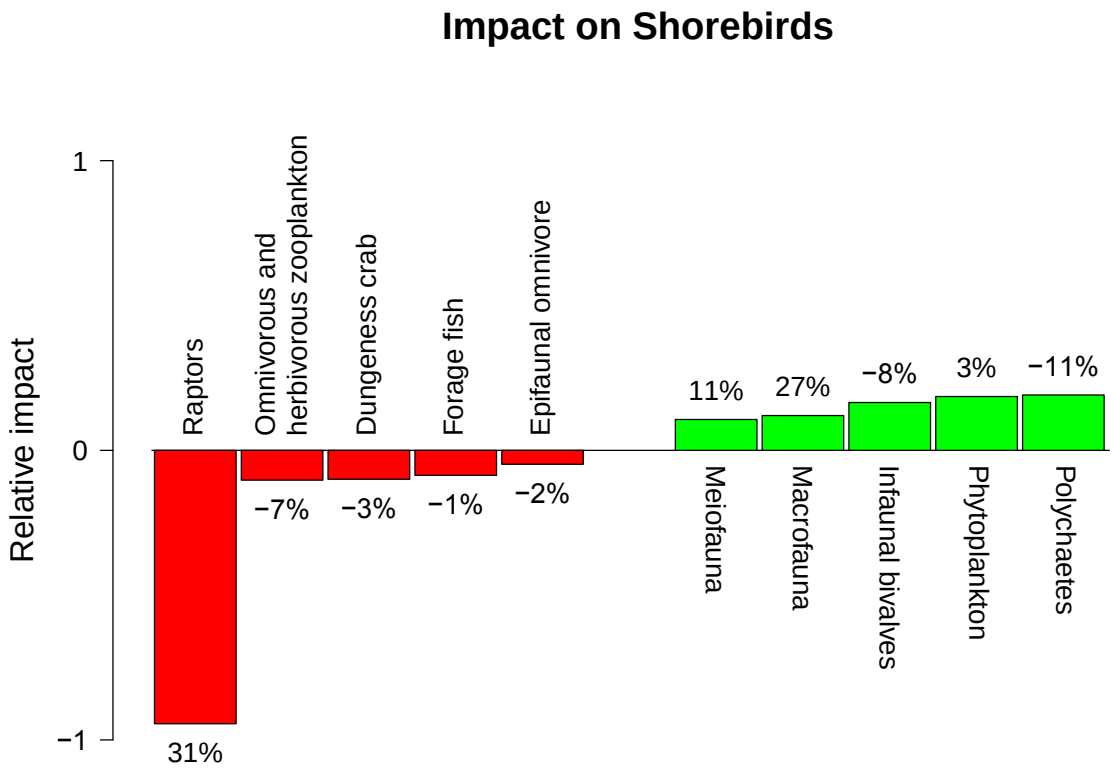
Shorebirds

Figure A1.7 Forecasted Biomass Distribution for Shorebirds, Without the Project, With the Project, and the Difference (With - Without)



Note: Shorebirds are distributed based on depth, and soft substrate. The colour scale indicates values from low (blue) to high (red)

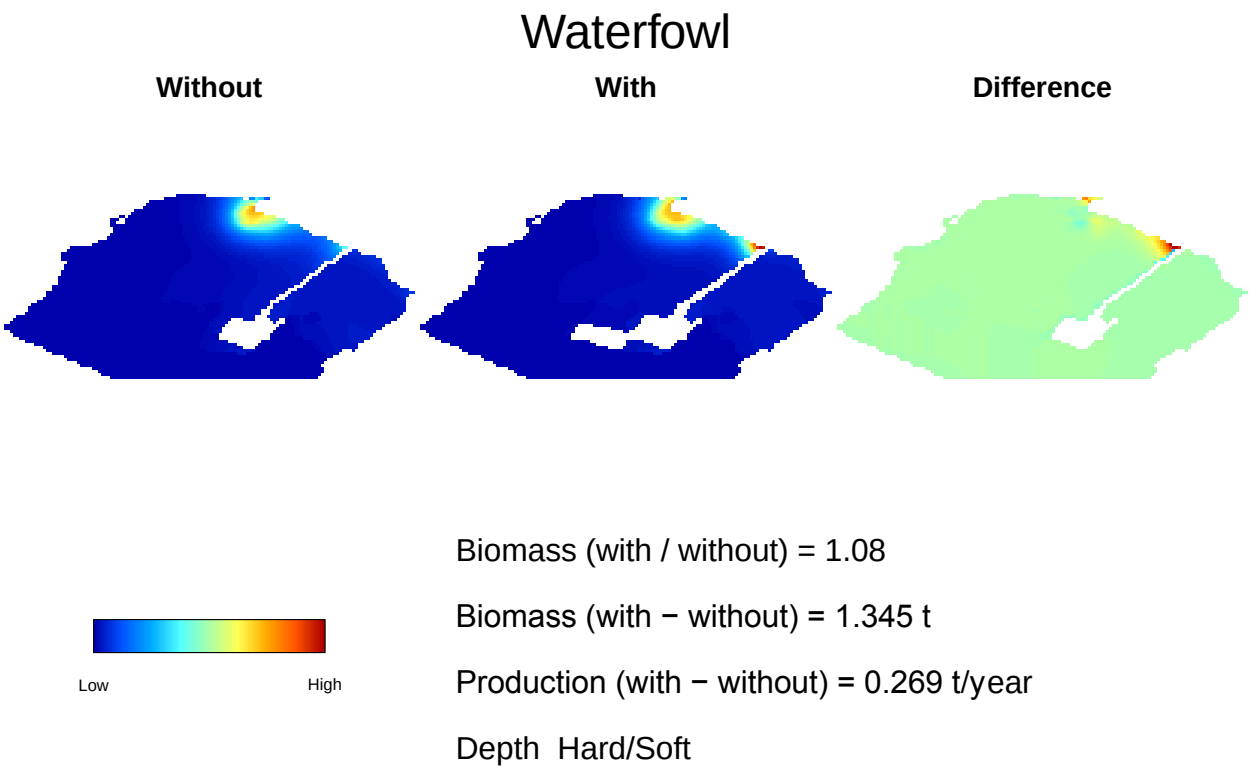
Figure A1.8 Mixed Trophic Impacts for Groups that have strongest relative Impact on Shorebirds



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

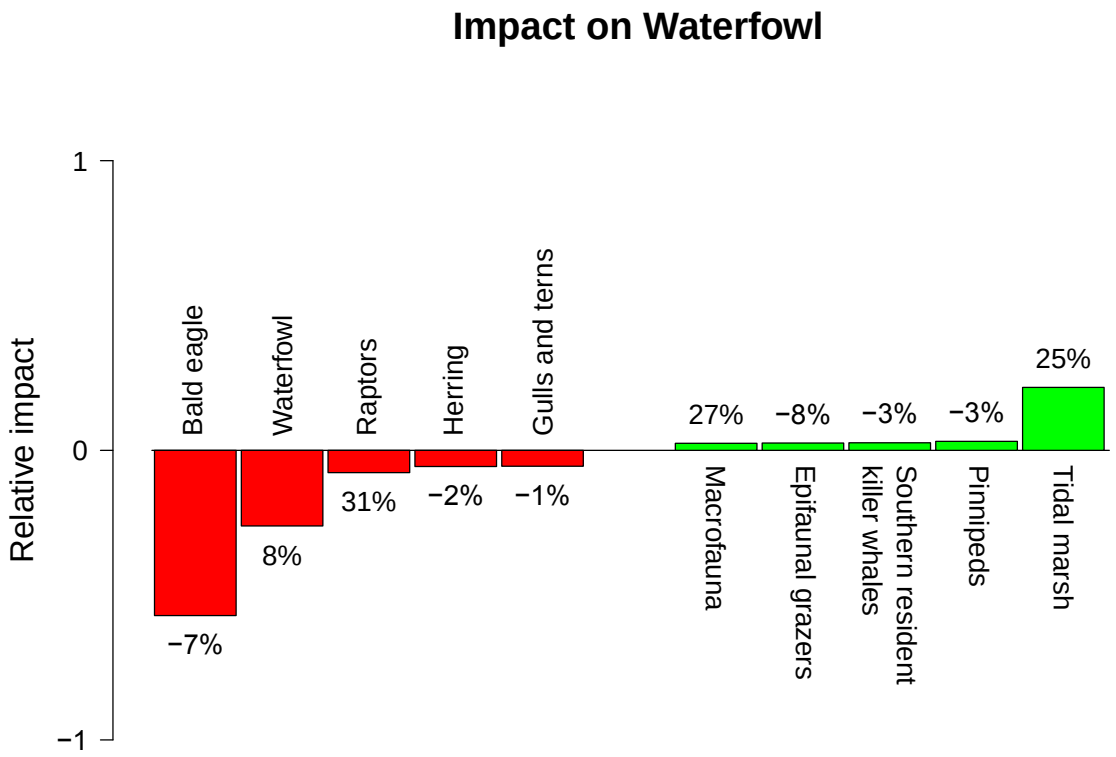
Waterfowl

Figure A1.9 Forecasted Biomass Distribution for Waterfowl, Without the Project, With the Project, and the Difference (With - Without)



Note: Waterfowl are distributed based on depth, and soft substrate. The colour scale indicates values from low (blue) to high (red)

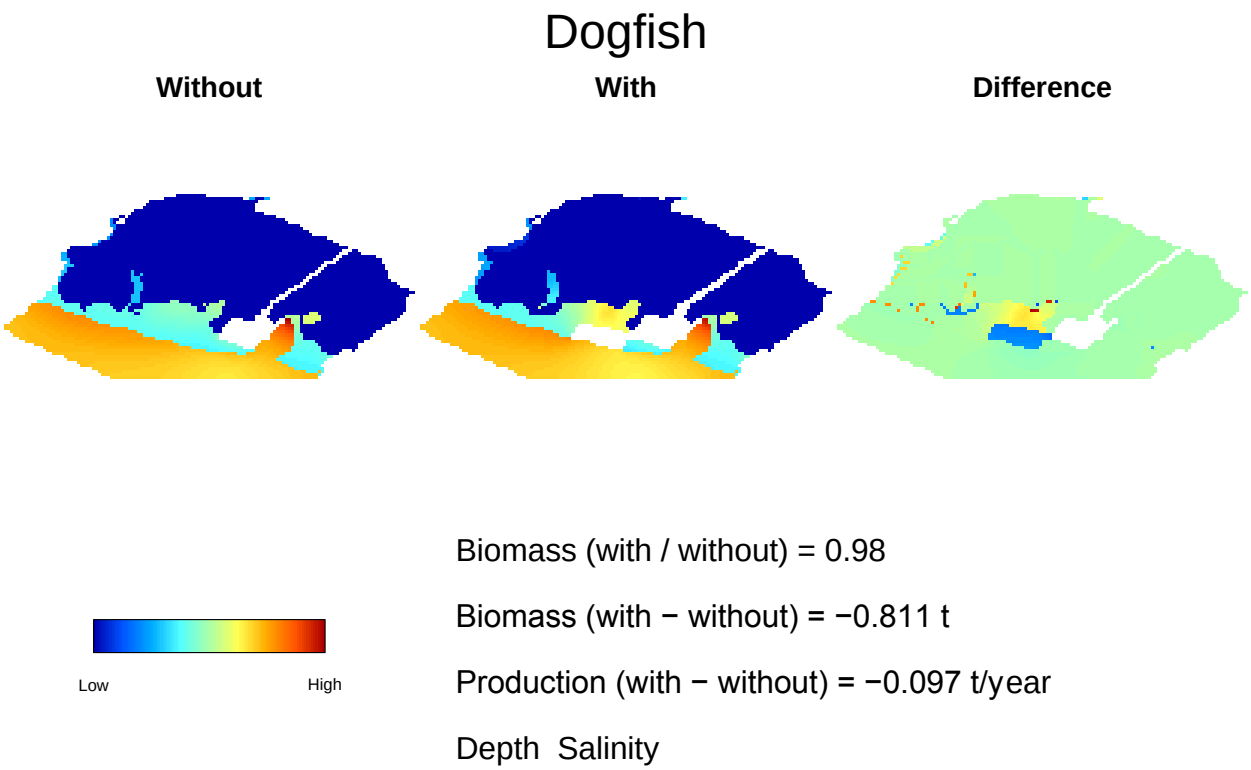
Figure A1.10 Mixed Trophic Impacts for Groups that have strongest relative Impact on Waterfowl



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

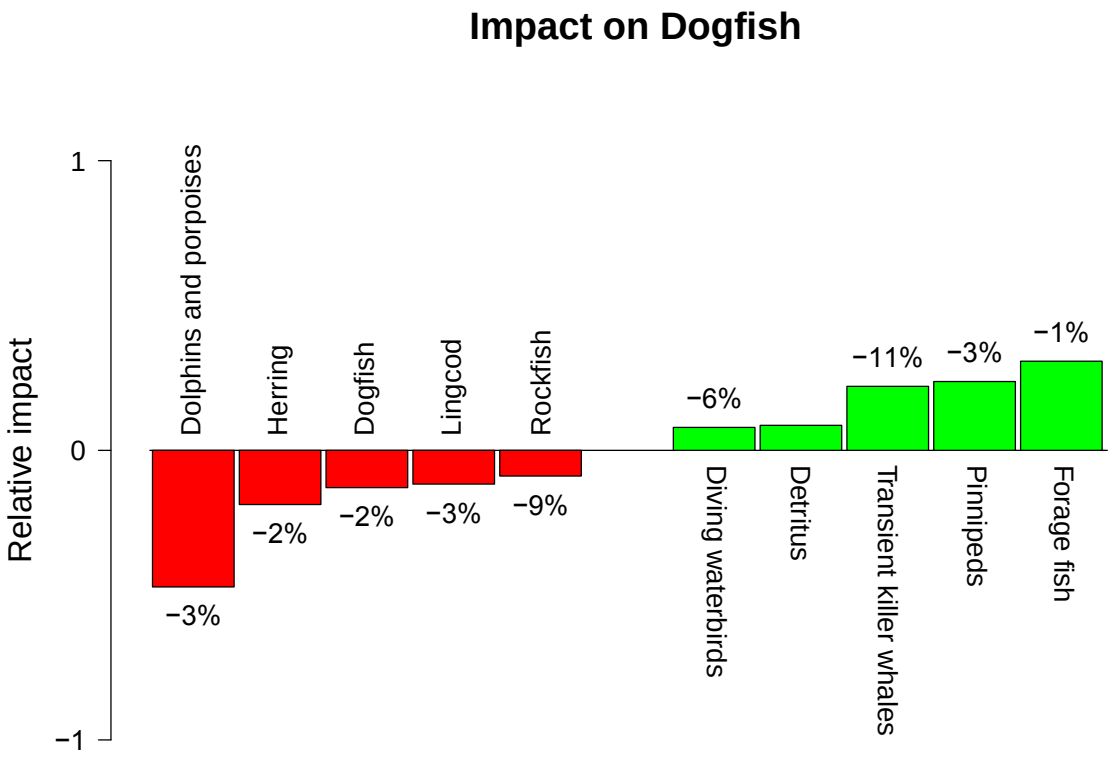
Dogfish

Figure A1.11 Forecasted Biomass Distribution for Dogfish, Without the Project, With the Project, and the Difference (With - Without)



Note: Dogfish are distributed based on depth, and salinity. The colour scale indicates values from low (blue) to high (red)

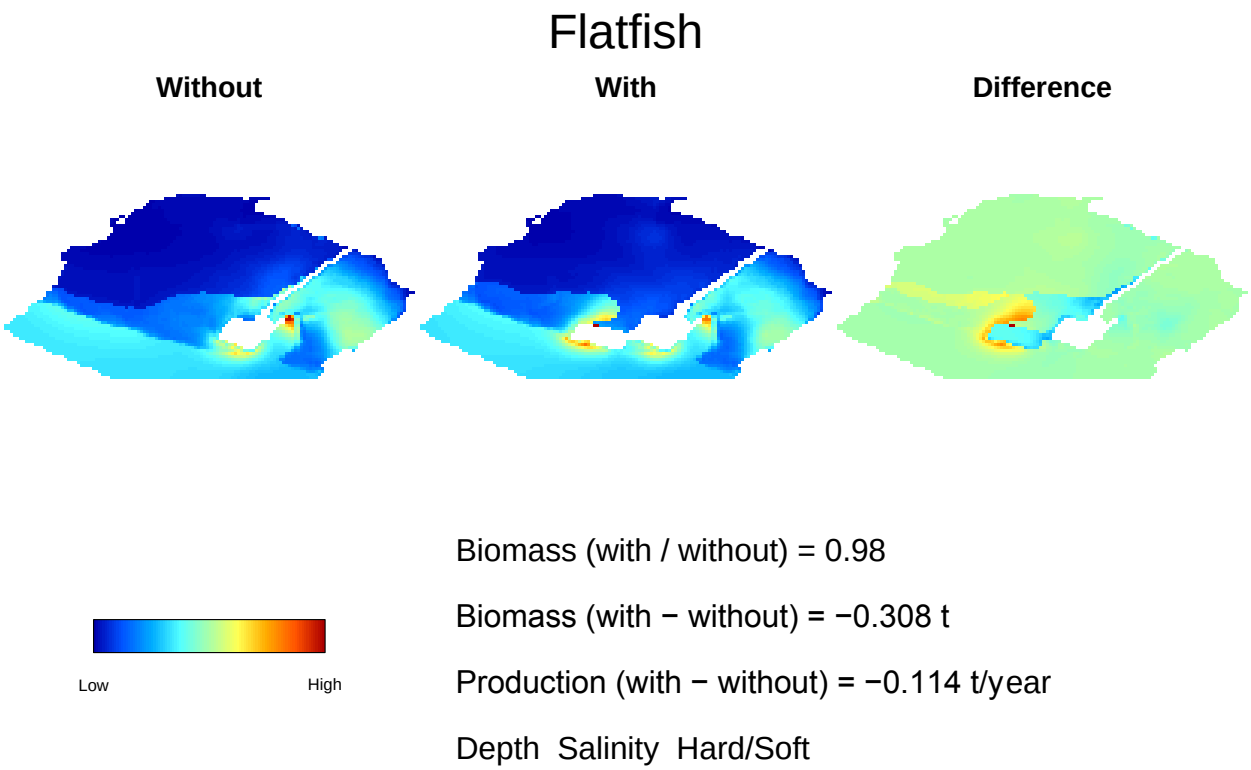
Figure A1.12 Mixed Trophic Impacts for Groups that have strongest relative Impact on Dogfish



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

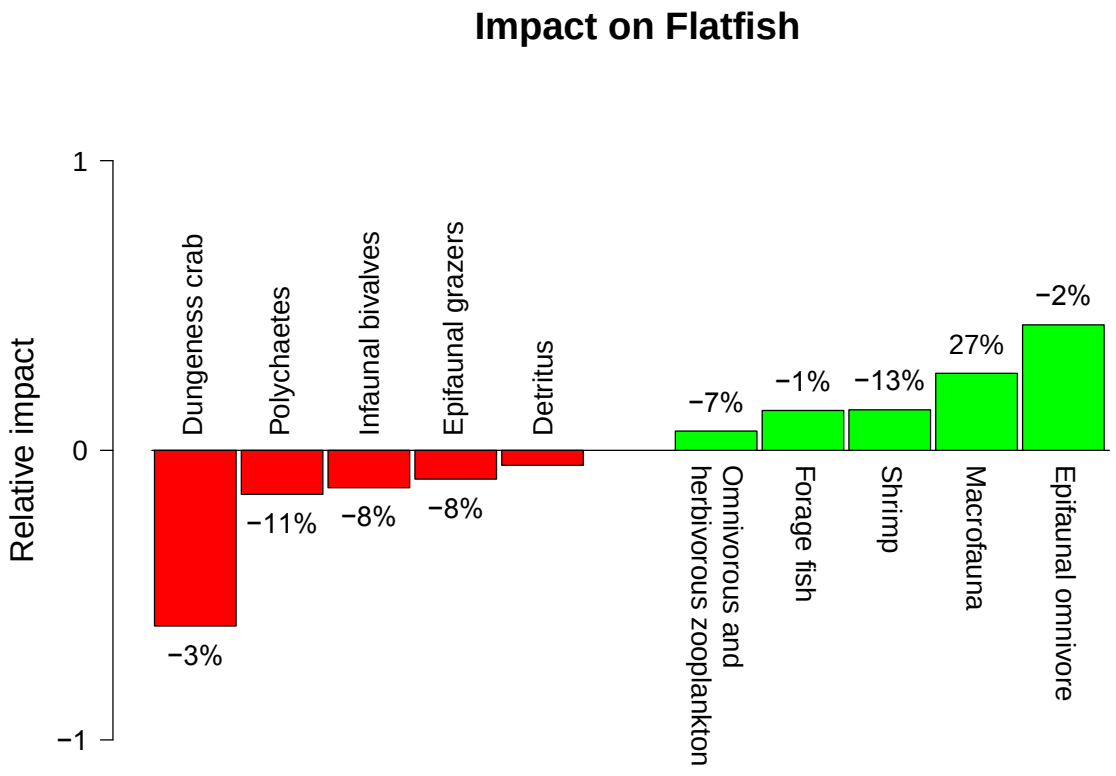
Flatfish

Figure A1.13 Forecasted Biomass Distribution for Flatfish, Without the Project, With the Project, and the Difference (With - Without)



Note: Flatfish are distributed based on depth, salinity, and soft substrate. The colour scale indicates values from low (blue) to high (red)

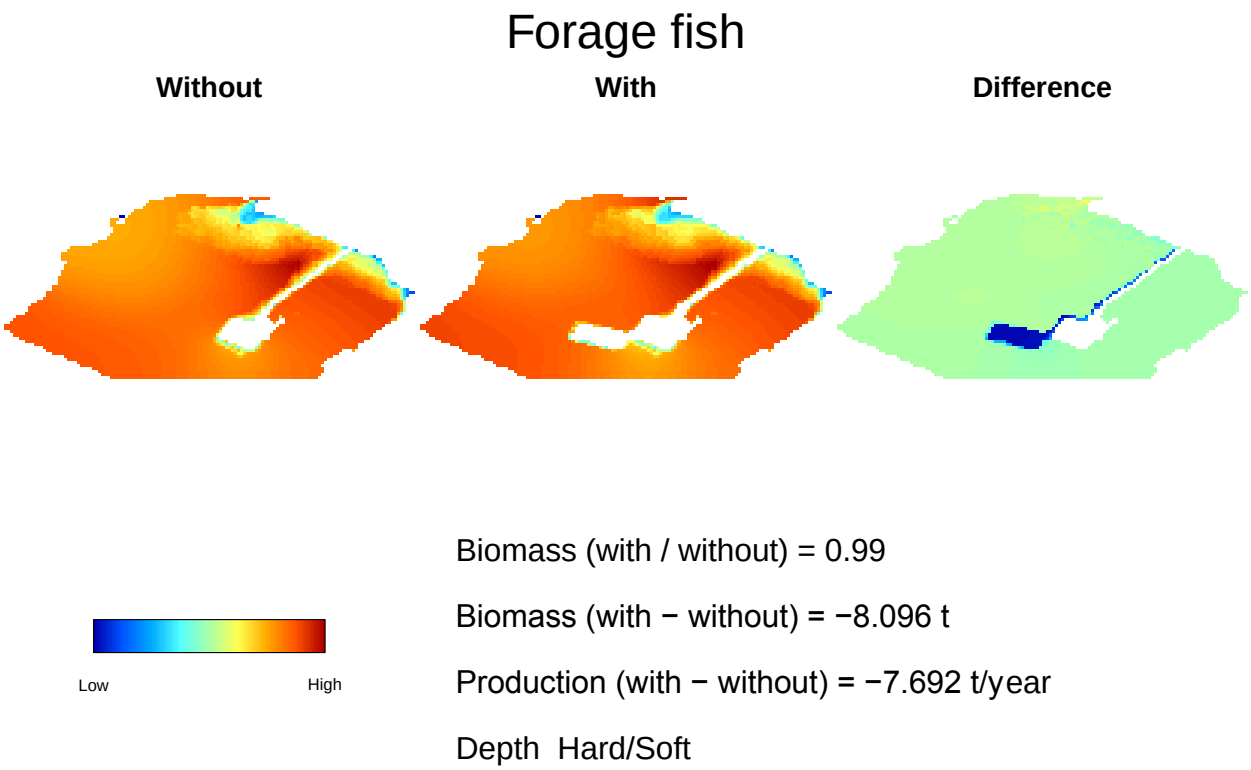
Figure A1.14 Mixed Trophic Impacts for Groups that have strongest relative Impact on Flatfish



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

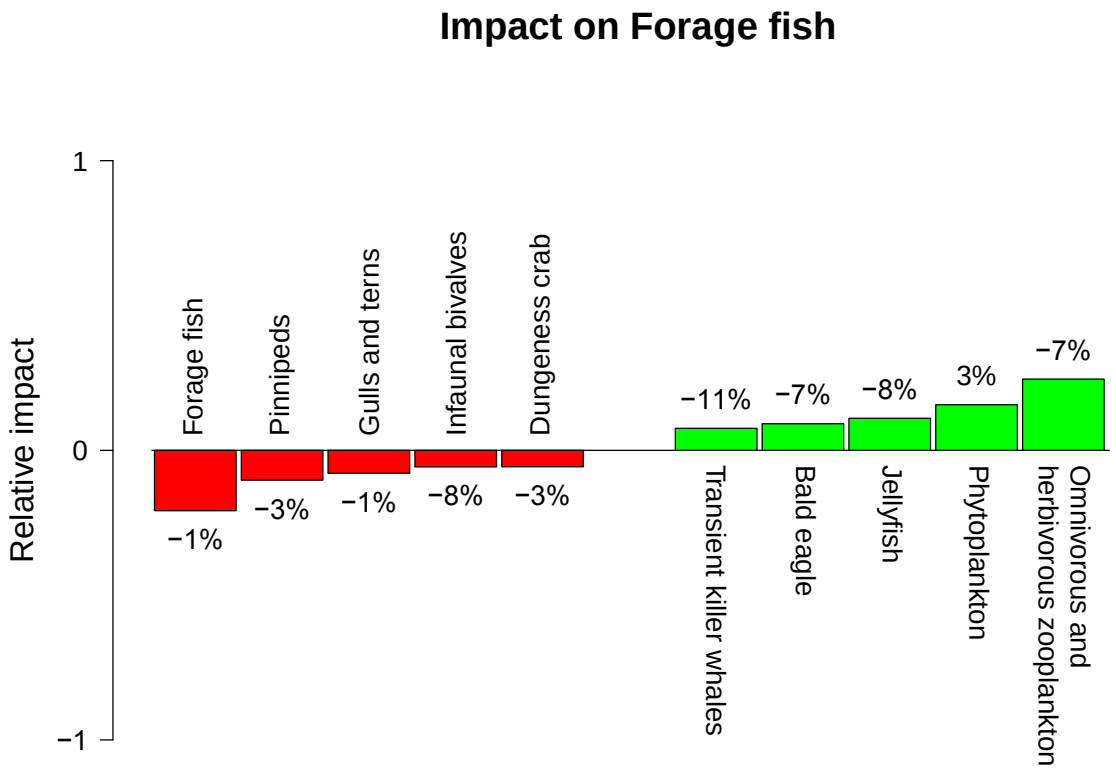
Forage Fish

Figure A1.15 Forecasted Biomass Distribution for Forage Fish, Without the Project, With the Project, and the Difference (With - Without)



Note: Forage fish are distributed based on depth, and soft substrate. The colour scale indicates values from low (blue) to high (red)

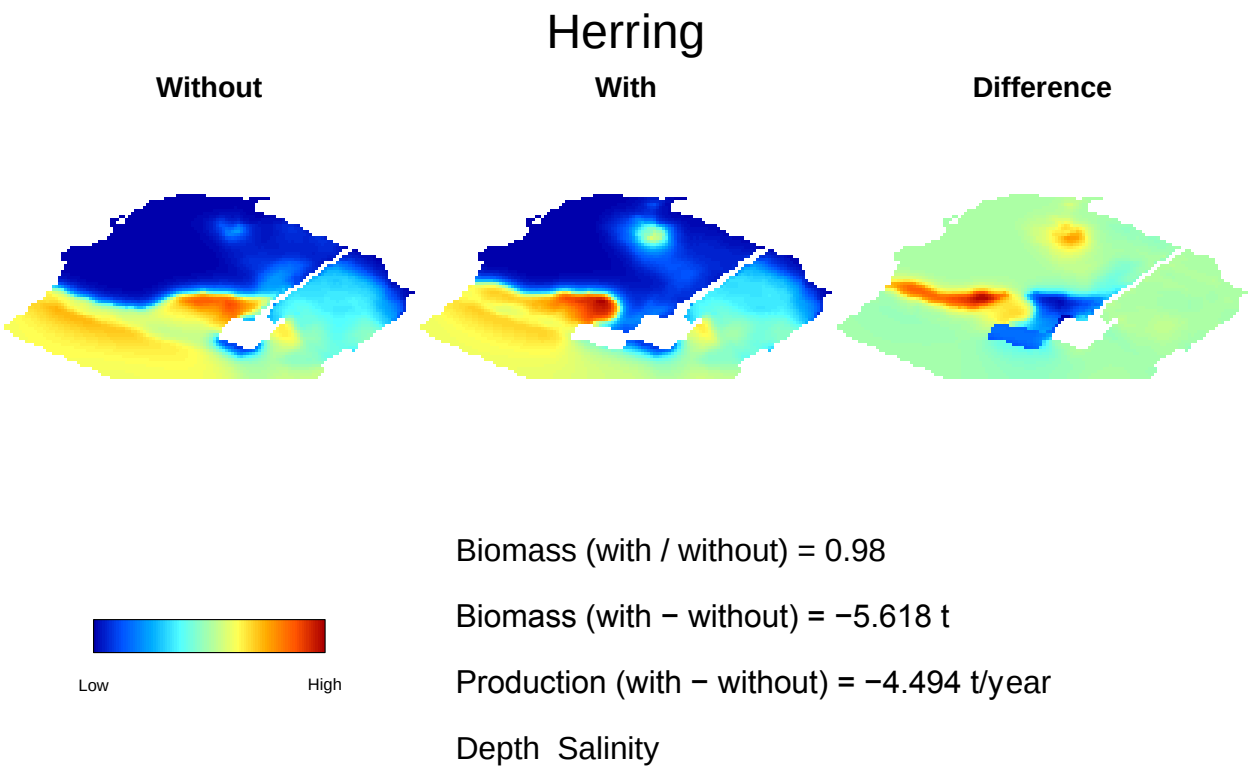
Figure A1.16 Mixed Trophic Impacts for Groups that have strongest relative Impact on Forage fish



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

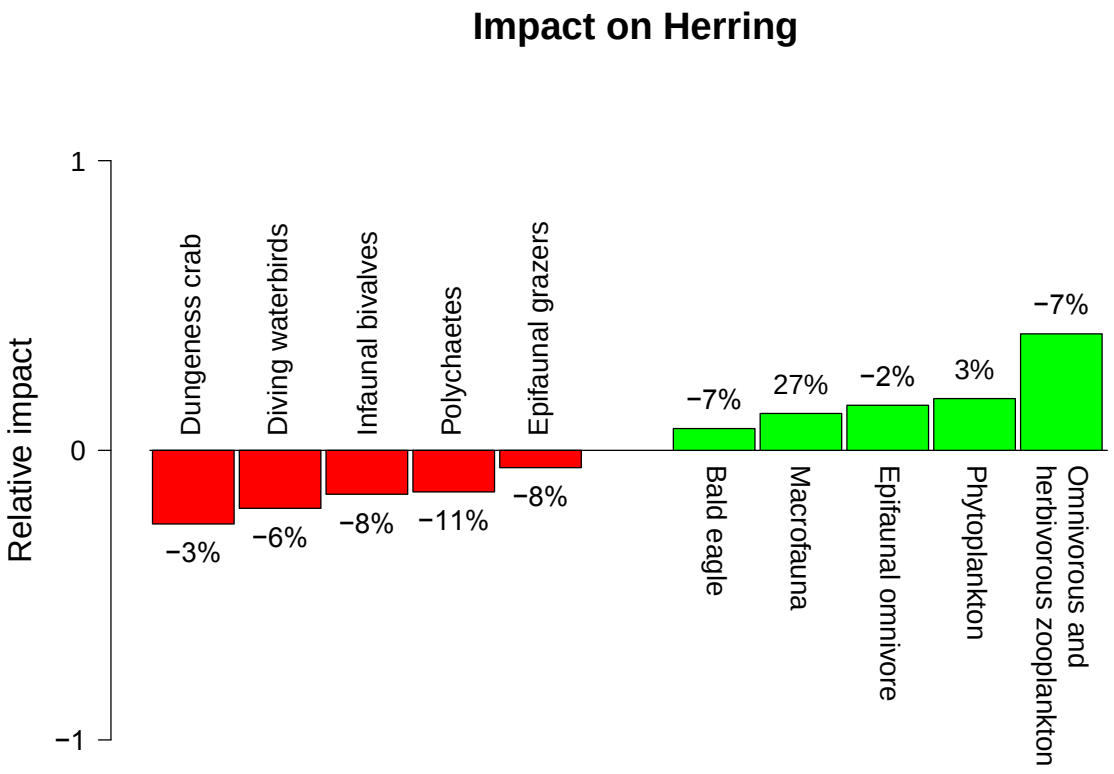
Herring

Figure A1.17 Forecasted Biomass Distribution for Herring, Without the Project, With the Project, and the Difference (With - Without)



Note: Herring are distributed based on depth, and salinity. The colour scale indicates values from low (blue) to high (red)

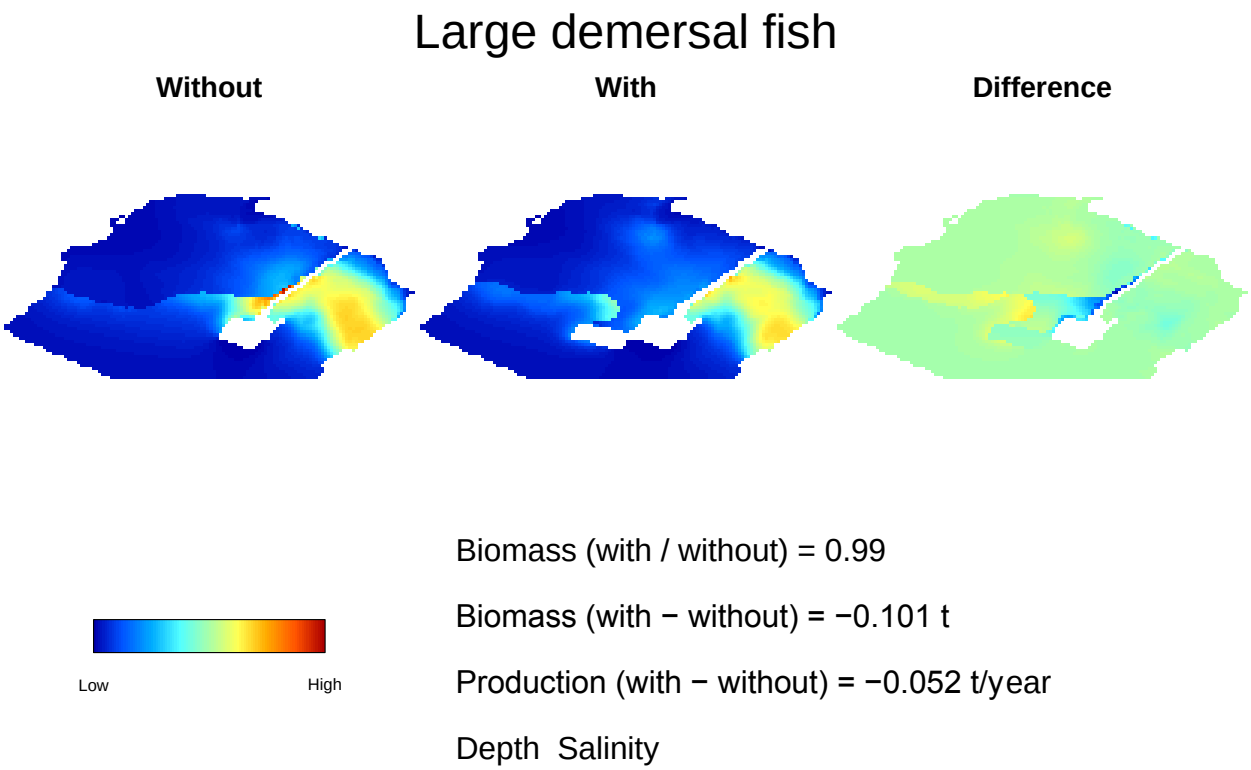
Figure A1.18 Mixed Trophic Impacts for Groups that have strongest relative Impact on Herring



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

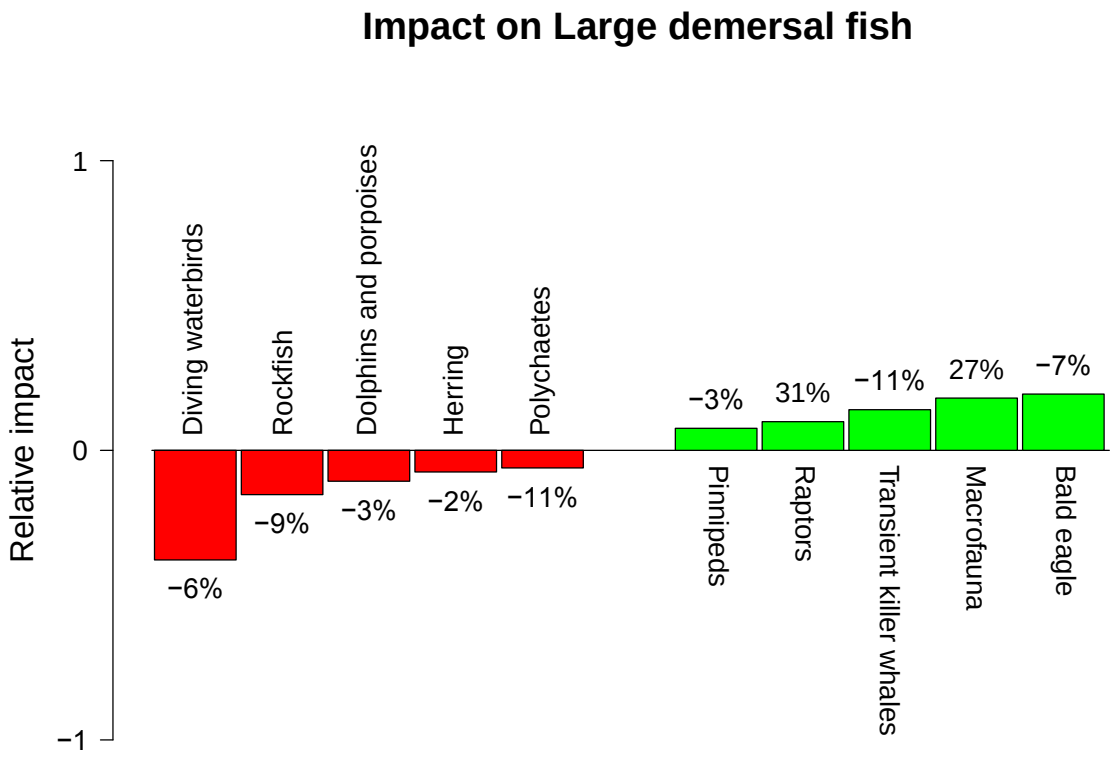
Large Demersal Fish

Figure A1.19 Forecasted Biomass Distribution for Large Demersal Fish, Without the Project, With the Project, and the Difference (With - Without)



Note: Large demersal fish are distributed based on depth, and salinity. The colour scale indicates values from low (blue) to high (red)

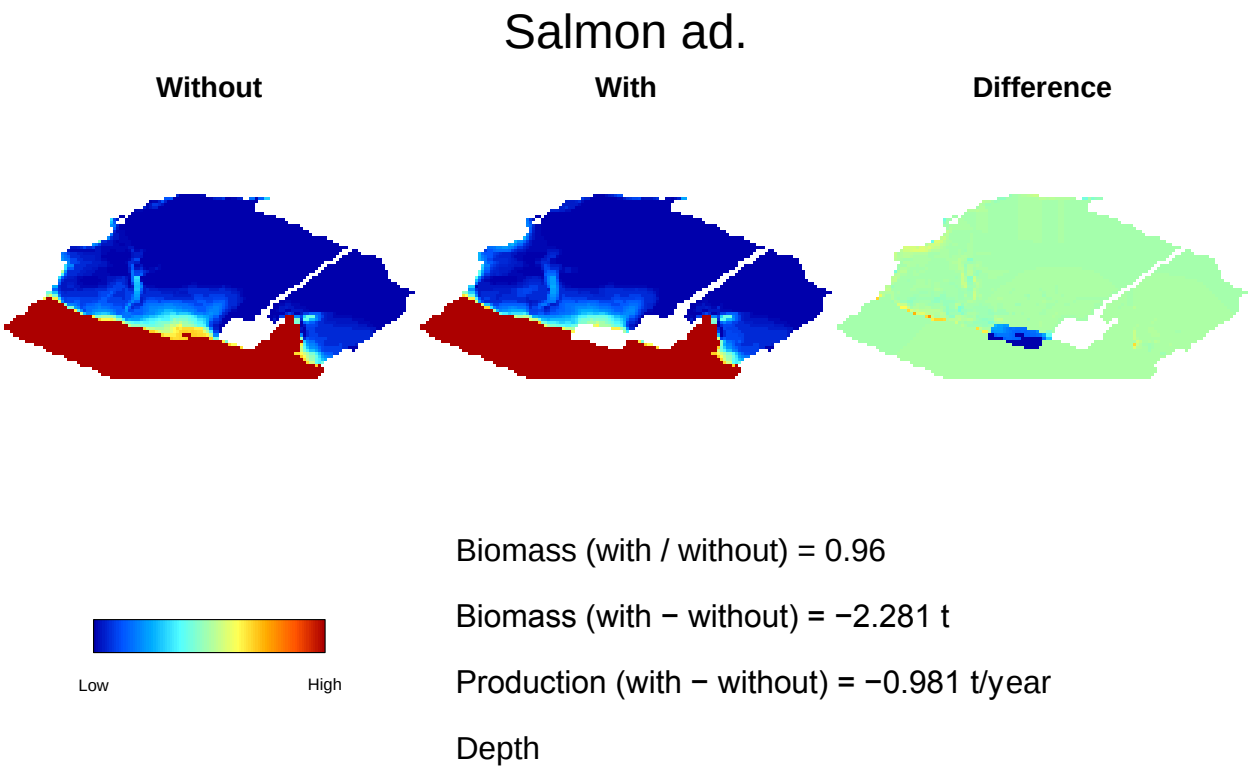
Figure A1.20 Mixed Trophic Impacts for Groups that have strongest relative Impact on Large Demersal Fish



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

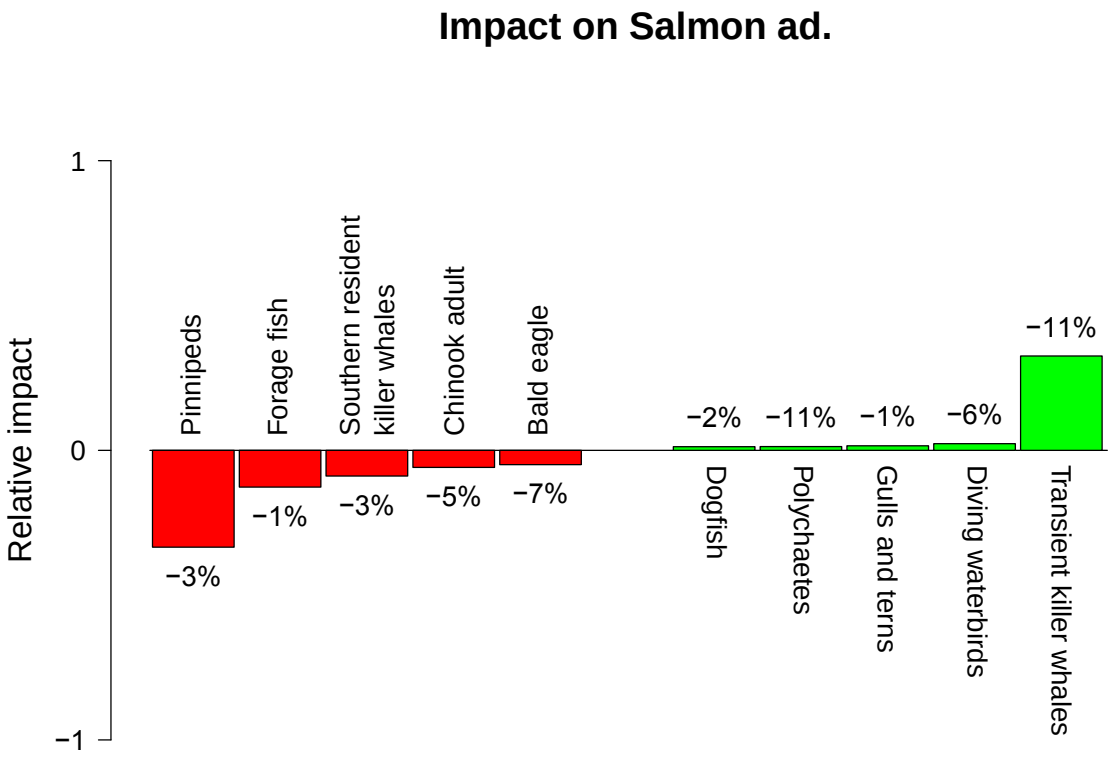
Salmon Adult

Figure A1.21 Forecasted Biomass Distribution for Adult Salmon, Without the Project, With the Project, and the Difference (With - Without)



Note: Adult salmon are distributed based on depth. The colour scale indicates values from low (blue) to high (red)

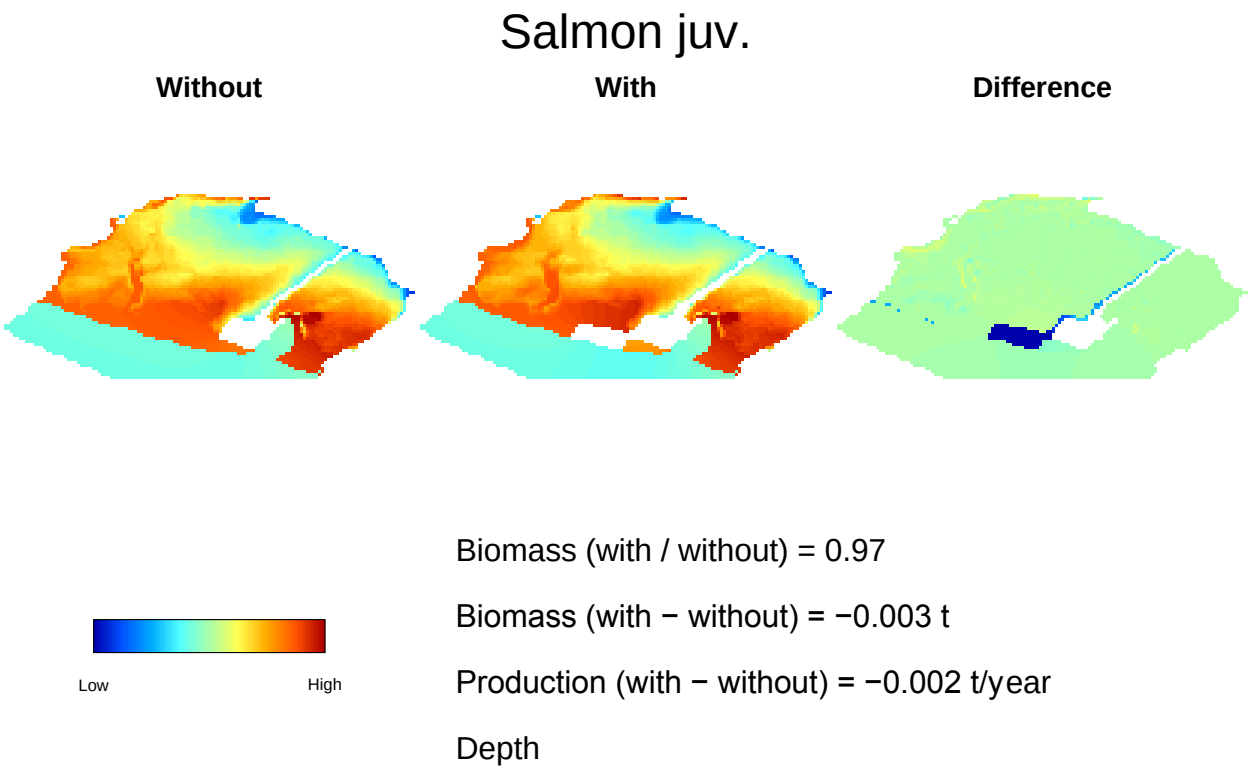
Figure A1.22 Mixed Trophic Impacts for Groups that have strongest relative Impact on Adult Salmon



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

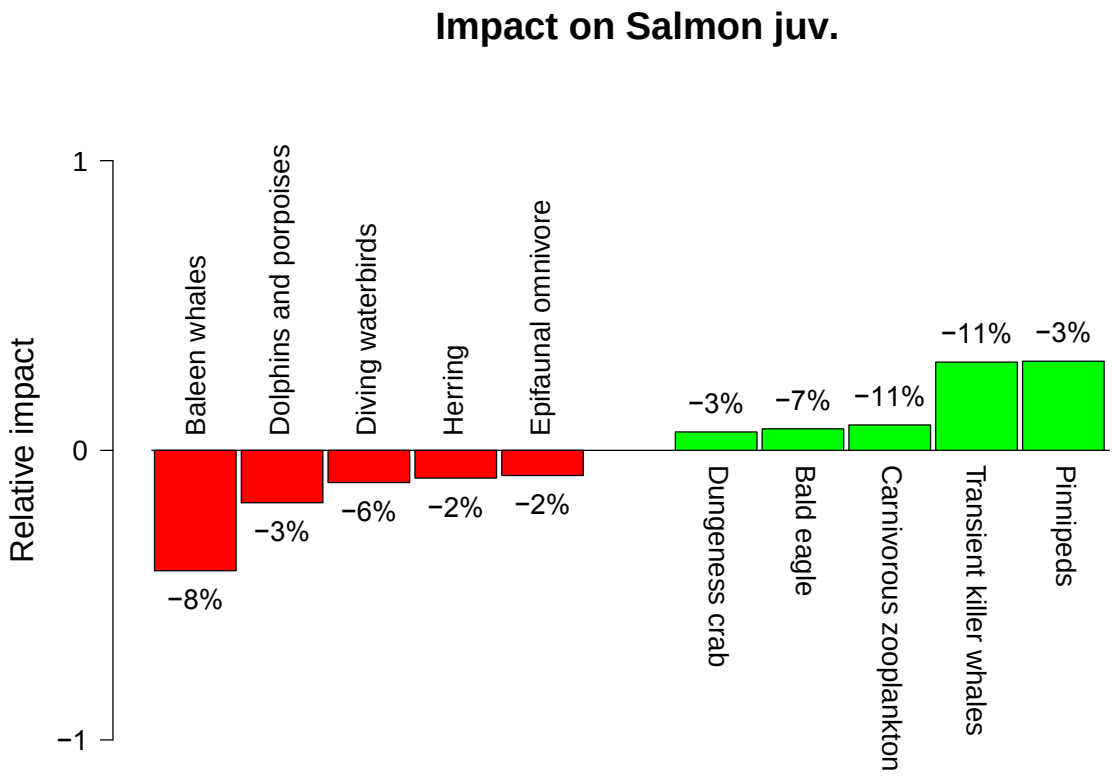
Salmon Juvenile

Figure A1.23 Forecasted Biomass Distribution for Juvenile Salmon, Without the Project, With the Project, and the Difference (With - Without)



Note: Juvenile salmon are distributed based on depth. The colour scale indicates values from low (blue) to high (red)

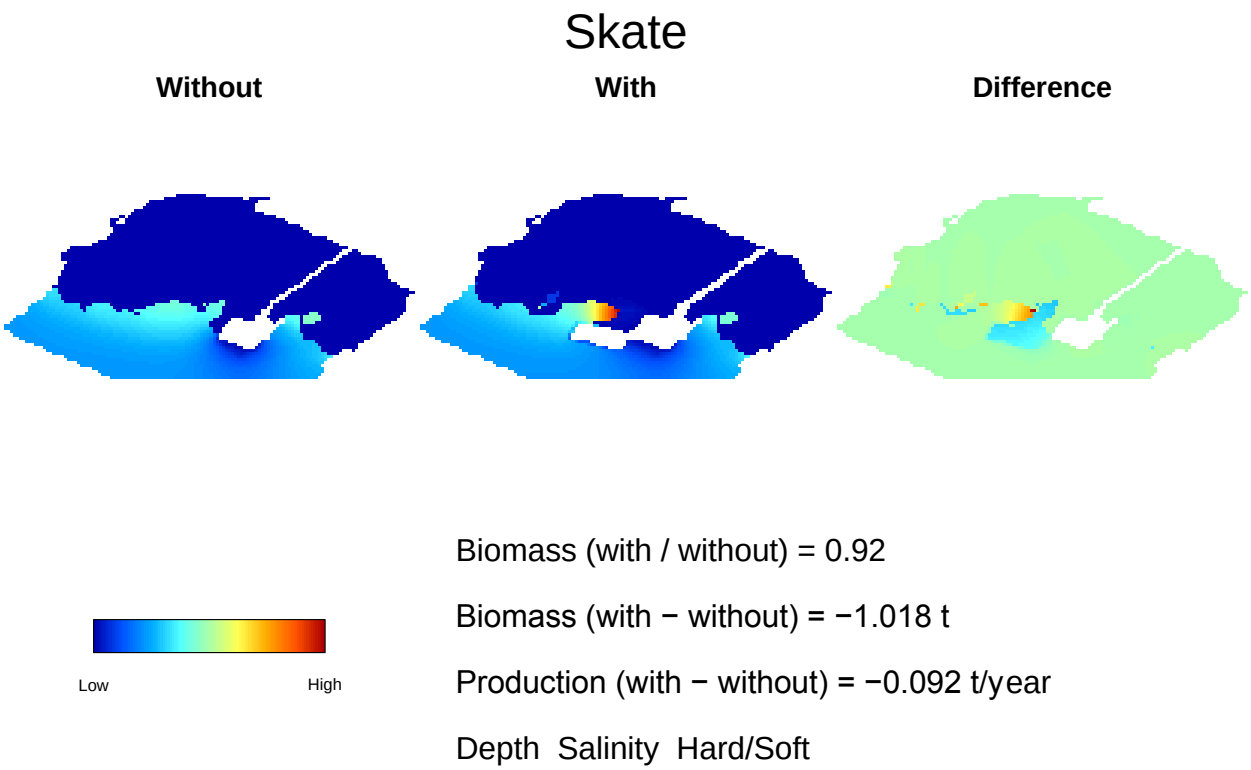
Figure A1.24 Mixed Trophic Impacts for Groups that have strongest relative Impact on Juvenile Salmon



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

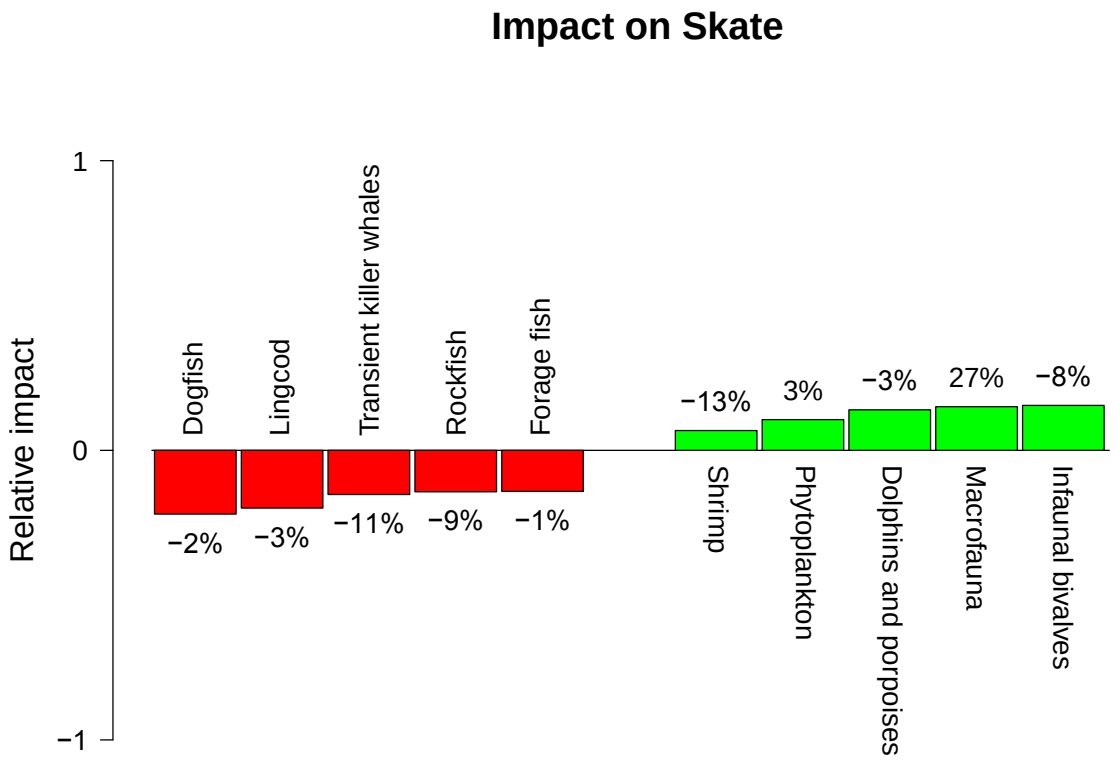
Skate

Figure A1.25 Forecasted Biomass Distribution for Skate, Without the Project, With the Project, and the Difference (With - Without)



Note: Skate are distributed based on depth, salinity, and soft substrate. The colour scale indicates values from low (blue) to high (red)

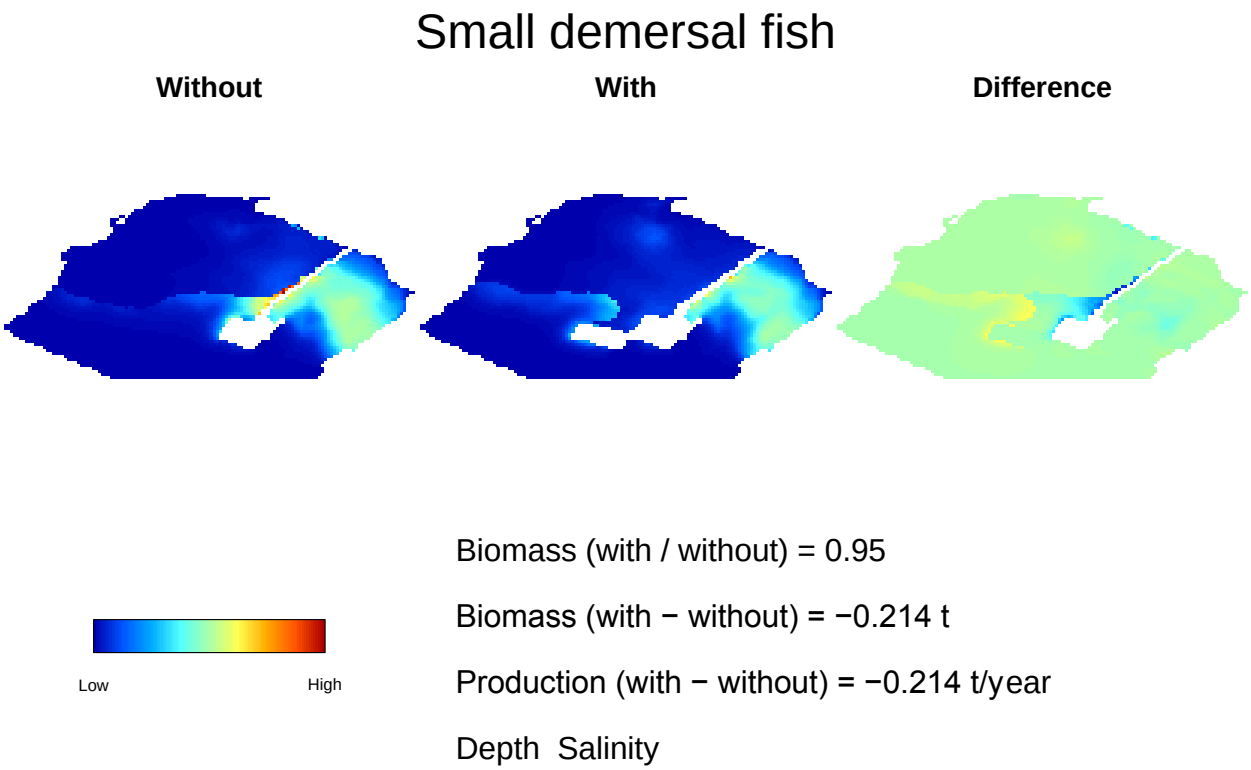
Figure A1.26 Mixed Trophic Impacts for Groups that have strongest relative Impact on Skate



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

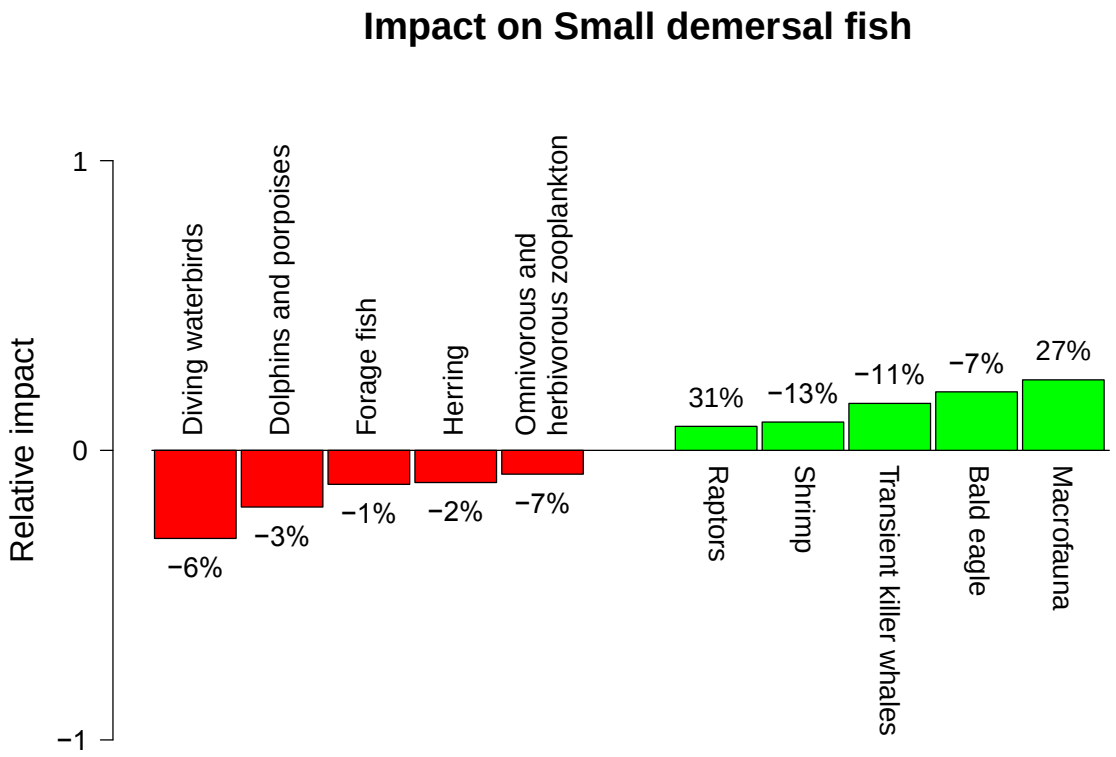
Small Demersal Fish

Figure A1.27 Forecasted Biomass Distribution for Small Demersal Fish, Without the Project, With the Project, and the Difference (With - Without)



Note: Small demersal fish are distributed based on depth, and salinity. The colour scale indicates values from low (blue) to high (red)

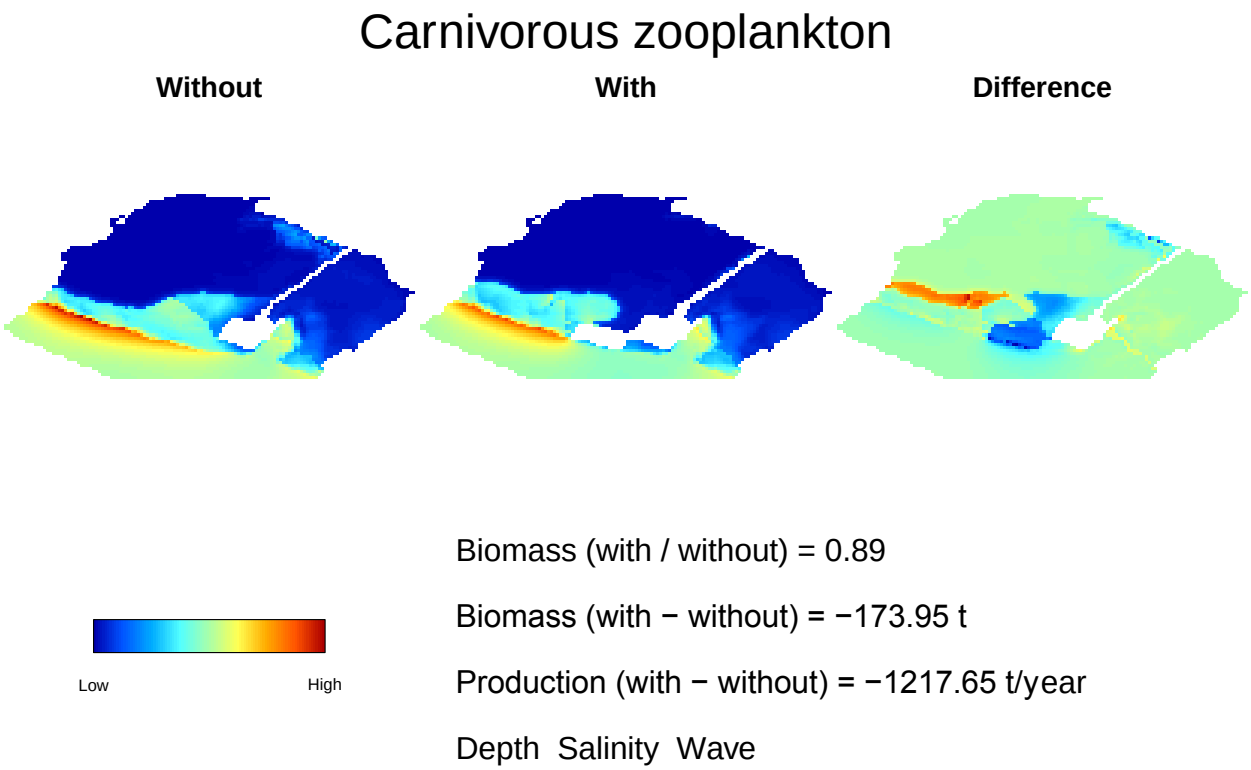
Figure A1.28 Mixed Trophic Impacts for Groups that have strongest relative Impact on Small Demersal Fish



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

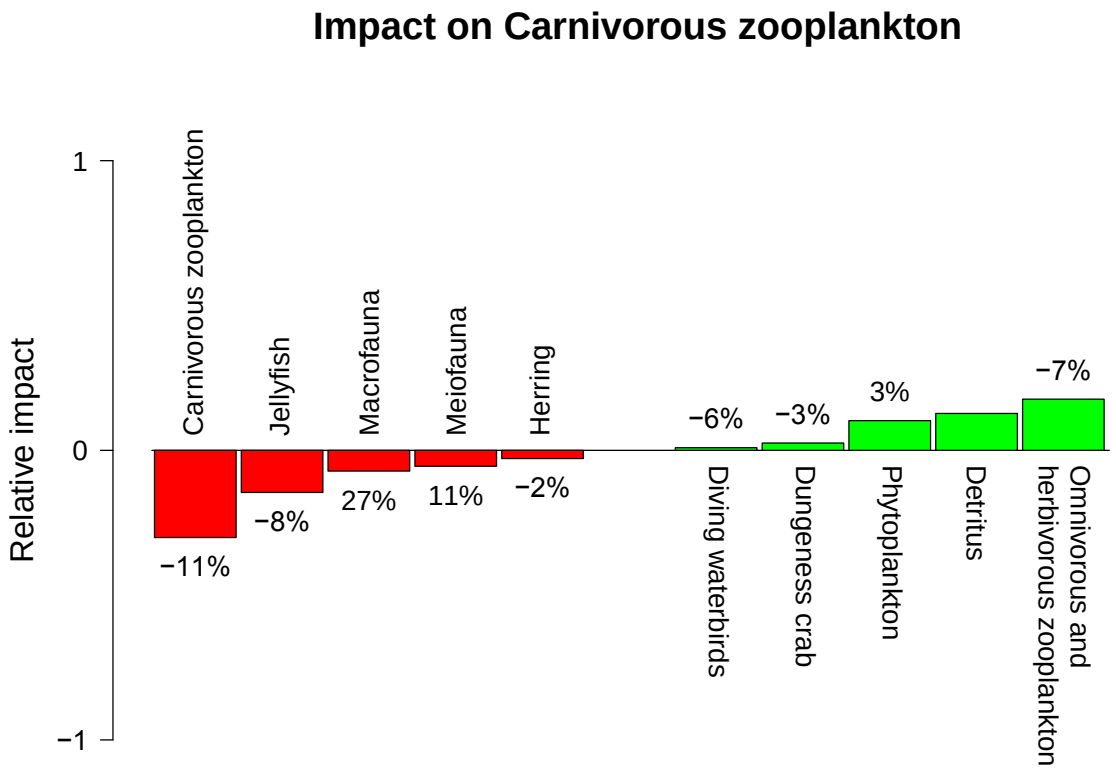
Carnivorous Zooplankton

Figure A1.29 Forecasted Biomass Distribution for Carnivorous Zooplankton, Without the Project, With the Project, and the Difference (With - Without)



Note: Carnivorous zooplankton is distributed based on depth, salinity, and wave height. The colour scale indicates values from low (blue) to high (red)

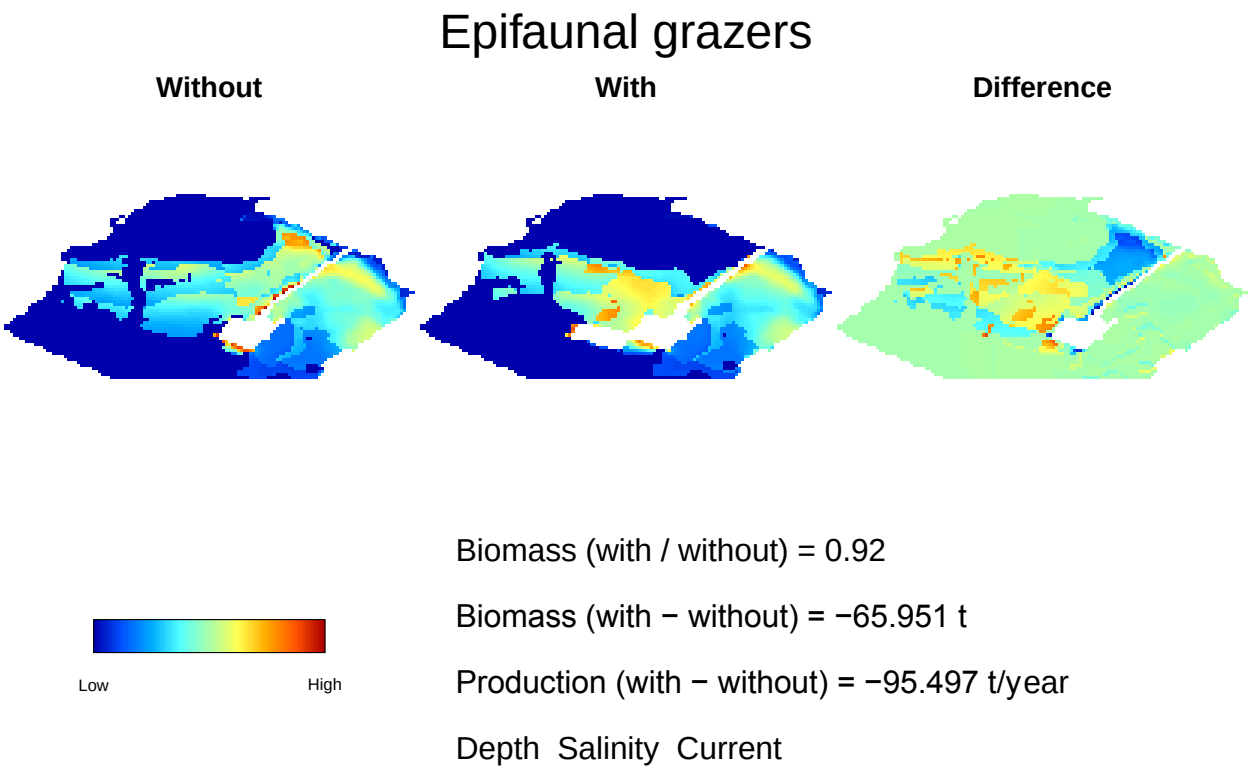
Figure A1.30 Mixed Trophic Impacts for Groups that have strongest relative Impact on Carnivorous Zooplankton



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

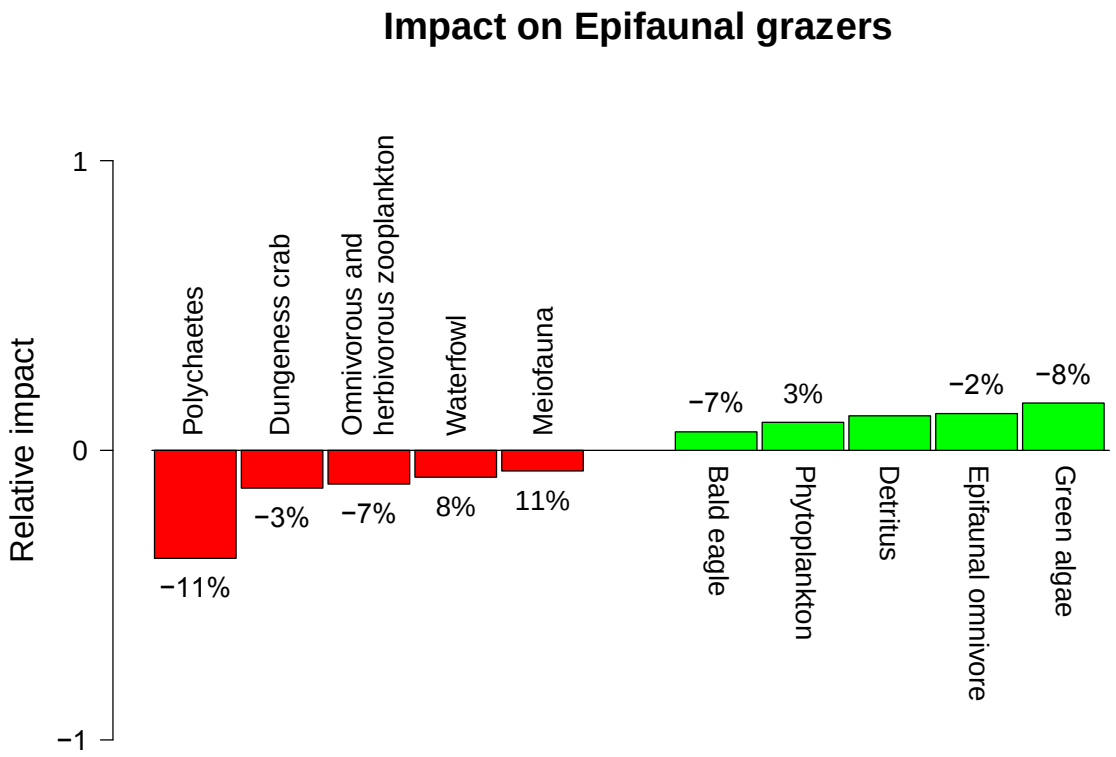
Epifaunal Grazers

Figure A1.31 Forecasted Biomass Distribution for Epifaunal Grazers, Without the Project, With the Project, and the Difference (With - Without)



Note: Epifaunal grazers are distributed based on depth, salinity, and bottom current. The colour scale indicates values from low (blue) to high (red)

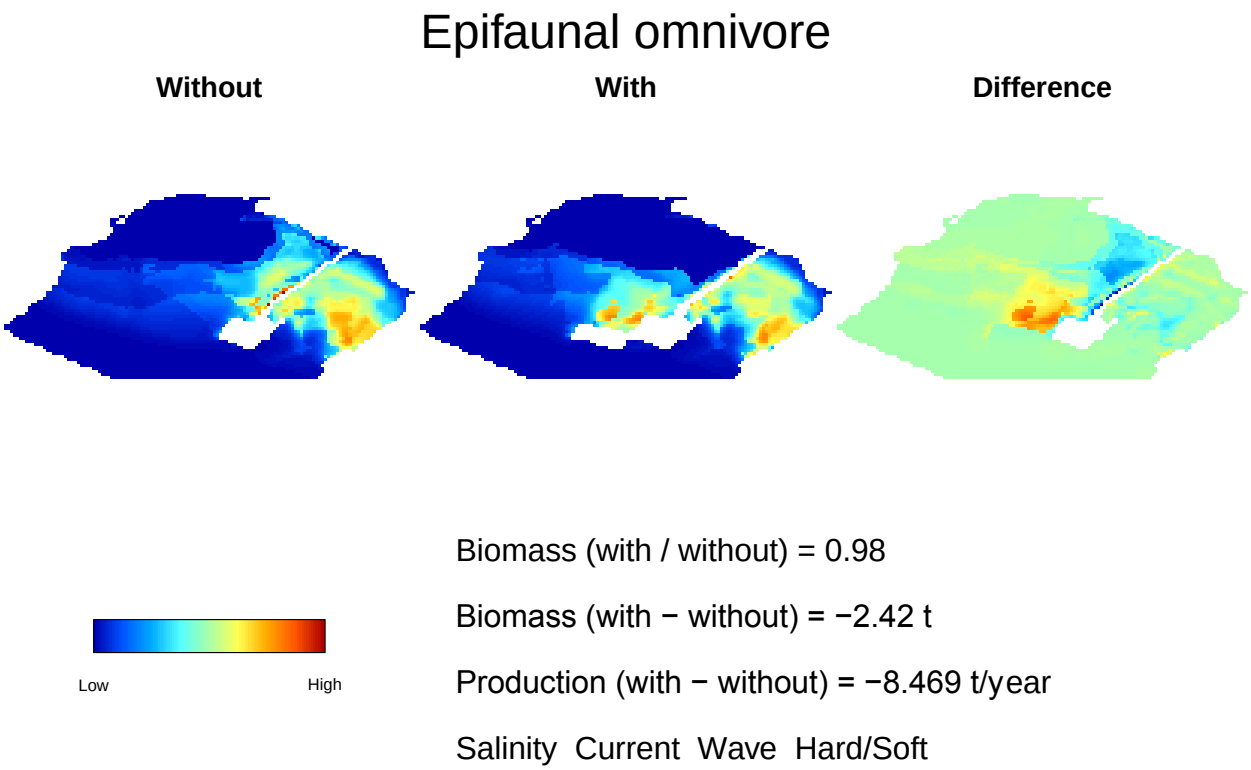
Figure A1.32 Mixed Trophic Impacts for Groups that have strongest relative Impact on Epifaunal Grazers



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

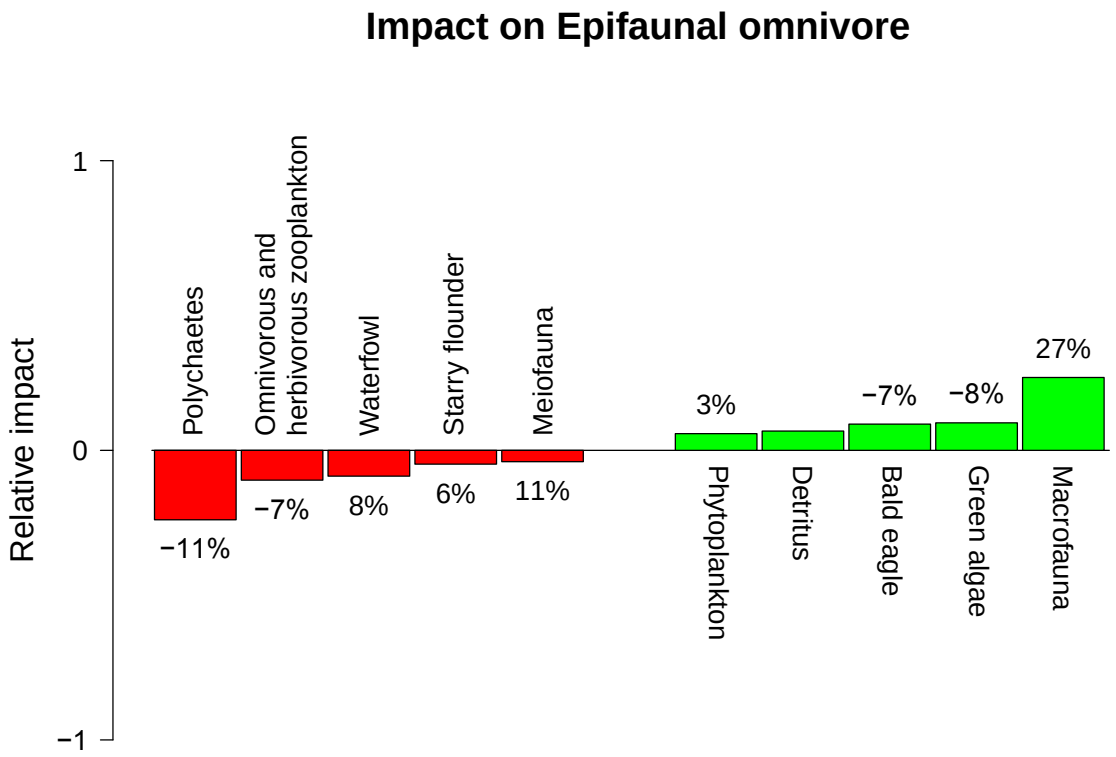
Epifaunal Omnivores

Figure A1.33 Forecasted Biomass Distribution for Epifaunal Omnivores, Without the Project, With the Project, and the Difference (With - Without)



Note: Epifaunal omnivores are distributed based on salinity, bottom current, wave height, and soft substrate. The colour scale indicates values from low (blue) to high (red)

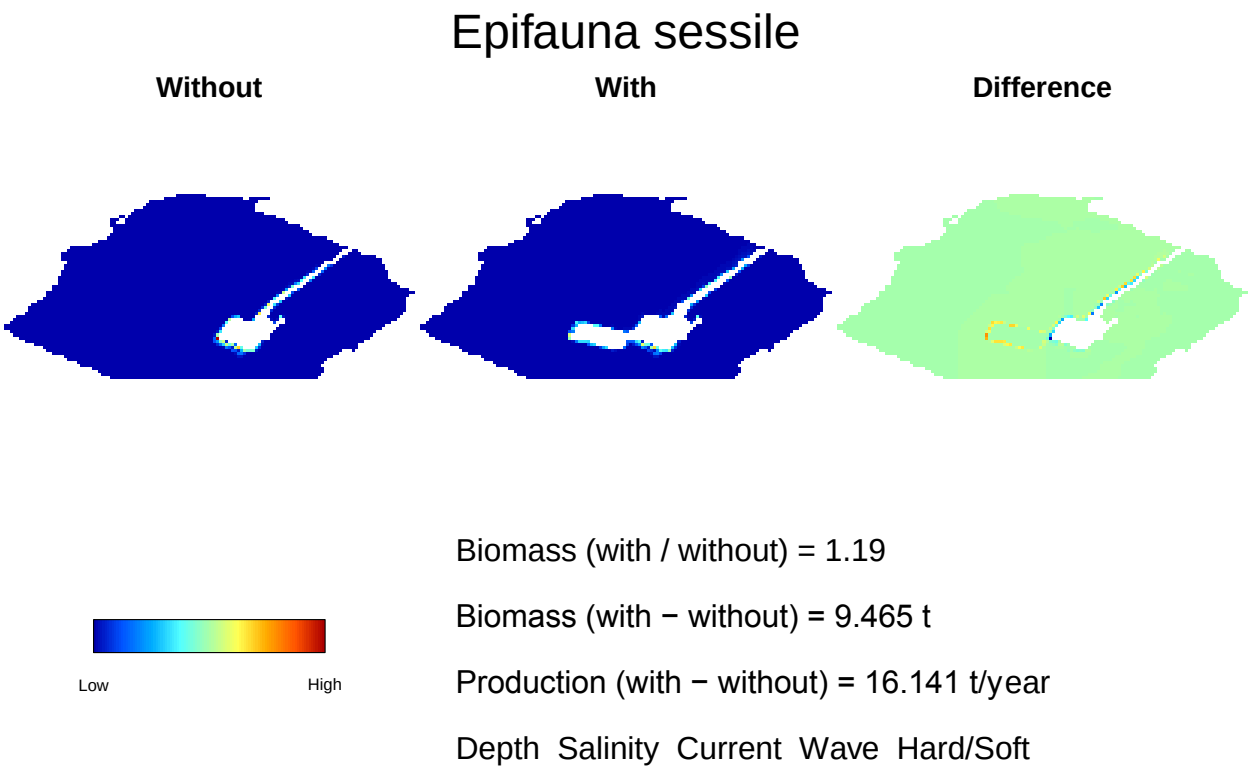
Figure A1.34 Mixed Trophic Impacts for Groups that have strongest relative Impact on Epifaunal Omnivores



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

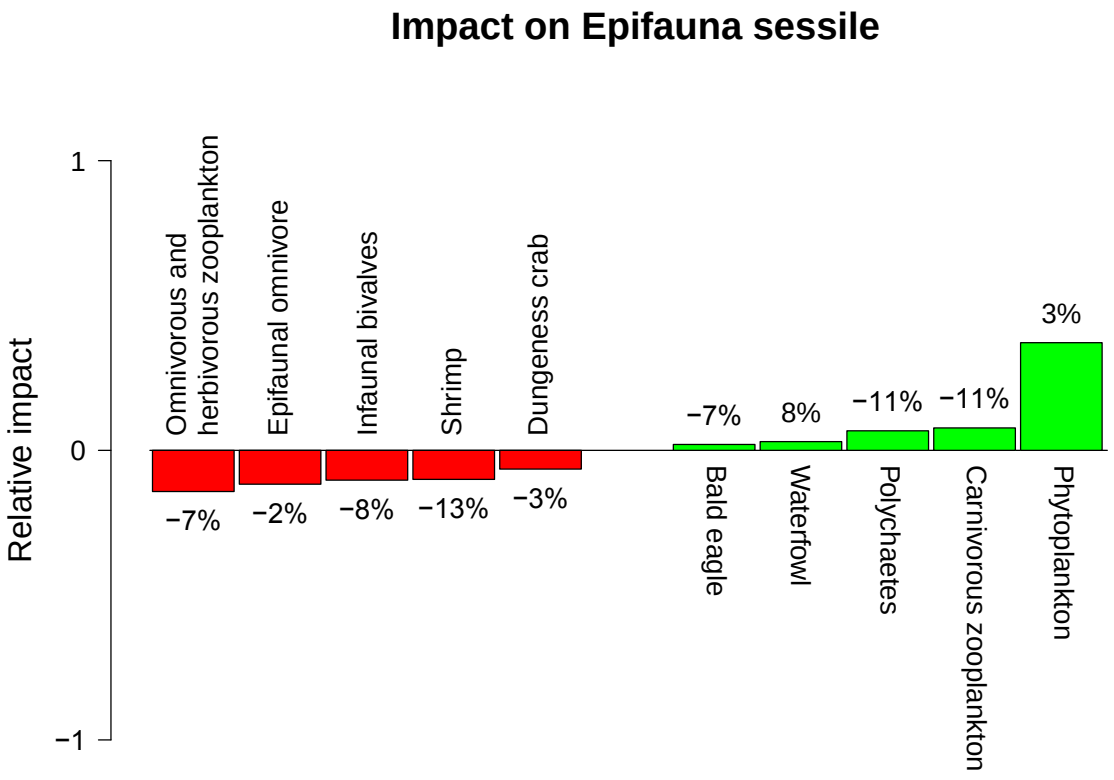
Epifauna Sessile Suspension Feeder

Figure A1.35 Forecasted Biomass Distribution for Epifaunal Sessile Suspension Feeders, Without the Project, With the Project, and the Difference (With - Without)



Note: Epifaunal sessile suspension feeders are distributed based on depth, salinity, bottom current, wave height, and soft substrate. The colour scale indicates values from low (blue) to high (red)

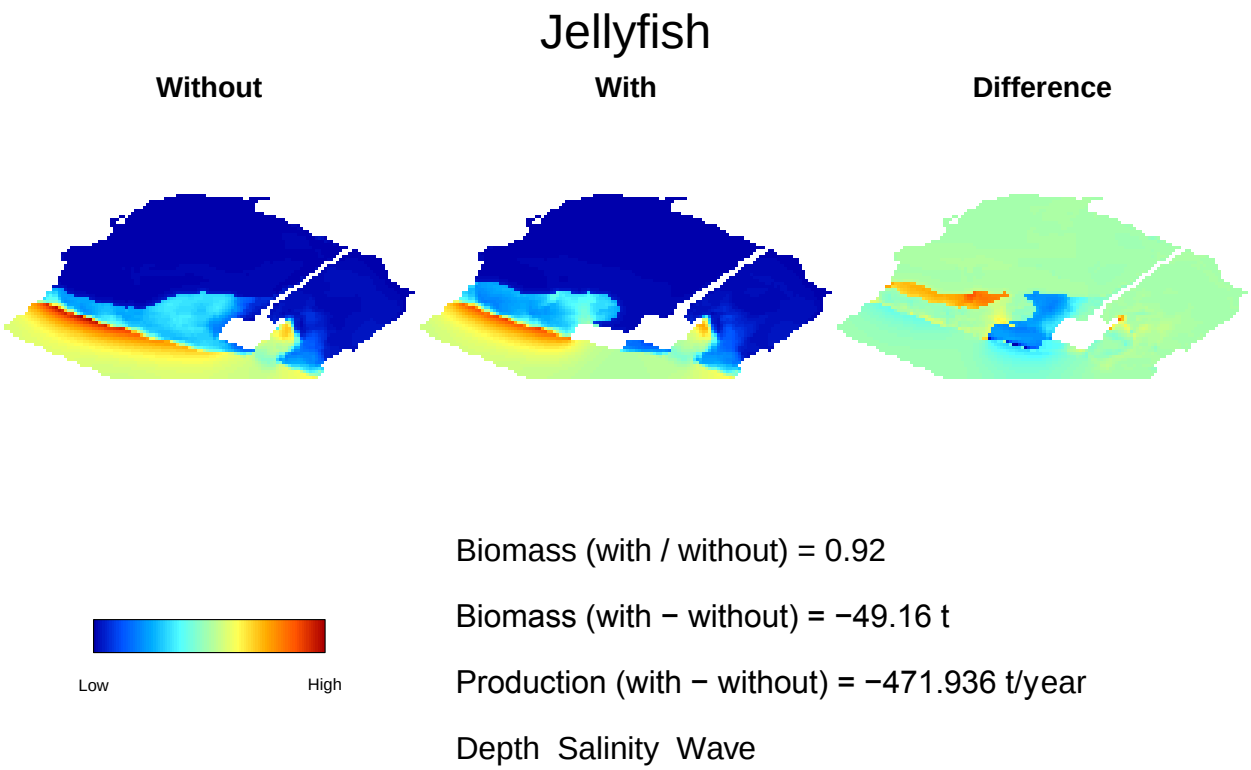
Figure A1.36 Mixed Trophic Impacts for Groups that have strongest relative Impact on Epifaunal Sessile Suspension Feeders



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

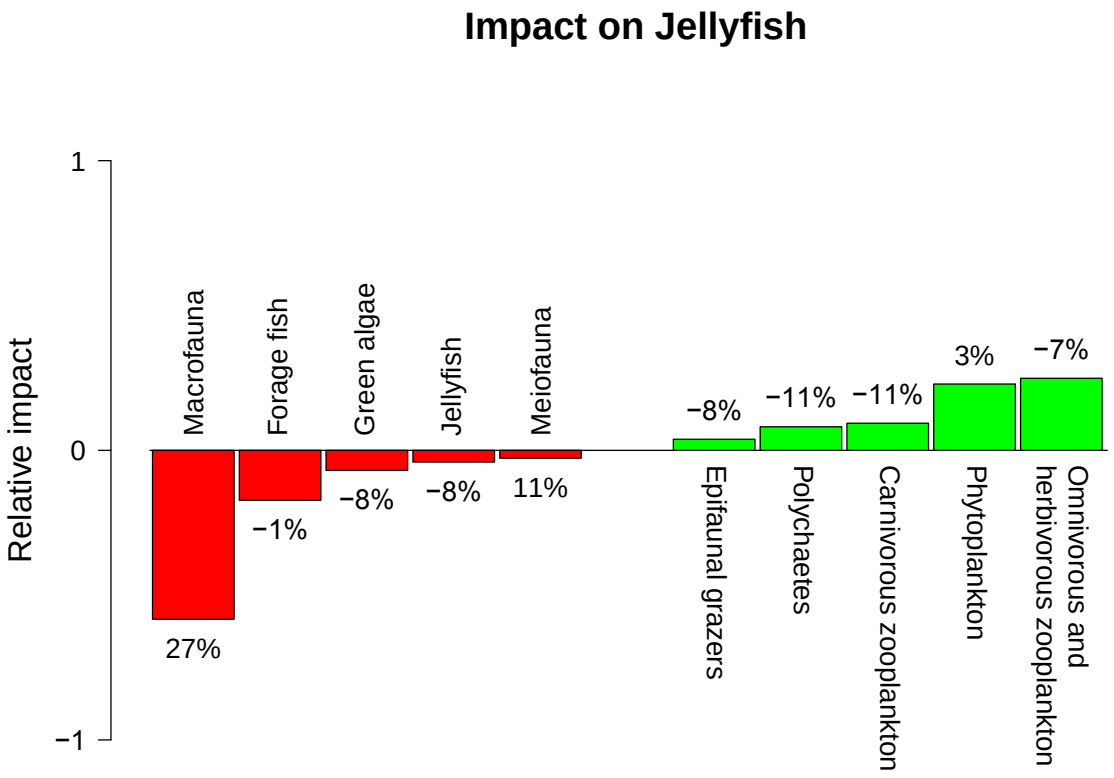
Jellyfish

Figure A1.37 Forecasted Biomass Distribution for Jellyfish, Without the Project, With the Project, and the Difference (With - Without)



Note: Jellyfish are distributed based on depth, salinity, and wave height. The colour scale indicates values from low (blue) to high (red)

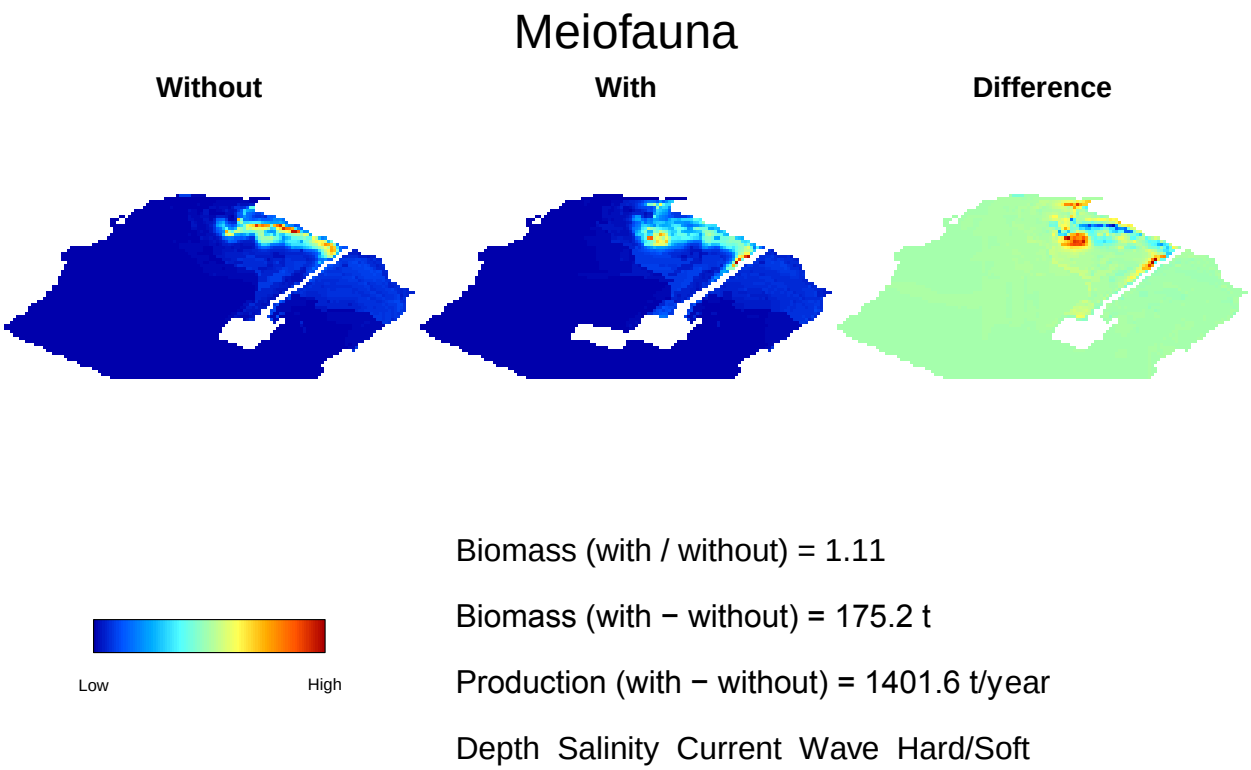
Figure A1.38 Mixed Trophic Impacts for Groups that have strongest relative Impact on Jellyfish



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

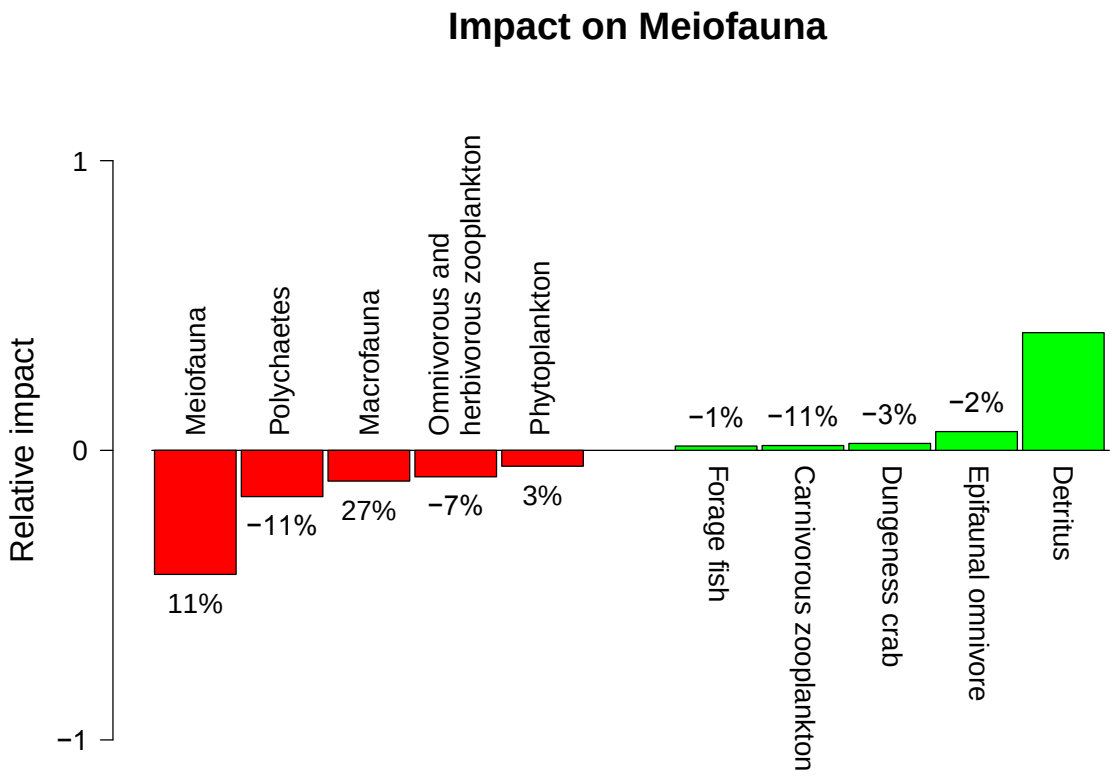
Meiofauna

Figure A1.39 Forecasted Biomass Distribution for Meiofauna, Without the Project, With the Project, and the Difference (With - Without)



Note: Meiofauna is distributed based on depth, salinity, bottom current, wave height, and soft substrate. The colour scale indicates values from low (blue) to high (red)

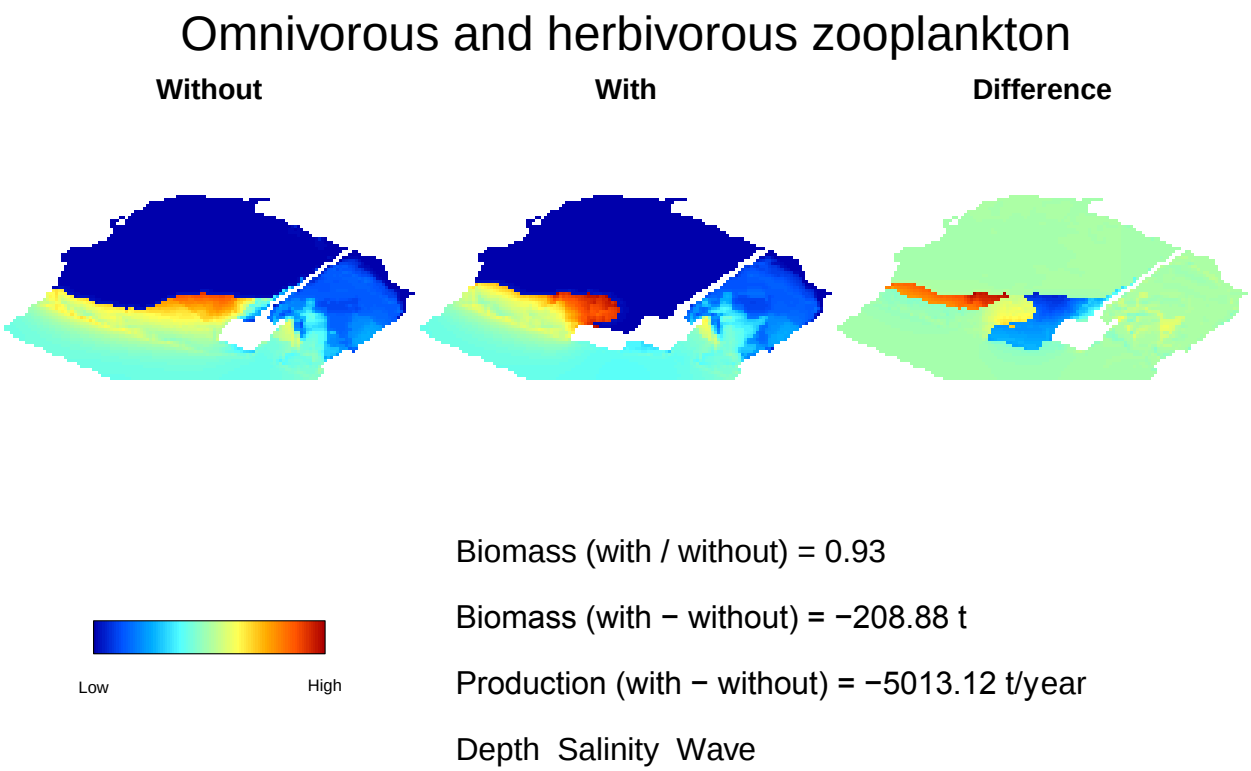
Figure A1.40 Mixed Trophic Impacts for Groups that have strongest relative Impact on Meiofauna



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

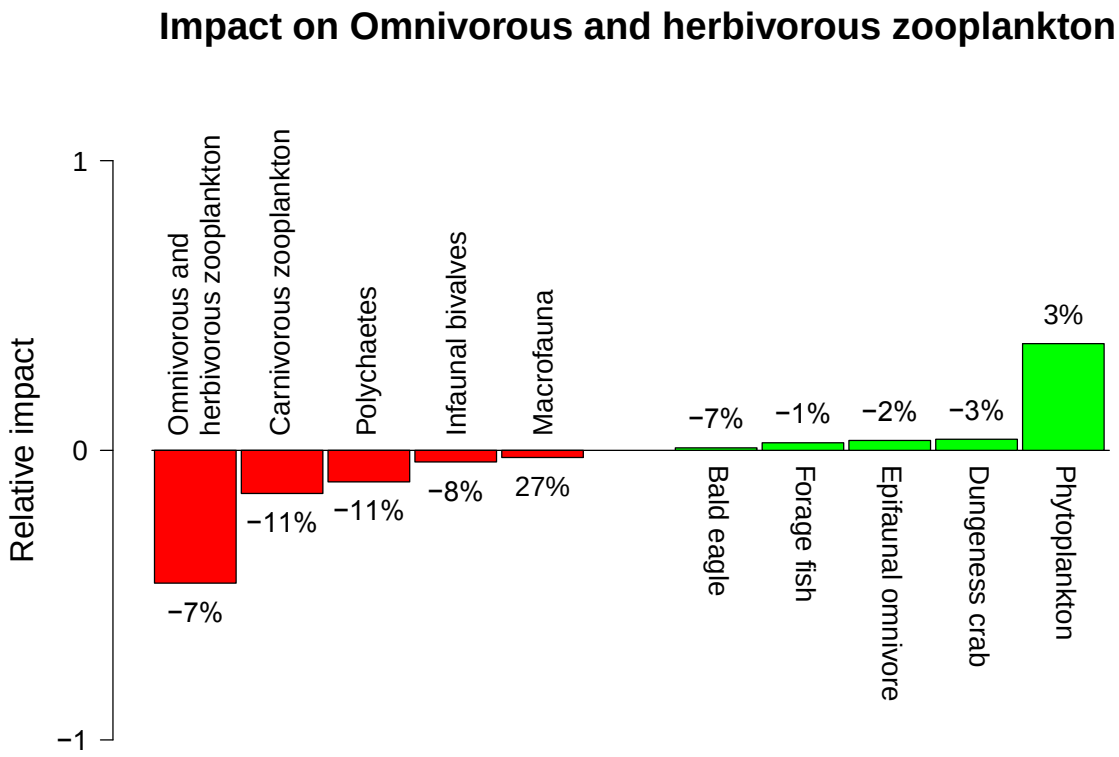
Omnivorous and Herbivorous Zooplankton

Figure A1.41 Forecasted Biomass Distribution for Omnivorous and Herbivorous Zooplankton, Without the Project, With the Project, and the Difference (With - Without)



Note: Omnivorous and herbivorous zooplankton is distributed based on depth, salinity, and wave height. The colour scale indicates values from low (blue) to high (red)

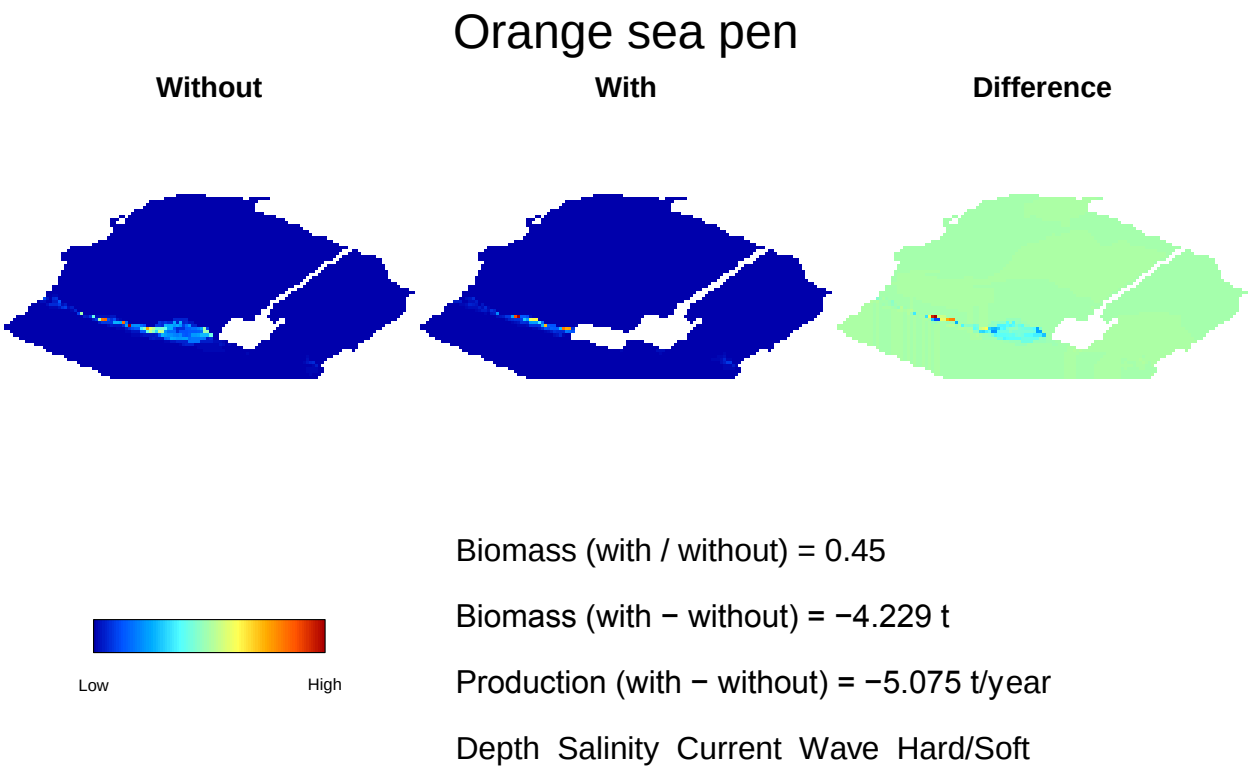
Figure A1.42 Mixed Trophic Impacts for Groups that have strongest relative Impact on Omnivorous and Herbivorous Zooplankton



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

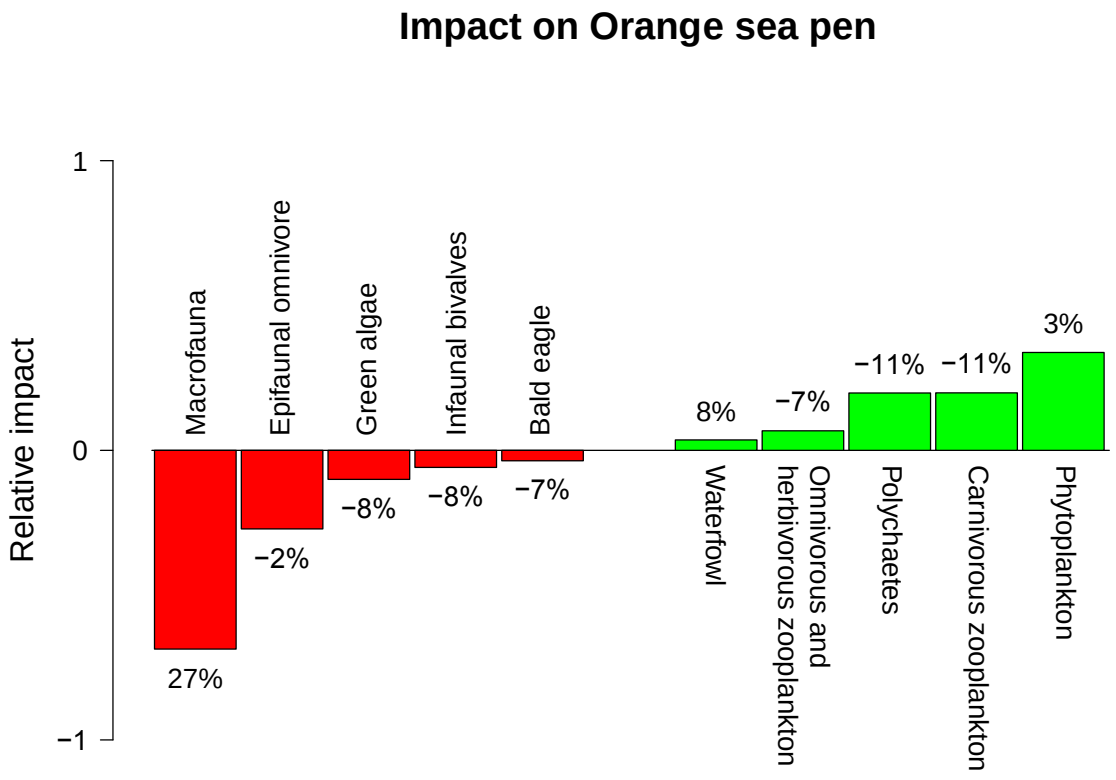
Orange Sea Pen

Figure A1.43 Forecasted Biomass Distribution for Orange Sea Pen, Without the Project, With the Project, and the Difference (With - Without)



Note: Orange sea pen is distributed based on depth, salinity, bottom current, wave height, and soft substrate. The colour scale indicates values from low (blue) to high (red)

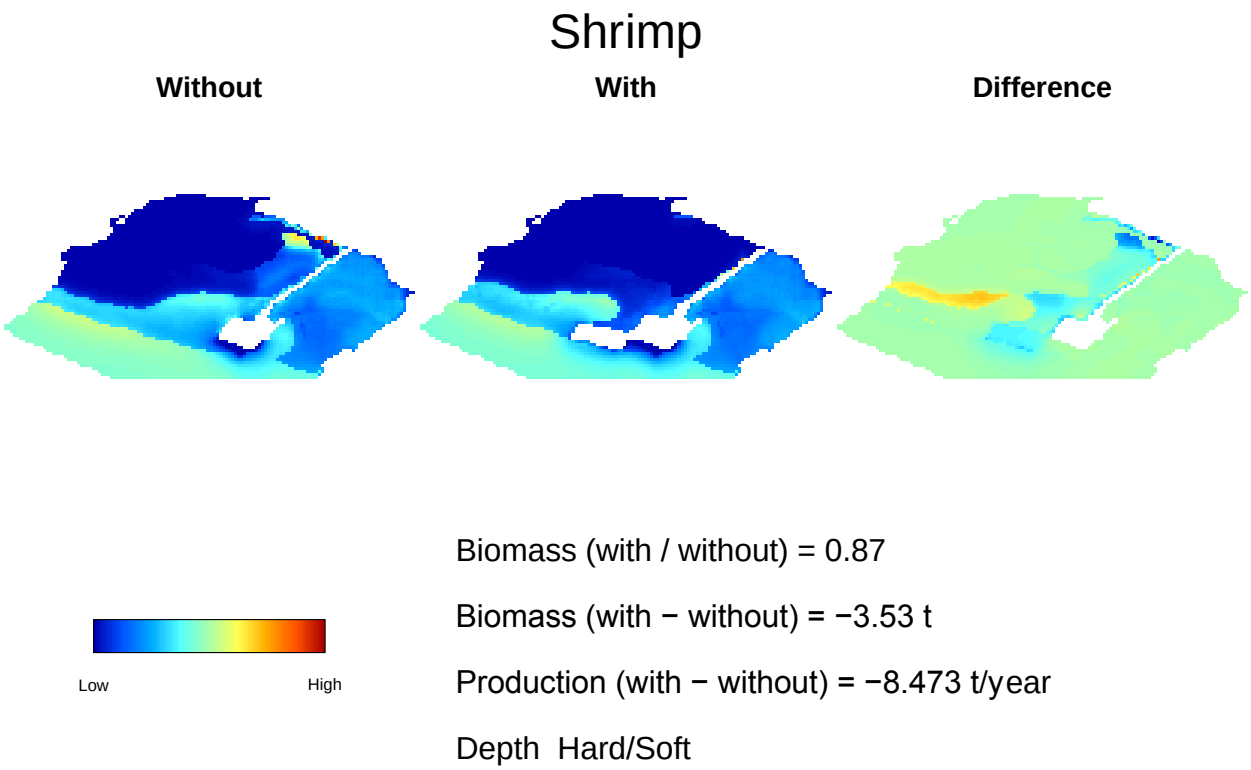
Figure A1.44 Mixed Trophic Impacts for Groups that have strongest relative Impact on Orange Sea Pen



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

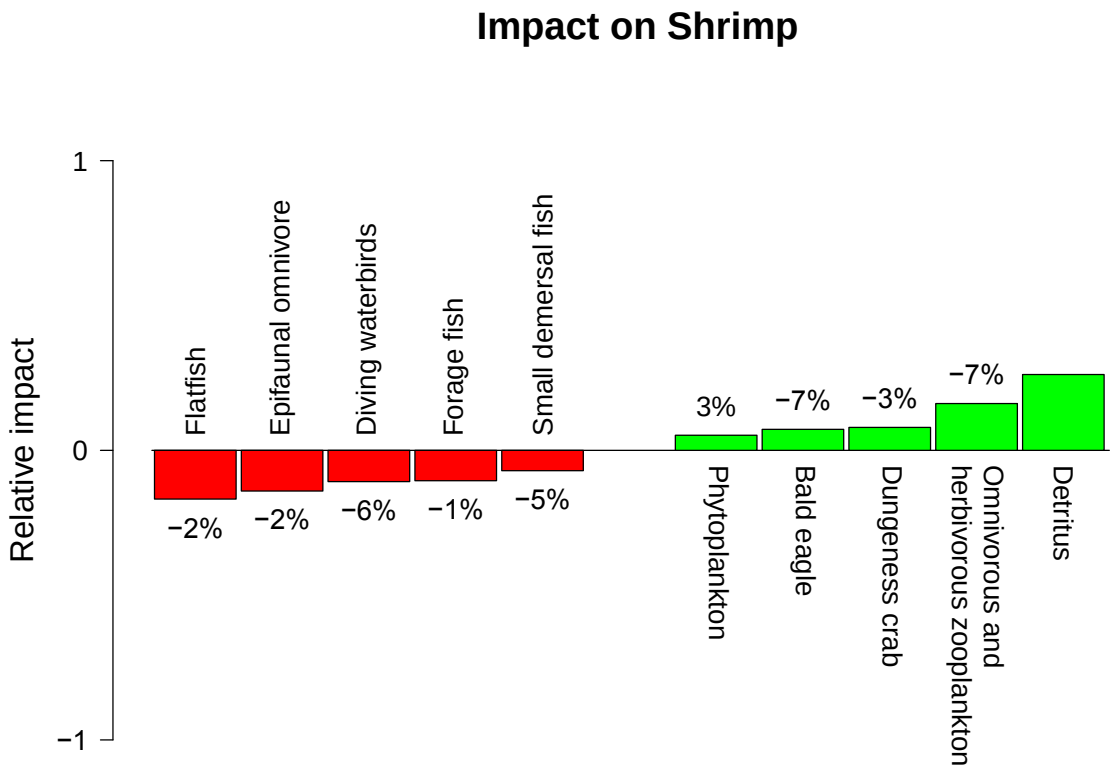
Shrimp

Figure A1.45 Forecasted Biomass Distribution for Shrimp, Without the Project, With the Project, and the Difference (With - Without)



Note: Shrimp is distributed based on depth, salinity, and soft substrate. The colour scale indicates values from low (blue) to high (red)

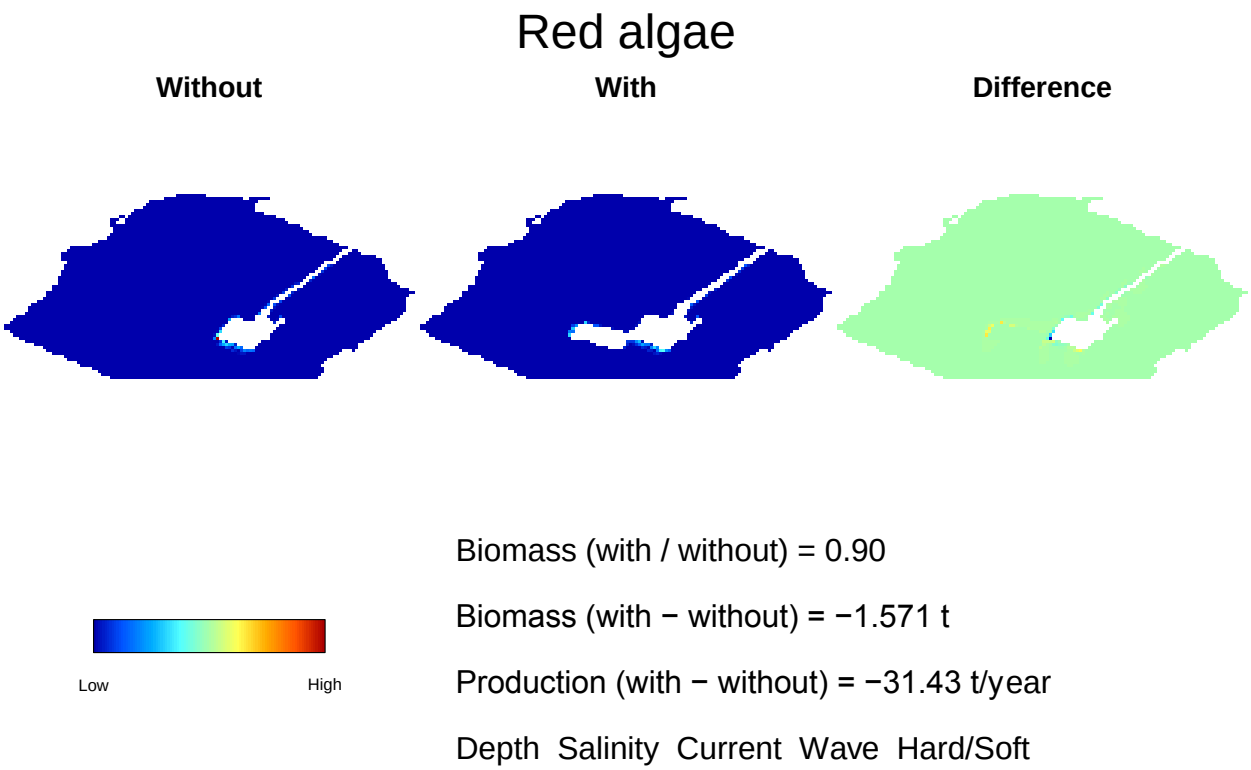
Figure A1.46 Mixed Trophic Impacts for Groups that have strongest relative Impact on Shrimp



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

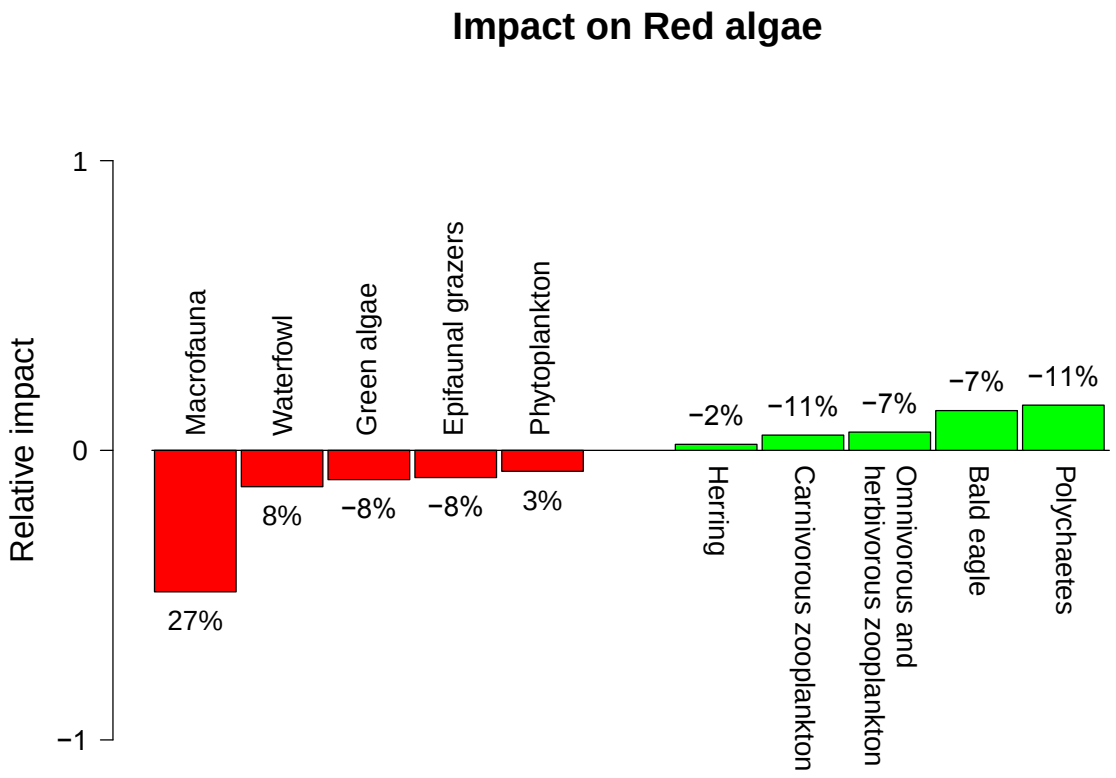
Red Algae

Figure A1.47 Forecasted Biomass Distribution for Red Algae, Without the Project, With the Project, and the Difference (With - Without)



Note: Red algae are distributed based on depth, salinity, bottom current, wave height, and hard substrate. The colour scale indicates values from low (blue) to high (red)

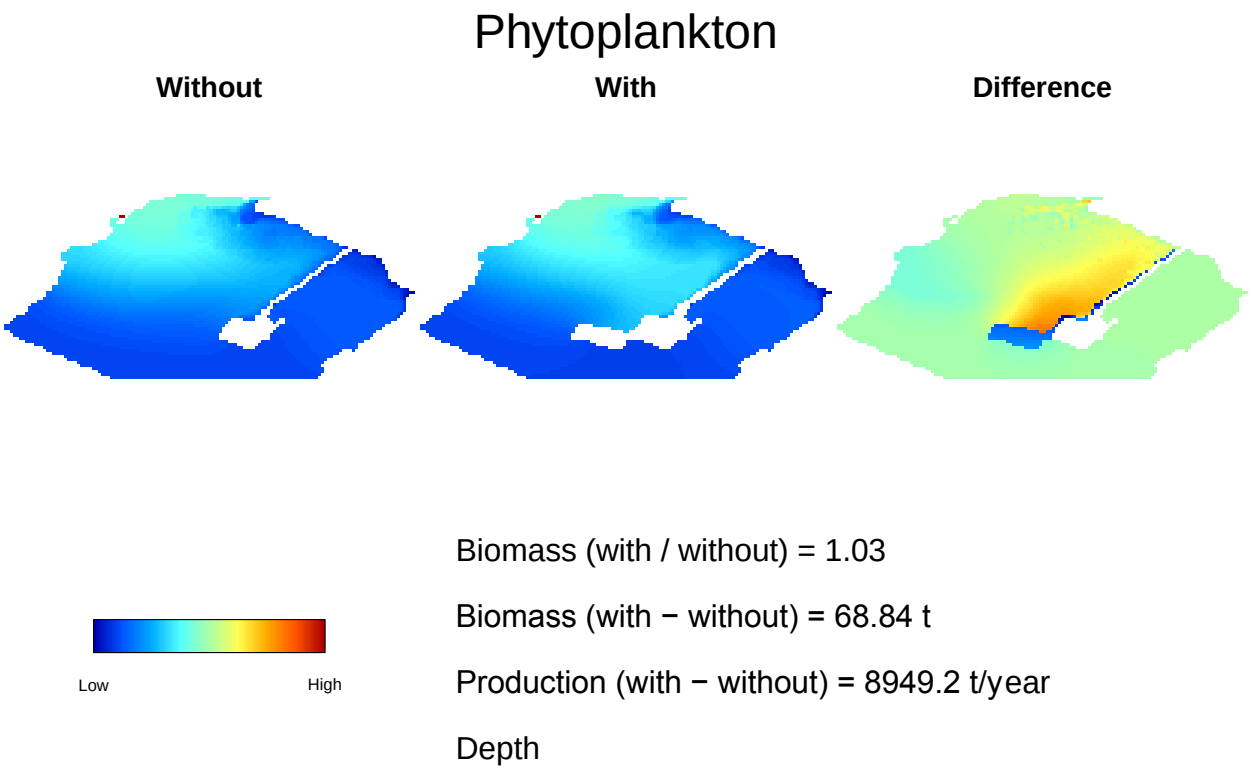
Figure A1.48 Mixed Trophic Impacts for Groups that have strongest relative Impact on Red Algae



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

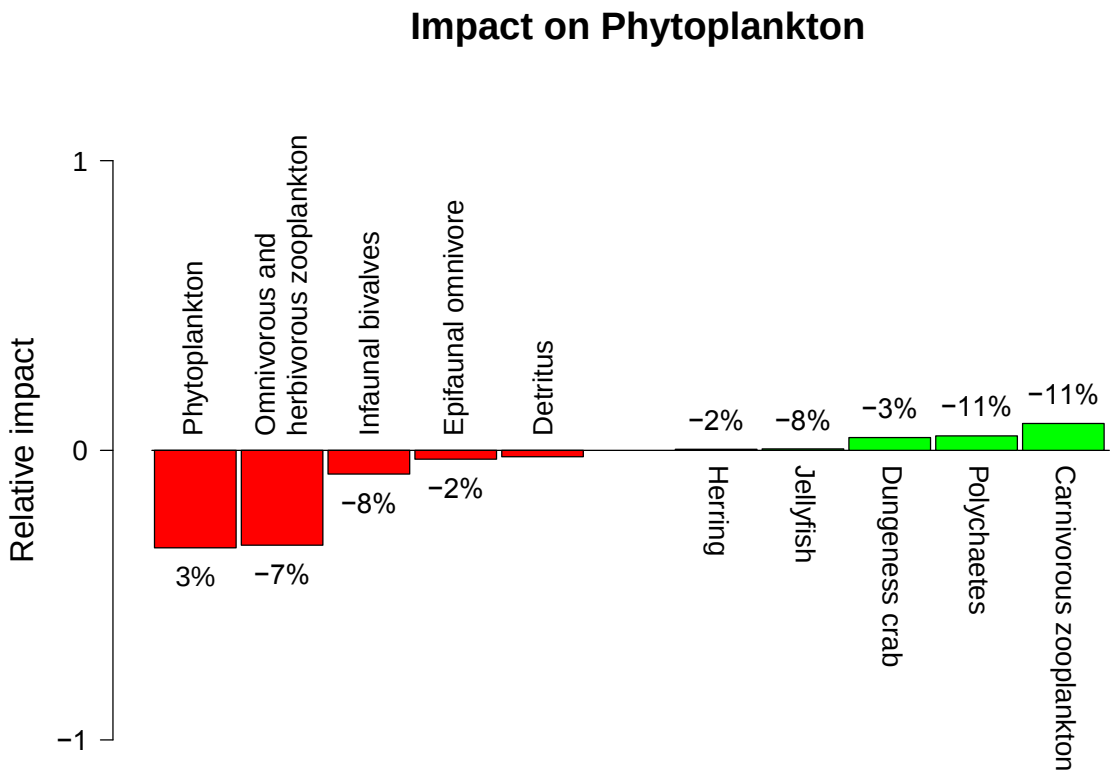
Phytoplankton

Figure A1.49 Forecasted Biomass Distribution for Phytoplankton, Without the Project, With the Project, and the Difference (With - Without)



Note: Phytoplankton is distributed based on depth. The colour scale indicates values from low (blue) to high (red)

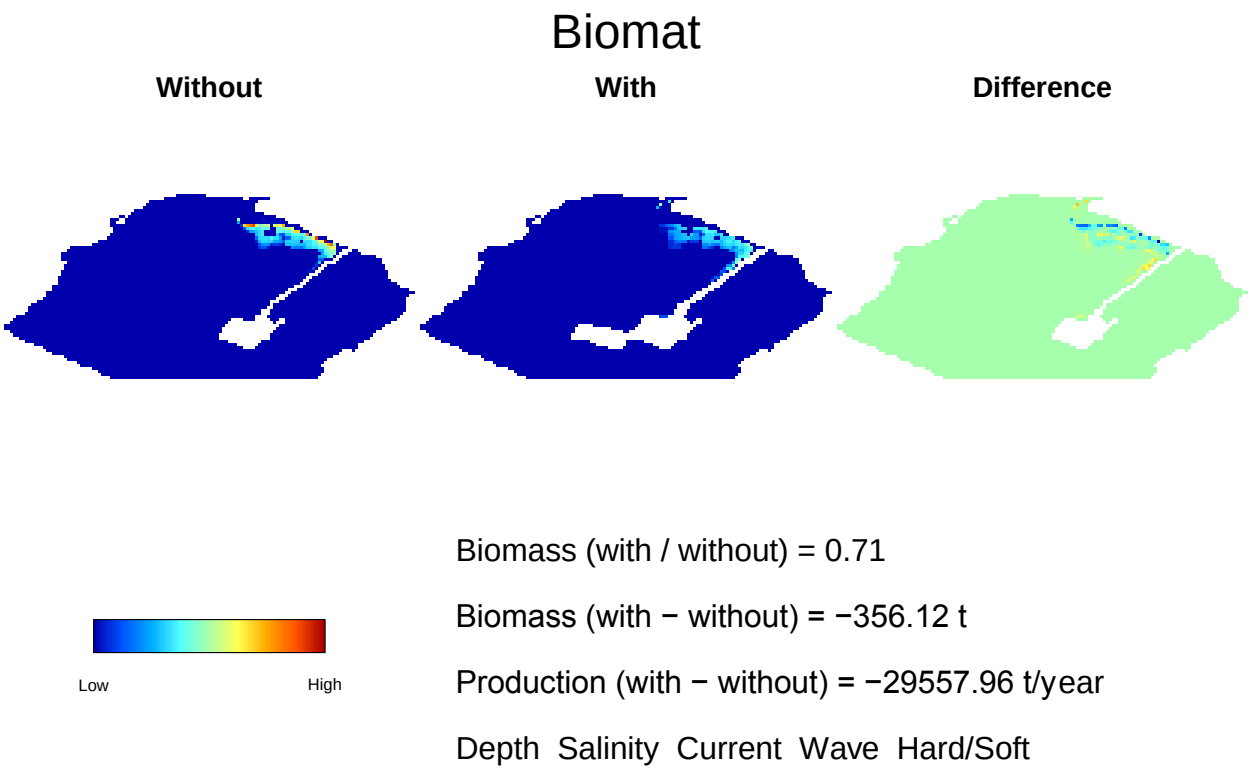
Figure A1.50 Mixed Trophic Impacts for Groups that have strongest relative Impact on Phytoplankton



Note: The percentages give the biomass ratio (with/without Project) for the impacting groups

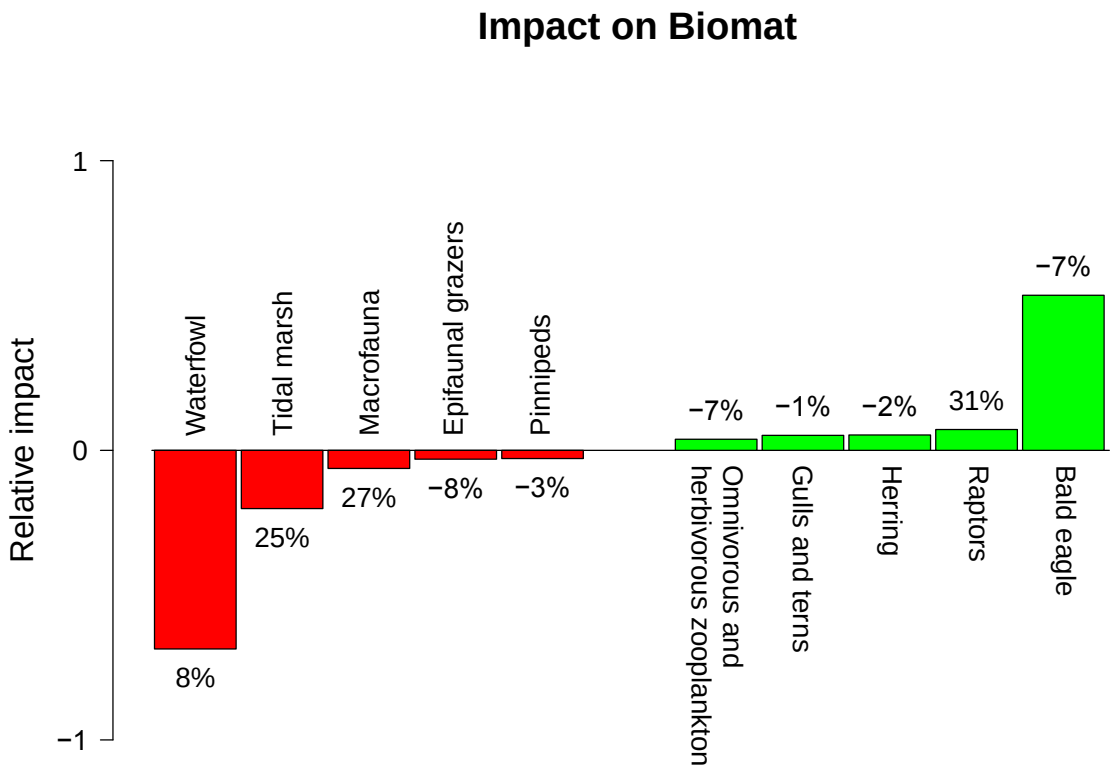
Biomat

Figure A1.51 Forecasted Biomass Distribution for Biomat, Without the Project, With the Project, and the Difference (With - Without)



Note: Biomat is distributed based on depth, salinity, bottom current, wave height, and soft substrate. The colour scale indicates values from low (blue) to high (red)

Figure A1.52 Mixed Trophic Impacts for Groups that have strongest relative Impact on Biomat



Note: The percentages give the biomass ratio (with/without Project) for the impacting group

APPENDIX 10-D

Roberts Bank Spatial Ecosystem Model Sensitivity Analysis

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Roberts Bank Ecosystem Model Sensitivity Analyses

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December 2014

TECHNICAL REPORT/TECHNICAL DATA REPORT DISCLAIMER

The Canadian Environmental Assessment Agency determined the scope of the proposed Roberts Bank Terminal 2 Project (RBT2 or the Project) and the scope of the assessment in the Final Environmental Impact Statement Guidelines (EISG) issued January 7, 2014. The scope of the Project includes the project components and physical activities to be considered in the environmental assessment. The scope of the assessment includes the factors to be considered and the scope of those factors. The Environmental Impact Statement (EIS) has been prepared in accordance with the scope of the Project and the scope of the assessment specified in the EISG. For each component of the natural or human environment considered in the EIS, the geographic scope of the assessment depends on the extent of potential effects.

At the time supporting technical studies were initiated in 2011, with the objective of ensuring adequate information would be available to inform the environmental assessment of the Project, neither the scope of the Project nor the scope of the assessment had been determined.

Therefore, the scope of supporting studies may include physical activities that are not included in the scope of the Project as determined by the Agency. Similarly, the scope of supporting studies may also include spatial areas that are not expected to be affected by the Project.

This out-of-scope information is included in the Technical Report (TR)/Technical Data Report (TDR) for each study, but may not be considered in the assessment of potential effects of the Project unless relevant for understanding the context of those effects or to assessing potential cumulative effects.

EXECUTIVE SUMMARY

The Roberts Bank Terminal 2 Project (RBT2 or Project) is a proposed new three-berth marine terminal at Roberts Bank in Delta, B.C. that could provide 2.4 million TEUs (twenty-foot equivalent unit containers) of additional container capacity annually. The Project is part of Port Metro Vancouver's Container Capacity Improvement Program, a long-term strategy to deliver projects to meet anticipated growth in demand for container capacity to 2030. RBT2 is subject to a federal environmental assessment (EA) by an independent review panel under the *Canadian Environmental Assessment Act, 2012*. As part of the Project's environmental studies program undertaken in advance of the environmental assessment, PMV established a **Productive Capacity Technical Advisory Group** (PC-TAG) that gathered scientific and technical expertise to evaluate how the productive potential of Roberts Bank can most appropriately be defined from an ecological perspective and how changes in habitat productivity as a result of RBT2 can be quantified.

The PC-TAG agreed Ecopath with Ecosim (EwE), an ecosystem modelling software package, was an appropriate methodology to quantify the productive potential of the area. Hemmera developed the required inputs for the **Roberts Bank ecosystem model** (Hemmera 2014). ESSA described the methodology for evaluating changes in productivity, and results of the Roberts Bank ecosystem model's key run (measured in biomass and production) (ESSA 2014). The present report builds on this work to evaluate the uncertainty in model forecasts that may influence the Project's EA.

Most of the **functional groups** used in the Roberts Bank ecosystem model were robust to changes in biotic factors (specifically, density dependence). Thirty-three of 53 groups assessed for changes in biomass showed a difference of 2% or less in biomass ratio **with** versus **without** Project in alternate scenarios of density dependence. Thirteen groups showed a significant difference in biomass (i.e. 5% or more) under alternative scenarios of density dependence: meiofauna (0.05), starry flounder (0.05), sandlance (0.05), waterfowl (0.06), juvenile chum (0.06), dungeness crab (0.07), juvenile chinook (0.08), macrofauna (0.09), shiner perch (0.09), rockfish (0.09), epifaunal sessile suspension feeders (0.13), raptors (0.14) and lingcod (0.22).

The Roberts Bank ecosystem model relies on forecasts of how five abiotic factors (depth, salinity, bottom current, wave height, and hard/soft bottom) may change as a result of RBT2, and how this could affect the functional and **aggregated groups** in the ecosystem

(NHC 2014, ESSA 2014). In the context of Project-related change on the Roberts Bank ecosystem, the sensitivity analyses considered:

1. Increases and decreases in the predators' ability to influence prey dynamics;
2. The effects of omitting one abiotic factor at a time for each functional group;
3. 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
4. Sensitivity to input parameter uncertainty through a Monte Carlo approach, where input parameters were drawn randomly from distributions that reflected their uncertainty.

These sensitivity analyses demonstrated the degree to which abiotic and biotic factors can influence functional group biomass in both direct and indirect ways. In general, the Roberts Bank ecosystem model forecasts were robust to the four sensitivity analyses. Most aggregated groups showed only insignificant biomass responses (i.e. less than 5% difference) to the proposed Project when abiotic factors were varied. However, larger responses were observed for the Roberts Bank Ecosystem (≤7%), birds (≤12%), and primary producers (≤12%). Some functional groups were more sensitive to variation in abiotic factors than the ecological guild they are part of. These sensitivity analyses demonstrate the importance of these abiotic factors in directly or indirectly affecting the biomass responses of different organisms. The most sensitive functional groups, i.e. those with a change in biomass ratio of more than 10% when an abiotic factor was omitted, and the abiotic factors to which their biomass responses were sensitive, included:

- Freshwater biofilm (salinity, wave height, bottom current, depth)
- Tidal marsh (depth, salinity, wave height)
- Orange sea pens (depth)
- Red algae (depth, salinity, hard substrate)
- Native eelgrass (salinity, wave height, bottom current)
- Epifaunal grazers (salinity)

- Brown algae (depth, salinity)
- Marine biofilm (wave height, depth)
- Macrofauna (salinity, bottom current)
- Epifaunal omnivore (salinity)
- Biomat (depth, bottom current)
- Epifauna sessile (salinity, hard substrate)
- Small demersal fish (salinity)
- Shrimp (salinity)
- Rockfish (depth)
- Polychaetes (wave height)
- Lingcod (depth)
- Japanese eelgrass (wave height, salinity)
- Raptors (salinity)
- Green algae (wave height, salinity)
- Dungeness crab (depth)
- Large demersal fish (salinity)

The present study evaluates the effect of sources of uncertainty on the forecasted changes in ecosystem productivity as a result of the Project. A more complex evaluation of the combined effects of various uncertainties was not performed.

Other limitations were in assumptions that: 1) the current geographic distributions of the functional groups reflect their environmental preferences; and 2) these distributions and preferences are directly linked to their potential productivity in the study area. The sensitivity tests that are reported here indicated that the model forecasts were robust to uncertainties in various model inputs.

The key run of the Roberts Bank ecosystem model forecasted that for most functional groups the proposed Project would result in variable changes of limited magnitude (ESSA 2014). The evaluations of uncertainty in the present report did not substantively change the findings from the key run report (ESSA 2014).

Overall the conclusions from the ecosystem modelling studies are that the proposed Project will have an impact on the study area, that the effect varies between species, and that the findings are robust to parameter uncertainty.

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LIST OF ACRONYMS

EA	environmental assessment
ESSA	ESSA Technologies Ltd.
EwE	Ecopath with Ecosim and Ecospace, ecosystem modelling approach and framework
NHC	Northwest Hydraulic Consultants
P/B	production/biomass ratio
PC-TAG	Productive Capacity Technical Advisory Group
PMV	Port Metro Vancouver
Project	Roberts Bank Terminal 2 Project (Project interchangeable with RBT2)
RBT2	Roberts Bank Terminal 2 Project (RBT2 interchangeable with Project)

SYMBOLS, MEASUREMENTS AND ABBREVIATIONS

%	percent
g	gram
km	kilometre
m	metre
pct	percentile
psu	practical salinity units
t	tonnes (metric)

GLOSSARY

aggregated group	A collection of functional groups. Six aggregated groups were defined for this study: • Birds: American wigeon, bald eagle, brant goose, diving waterbirds, dunlin, Great blue heron, gulls/terns, raptors, shorebirds, waterfowl and western sandpiper • Fish: chinook adult, chinook juvenile, chum adult, chum juvenile, salmon adult (not including chinook and chum), salmon juvenile (not including chinook and chum), dogfish, flatfish, forage fish, herring, large demersal fish, lingcod, rockfish, sandlance, shiner perch, skate, small demersal fish and starry flounder • Invertebrates: carnivorous zooplankton, Dungeness crab, epifaunal grazers, epifaunal omnivores, epifauna sessile suspension feeder, infaunal bivalve, jellyfish, macrofauna, meiofauna, omnivorous and herbivorous zooplankton, polychaetes, orange sea pen and shrimp • Primary Producers: freshwater and marine biofilm, brown algae, native eelgrass (*Z. marina*), green algae, non-native eelgrass (*Z. japonica*), red algae, phytoplankton, tidal marsh and biomat • CRA Fisheries: (chinook adult, chinook juveniles, chum adult, chum juveniles, forage fish, herring, lingcod, rockfish, Dungeness crab, infaunal bivalves and shrimp • Roberts Bank ecosystem: all functional groups except detritus • Marine mammals are included in the EwE model for their important role as top predators, but the EwE model is not being used to assess effects to marine mammals. For more information, see Section 14.0 Marine Mammals.
biomass (B)	The mass of living tissue in either an individual or cumulatively across organisms in a population or ecosystem. Expressed as mass per unit area (t km^{-2} = g m^{-2}) or total mass (t) over the study area (54.68 km^2).
biomass ratio (with/without Project)	Indicator for if biomass of a functional or aggregated group increased or decreased with the Project relative to without the Project. The ratio is calculated as the biomass for a functional or aggregated group 'with Project' divided by the biomass 'without Project'. A ratio below 1 indicates a decrease in biomass with the Project.
consumption/biomass ratio Q/B ($year^{-1}$)	The amount of food consumed by a group relative to its biomass over a period of time and is expressed as the ratio of consumption (Q) over biomass (B). Absolute consumption (Q) is defined as a flow and expressed in t/km^2/yr; B is the amount of biomass per area, resulting in Q/B being expressed as per year ($year^{-1}$).

CRA fisheries	Commercial, recreational and Aboriginal fisheries. A collection of functional groups of economic importance (see aggregated groups for definition). The functional groups supporting the CRA fisheries are not included since they are considered through the Roberts Bank ecosystem model diet matrix.
functional group	Species or collections of species that share similar life history traits and ecological function. The functional group is a modelling unit, which can consist of a group with similar ecological characteristics, (e.g., rockfish), a species, (e.g., bald eagle), or a life stage (e.g., juvenile chum salmon)
Monte Carlo (MC)	The Monte Carlo approach evaluated uncertainty by iteratively drawing input parameters from an assumed distribution and parameter uncertainty.
pedigree	Indicator for how well-rooted the model is in local data (no unit; range is [0, 1] with 1 being fully based on local, high quality data)
production (P)	Elaboration of tissue (whether it survives or not) by a group over the period considered. In ecosystem modelling, a ratio of production over biomass is used (P/B; both expressed in the same units), which is equivalent to total mortality (Z). In the Ecopath model, production is estimated as the sum of the predation mortality, fishing mortality, net migration, biomass accumulation, and other mortality terms.
production/biomass ratio (P/B) ($year^{-1}$)	Elaboration of tissue (whether it survives or not) by a group over the period considered. In ecosystem modelling, a ratio of production over biomass is used (P/B; both expressed in the same units), which is equivalent to total mortality (Z).
production ratio (with/without Project)	Indicator of whether production of a functional or aggregated group increased or decreased with the Project relative to without the Project. The ratio is calculated as the group production 'with Project' divided by the group production 'without Project'. A ratio below 1 indicates a decrease in production with the Project.
Roberts Bank ecosystem model	Refers to the EwE model of the Roberts Bank study area.
with	Used to describe analysis with the proposed RBT2.
without	Used to describe analysis of simulations without the proposed RBT2 (i.e., modelled existing conditions).

1.0 INTRODUCTION

The Roberts Bank Terminal 2 Project (RBT2 or Project) is a proposed new three-berth marine terminal at Roberts Bank in Delta, B.C. that could provide 2.4 million TEUs (twenty-foot equivalent unit containers) of additional container capacity annually. The Project is part of Port Metro Vancouver's (PMV) Container Capacity Improvement Program, a long-term strategy to deliver projects to meet anticipated growth in demand for container capacity to 2030. RBT2 is subject to a federal EA by an independent review panel under the *Canadian Environmental Assessment Act, 2012*. As part of the environmental studies program undertaken in advance of the environmental assessment, PMV established a PC-TAG that gathered scientific and technical expertise to evaluate how the productive capacity of Roberts Bank can be ecologically defined, and how changes in productivity as a result of the proposed RBT2 can be quantified.

The PC-TAG evaluated the suitability of alternative modelling approaches for these tasks, and selected the spatial module (Ecospace) of the EwE modelling complex to evaluate potential changes in productivity as a result of the proposed Project. Given that Roberts Bank is a productive, high biodiversity area with freshwater, estuarine and marine environments, the PC-TAG selected 25 focal species to assess potential changes in productivity related to the proposed Project. The focal species were drawn from all trophic levels. During the modelling process, it was determined that juvenile and adult life stages of chinook and chum salmon were more appropriately modelled as individual groups, due to differences in life history patterns and diet. Also, biofilm was divided into two communities: freshwater and marine. This resulted in a total of 28 focal species.

The first stage in constructing the Roberts Bank ecosystem model is the development of a representation of the food web that provides an overview of the ecological resources at Roberts Bank. The Roberts Bank ecosystem model included 58 functional groups. The modelled functional groups include the PC-TAG focal species (Hemmera 2014). The functional groups included single species (e.g., western sandpiper), life stages of a species (e.g., juvenile and adult chinook salmon), and broad functional groups of two or more ecologically similar species (e.g., forage fish). The Roberts Bank Ecosystem Model Parameter Estimates report provides input data and parameters for the dynamic and spatial modelling, as well as other information that was needed to construct the environmental preference functions (Hemmera 2014).

The second stage of ecosystem modelling was the development of a spatial model of Roberts Bank with the purpose of evaluating how productivity might be affected by the proposed Project (ESSA 2014). The Roberts Bank Ecosystem Model Development and Key Run report provides results for a 'key run' describing changes in **biomass** and **production** of functional groups at Roberts Bank (ESSA 2014). The key run serves as a basis for further evaluations of uncertainty as well as of alternative model scenarios (conducted within this report). The key run can be considered as being near the middle of the distribution of possible future outcomes, but does not necessarily represent the most likely outcome.

The key run forecasts are considered robust to alternative scenarios if forecasts of increased or decreased productive potential by a functional or aggregated group are the same in all scenarios. The present report describes the third stage of the ecosystem modelling: analysing the sensitivity of model forecasts given alternative scenarios. The purpose of this analysis was to assess the robustness of the key run forecasts of changes in productivity.

Sensitivity analysis involves understanding which abiotic and biotic factors drive the results of the Roberts Bank ecosystem model key run, which in turn inform an exploration of alternative scenarios and an evaluation of the resulting changes to biomass and production of Roberts Bank. In the context of Project-related change on the Roberts Bank ecosystem, the sensitivity analyses considered:

1. Increases and decreases in the predators' ability to influence prey dynamics;
2. The effects of omitting one abiotic factor at a time for each functional group;
3. 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
4. Sensitivity to input parameter uncertainty through a **Monte Carlo** approach, where input parameters were drawn randomly from distributions that reflected their uncertainty.

2.0 METHODS

2.1 SENSITIVITY TO BIOTIC FACTORS

Sensitivity to biotic factors was explored by varying the predator vulnerability setting in the Roberts Bank ecosystem model. The vulnerability setting emulates density-dependence and

can be thought of as representing how far a given functional group is from its carrying capacity. For instance, a vulnerability setting of 10 indicates that the predator can increase predation mortality on its prey no more than 10 times. Such a predator would be further from its carrying capacity than if vulnerability was lower, e.g., closer to 1 (which is the lowest vulnerability setting). Predators with higher vulnerability estimates exert increasing top-down control on their prey, whereas vulnerabilities closer to one imply a tendency to bottom-up control.

The standard procedure for calibrating temporally dynamic ecosystem models involves fitting such models to time series data (Christensen and Walters 2011). However, this was not possible for the Roberts Bank ecosystem model because there was no information on time trends (ESSA 2014). Recognising this limitation, vulnerability was set to 2.0 for the key run, a default value that is commonly used in EwE models when information on time trends is not available. This value represents a mix of top-down and bottom-up control. To evaluate the effect of varying vulnerability on biomass and production, the Roberts Bank ecosystem model was rerun with vulnerabilities representing moderate top-down (3.0) and bottom-up (1.5) control for all functional groups.

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: 1) the **biomass ratio**, expressed as functional group biomass 'with Project' divided by functional group biomass 'without Project'; and 2) the absolute difference in biomass ratio between the high and low vulnerability scenarios. The biomass ratio provides an index of sensitivity to biotic factors, with a larger difference indicating higher sensitivity.

2.2 SENSITIVITY TO ABIOTIC FACTORS

To evaluate each functional group's sensitivity to depth, salinity, bottom current, wave height and hard/soft bottom, simulations were conducted with these abiotic factors removed one at a time for each functional group. This approach allows for a separation of direct or indirect effects. Changes in biomass for a functional group can be due to environmental preferences (direct effect) or the environmental preferences of a prey or predator (indirect effect). Direct and indirect effects can also be estimated by comparing the results from this sensitivity analysis to the sensitivity analysis for biotic factors (**Section 2.1**).

For each of the analyses, the Roberts Bank ecosystem model was run both with and without the proposed Project. Changes in environmental preferences are expected to alter the functional groups' biomass with and without the proposed Project. The biomass ratio and the absolute difference in biomass ratio between the key run and the run omitting each abiotic factor (both defined in **Section 2.1**) were calculated. Finally, the results for each functional group were summarised by identifying which abiotic factors were responsible for the largest positive and negative differences in biomass ratios.

2.3 SENSITIVITY TO OVER- OR UNDERESTIMATION OF PROJECT EFFECTS

This sensitivity analysis attempts to assess how forecasted biomass and production estimates might change if the changes in abiotic factors due to the Project are over- or underestimated. The purpose of this analysis was to evaluate how model results would change if the coastal geomorphology model had forecasted higher or lower values for abiotic factors. Sensitivity was explored by increasing or decreasing the difference between the forecasted values for each abiotic factor with and without Project. The uncertainty in the coastal geomorphology model is estimated to be less than 5%, however, varying the abiotic factor by ≤5% would not generate variation sufficient to evaluate sensitivity within the ecosystem model. Instead, the effect on both aggregated and functional groups were evaluated using 20% variance, which was large enough to study the sensitivity without being too far from estimated variation of the coastal geomorphology model. For example, if the difference in salinity in a given location with and without Project was 10 psu, this analysis explored the effects on biomass and production by increasing and decreasing the salinity change by 20%, i.e., applying differences of 8 and 12 psu, although the coastal geomorphology model range for the change would be 9.5 to 10.5 psu.

First, the difference with and without Project was calculated for abiotic factors. The difference was then increased or decreased by 20%. The adjusted difference between scenarios was then used to calculate new values for 'with Project' abiotic factors. The 'without Project' values were unchanged as the purpose of this analysis was to study sensitivity to Project effects, i.e. uncertainty in 'without Project' abiotic factors are out of scope. Finally, EwE was used to calculate and compare biomass and production from the new values for the altered abiotic factors.

2.4 SENSITIVITY TO INPUT ASSUMPTIONS

The model's sensitivity to uncertainty in input parameters was evaluated using a Monte Carlo (MC) approach. The MC approach typically involves thousands of model runs while randomly varying the input parameters within specified confidence intervals and is a standard tool for evaluating the impact of uncertainty.

The EwE software has a routine to evaluate uncertainty that works with the time-dynamic version of Ecosim. This MC routine samples from a range of biomass (B), **production/biomass ratio** (P/B), **consumption/biomass ratio** (Q/B), and diet composition values. The range of values is determined based on the **pedigree** of model parameters (See **Appendix A: Table A1.1** to **Table A1.4**). For the Roberts Bank ecosystem model, the existing capabilities of the MC approach in EwE were extended to include spatial model simulations through the development of an EwE plug-in.

Using the MC approach, the 'with Project' and 'without Project' components of the Roberts Bank ecosystem model were evaluated by randomly varying the values of the Ecopath model parameters within the confidence intervals specified in the data Pedigree module of EwE (see **Appendix A: Table A1.1** to **Table A1.4**). Normal distributions were assumed for all parameter values. Each set of sampled parameters was checked to make sure they created a balanced Ecopath model, i.e. a model where production of each prey group exceeds the consumption by all of its predator groups. Each balanced Ecopath model called for around 1,000 samples of input parameter values since most models were unbalanced. For each set of balanced Ecopath parameters, the Ecospace simulations were run for 10 years until the ecosystem stabilised, and then for an additional 10 years projected into the future with and without Project. The biomass for a MC run was calculated by summing biomass values over the entire spatial extent of the model for the last year of the simulation.

Four thousand model runs were performed to evaluate the impact of input parameter uncertainty in the Roberts Bank ecosystem model. The MC approach generated 4,000 sets of output values, which were used to evaluate the most likely value (i.e., the 50th percentile for biomass of a functional group) and the associated uncertainty (i.e., the 95% confidence interval obtained as the range between the 2.5 and 97.5 percentile biomass result).

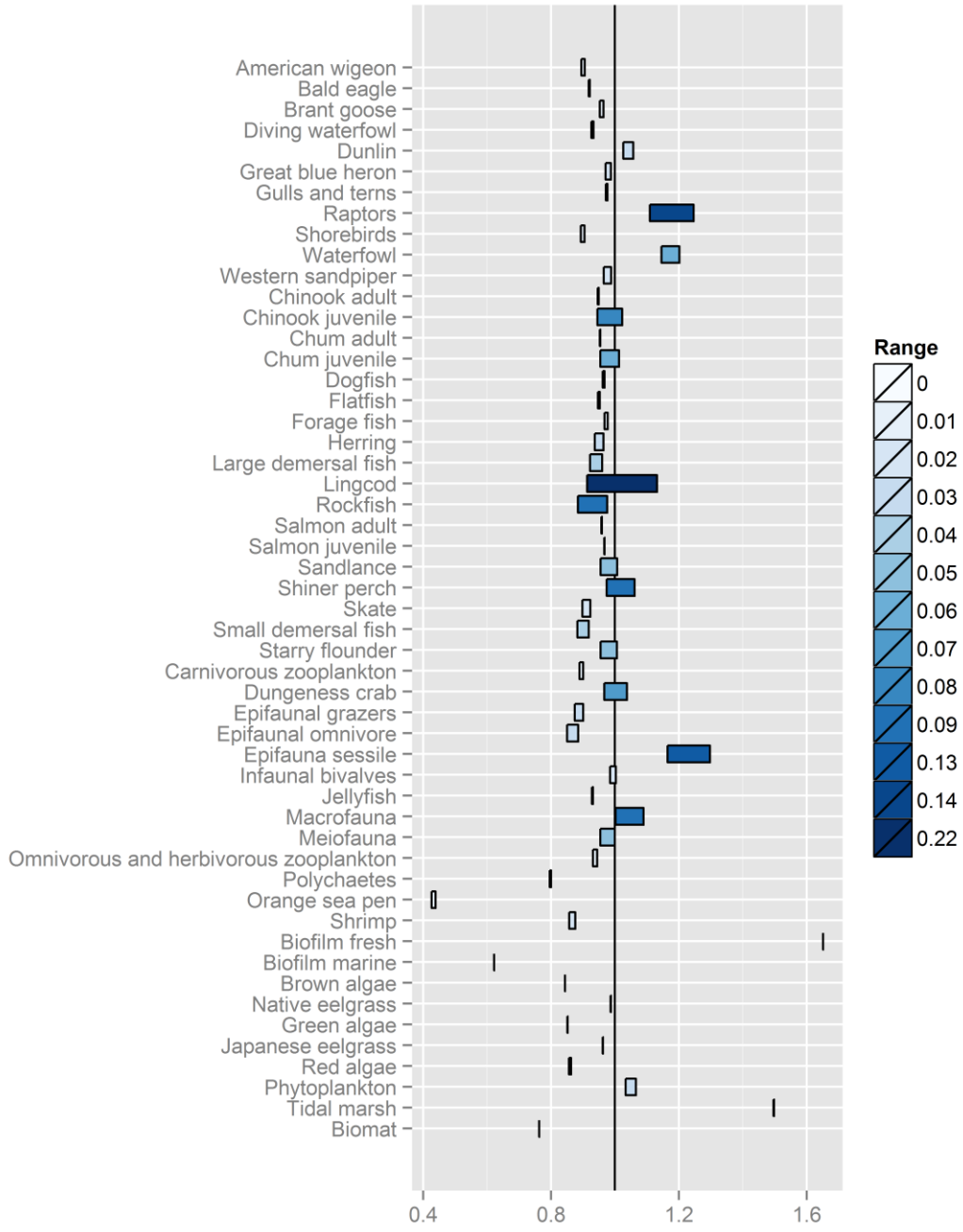
3.0 RESULTS

3.1 SENSITIVITY TO BIOTIC FACTORS

Most functional groups were relatively insensitive to changes in biotic factors, with 17 out of the 53 functional groups completely insensitive to changes in vulnerability (i.e. density dependent factors) (**Figure 3-1**). Thirteen functional groups showed a significant difference in biomass (i.e. 5% or more) under alternative scenarios of density dependence: meiofauna (0.05), starry flounder (0.05), sandlance (0.05), waterfowl (0.06), juvenile chum (0.06), dungeness crab (0.07), juvenile chinook (0.08), macrofauna (0.09), shiner perch (0.09), rockfish (0.09), epifaunal sessile suspension feeders (0.13), raptors (0.14) and lingcod (0.22). Lingcod was also one of the eight functional groups with a biomass ratio above and below 1 in some scenarios. The others are: juvenile chinook and chum, sandlance, shiner perch, starry flounder, Dungeness crab and infaunal bivalves.

The raptors group was the most sensitive of the aggregated bird group to changes in biotic factors, with a difference in biomass ratio of 0.14. Fish were the most sensitive of all aggregated groups to biotic factors as indicated by a mean difference in biomass ratio for all functional groups of 0.04. In the invertebrate group, only three functional groups showed significant differences in this analysis (i.e. differences in biomass ratio of more than 0.05): Epifaunal sessile (0.13), macrofauna (0.09) and Dungeness crab (0.007). The primary producers aggregated group was relatively insensitive with all groups showing insignificant changes. Here, 8 out of 10 functional groups were having biomass ratio differences of less than 0.01, and phytoplankton had the highest biomass ratio difference at 0.03.

Figure 3-1 Sensitivity of Functional Groups to Changes in Biotic Factors

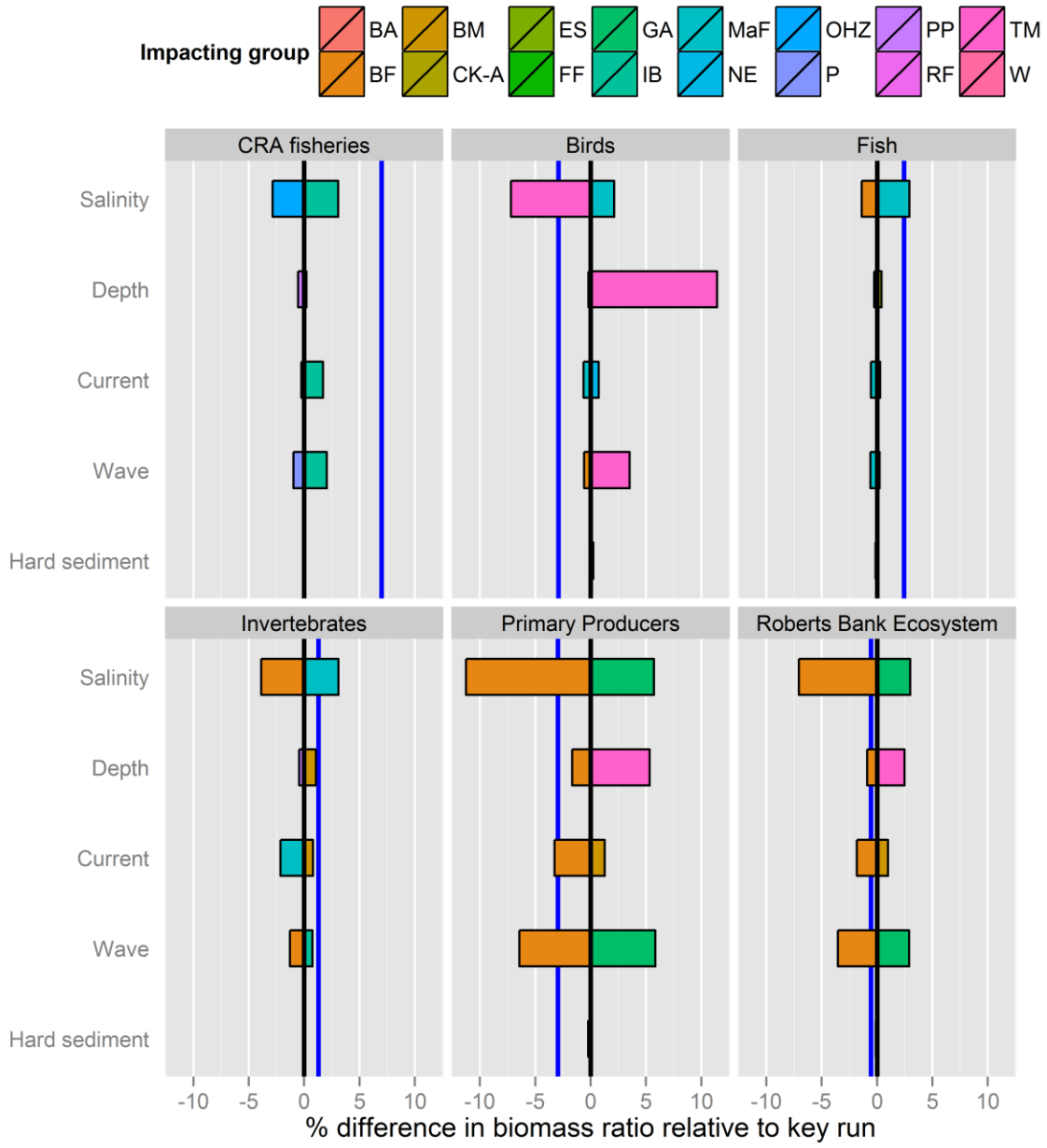


Note: The figure shows the range in biomass ratio, expressed as functional group biomass with Project divided by biomass without Project, between a high and low vulnerability scenario. The solid line shows a biomass ratio of 1.0, indicating no difference between biomass with/without Project. Dark blue indicates high sensitivity. Bars that are entirely on one side of the solid line are considered robust to alternative scenarios for biotic factors, i.e. the biomass ratio is higher or lower than 1 for all scenarios.

3.2 SENSITIVITY TO ABIOTIC FACTORS

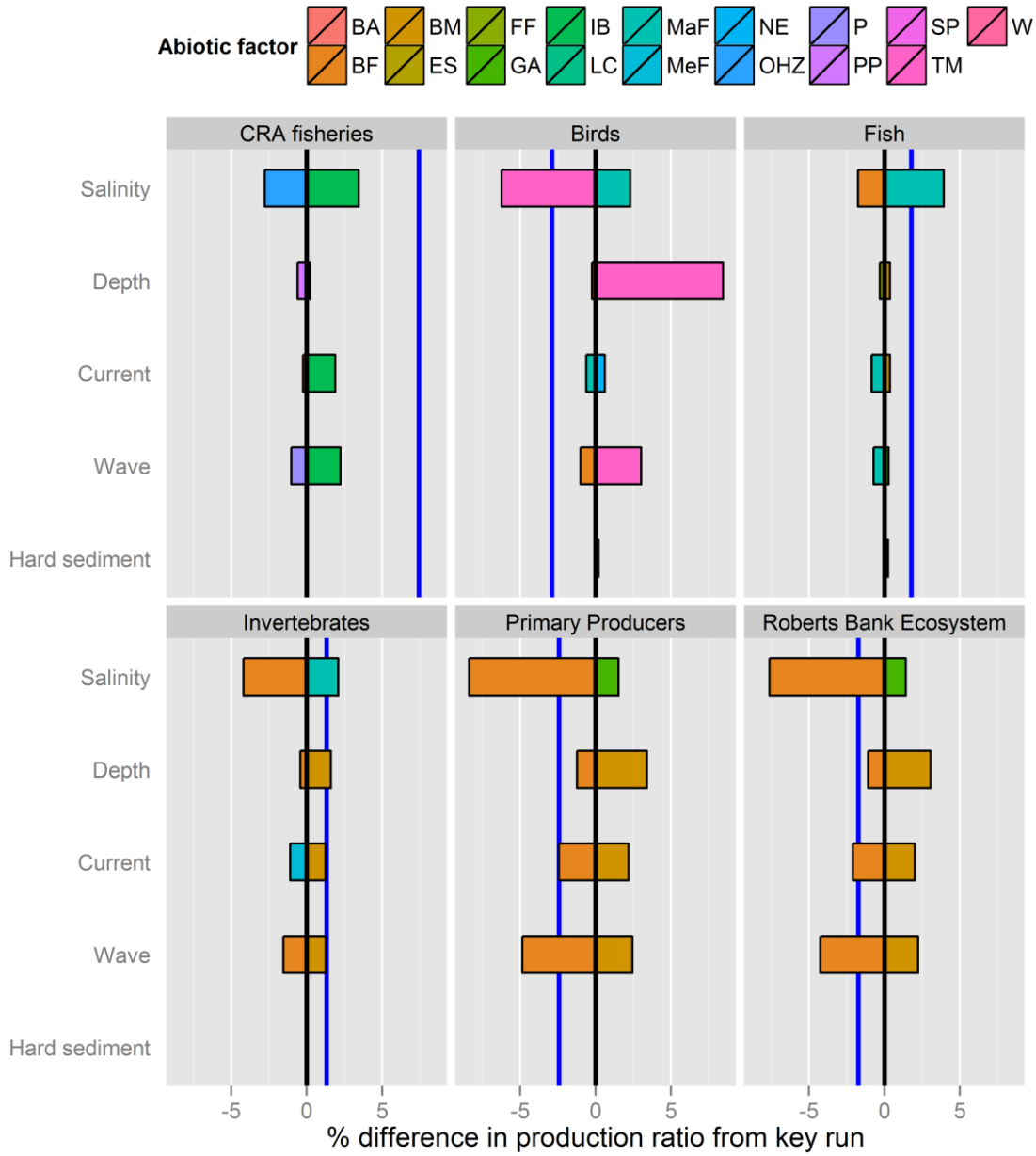
The birds and primary producers were the most sensitive aggregated groups to abiotic factors, both exhibiting a maximum change in biomass ratio of 0.11 (**Figure 3-2**). This change in biomass ratio does not reflect the uncertainty in the Roberts Bank ecosystem model, but can be considered an indicator of which abiotic factors are controlling the biomass and production of an aggregated (or functional) group. Birds were most sensitive to depth, waves and salinity, in all three cases due to the abiotic factors' impact on tidal marsh. More than 50% of the biomass in the birds group is waterfowl, and tidal marsh is an important food source for them. The primary producers were most sensitive to salinity and wave height. Primary producer biomass increased when environmental preferences for salinity and waves were removed for green algae, and decreased when they were removed from freshwater biofilm. The biomass also increases for primary producers when depth preference was removed for tidal marsh. Changes to production for aggregated group were generally similar to results for biomass (**Figure 3-3**). The ratio differed from the biomass ratio for aggregated groups because the biomass for component functional group was multiplied by their production per biomass (P/B).

Figure 3-2 Sensitivity of Biomass Ratio to Abiotic Factors



Note: The figure shows the maximum increase and decrease in biomass ratio relative to the key run, expressed as combined biomass for each aggregated group with Project divided by biomass without Project, when omitting each one of five abiotic factor. Bars to the right of a black line represent an increase in biomass ratio relative to the key run, and bars to the left represent a decrease. Bars extending beyond a blue line to the right indicate scenarios where the biomass ratio changes from a loss of biomass with Project to an increase; bars extending to the left of a blue line show decreases. The color of the bar indicates which functional group is responsible for the change. See **Appendix A: Table A-1** for impacting group abbreviations.

Figure 3-3 Sensitivity of Production Ratio to Abiotic Factors



Note: The figure shows the maximum increase and decrease in production ratio relative to the key run, expressed as combined production for each aggregated group with Project divided by production without Project, when omitting each one of five abiotic factor. Bars to the right of a black line represent an increase in production ratio relative to the key run, and bars to the left represent a decrease. Bars extending beyond a blue line to the right indicate scenarios where the production ratio changes from a loss of production with Project to an increase; bars to the left of a blue line show decreases. The color of the bar indicates which functional group is responsible for the change. See **Appendix A: Table A-1** for impacting group abbreviations.

Figure 3-4 to **Figure 3-7** show how sensitive the biomass ratios of functional groups were to the direct effect of an abiotic factor.

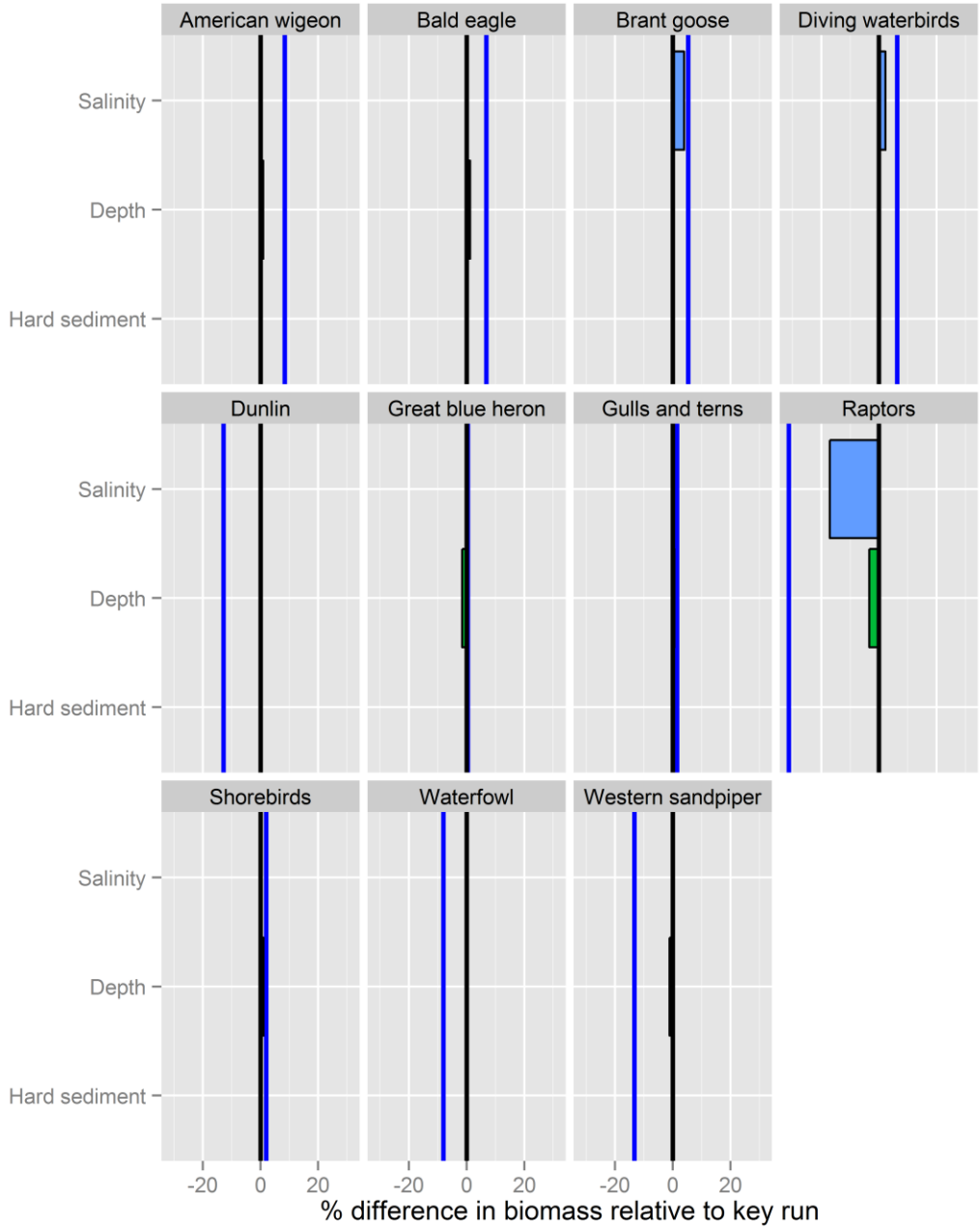
Up to three abiotic factors (salinity, depth and hard/soft substrate) were specified in the environmental preference for bird groups, (e.g., dunlin has a preference specified for each of the three abiotic factors whereas bald eagle only have one environmental preference specified. i.e. depth). All of the bird group forecasts were robust to changes in their environmental preferences, i.e. consistent forecast with either increase or decrease in biomass was obtained for all scenarios (**Figure 3-4**). Raptors were the most sensitive, with their forecast increase being reduced from 31% to 14% when their preference for salinity was removed.

Similar to birds, fish can have up to three abiotic factors (salinity, depth and hard substrate) specified in their environmental preferences. A consistent increase or decrease in biomass was forecasted for 14 of the 18 fish groups under all scenarios (**Figure 3-5**). The four remaining groups (flatfish, lingcod, large demersal fish, and small demersal fish) all changed from a forecasted decrease in biomass for the key run to an increase in biomass when their environmental preference for salinity was removed. Rockfish (22% decrease) and lingcod (20% decrease) were the two groups that exhibited the largest change in biomass ratio relative to the key run when the environmental preference for depth was removed.

Invertebrates can have environmental preferences specified for all five abiotic factors. Orange sea pens was the most sensitive group, changing from a forecasted decrease of 55% for the key run to only a 5% decrease without a preference specified for depth (**Figure 3-6**). Epifaunal sessile, epifaunal grazers, epifaunal omnivores, macrofauna and shrimp were the most sensitive groups after orange sea pens, all forecasting an increase in biomass relative to the key run when the salinity preference was omitted. For three groups, this changed the forecast of a decrease (epifaunal grazers and shrimp) or no change (epifaunal omnivore) in the key run to an increase in biomass.

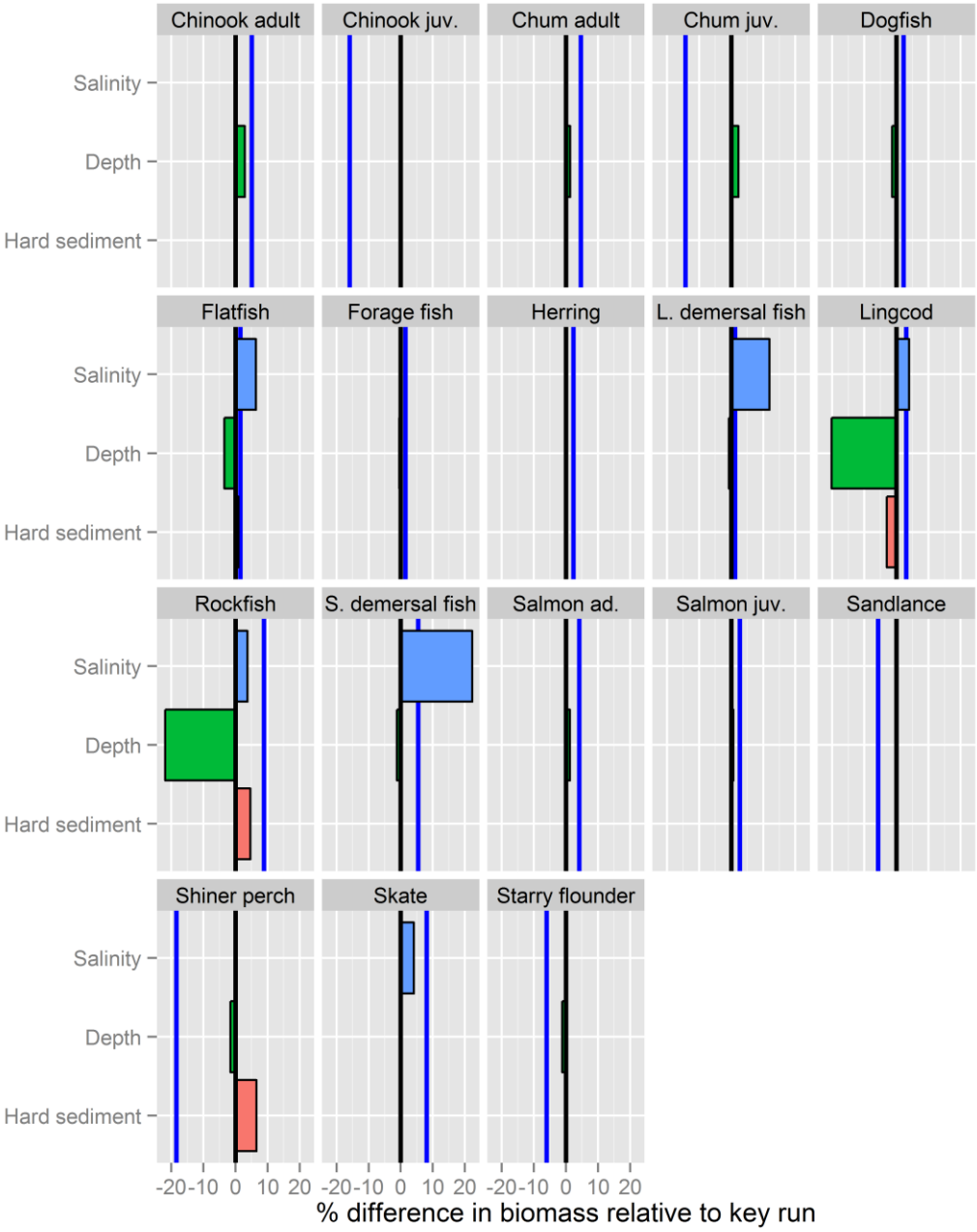
Of the five abiotic factors specified for all primary producers, salinity had the largest impact, changing the forecast for freshwater biofilm from a 90% increase in the key run to a 20% decrease without an environmental preference specified for salinity (**Figure 3-7**). Tidal marsh similarly changed from an increase (25%) to a decrease (5%), but unlike tidal marsh, freshwater biofilm increases by 90% if depth is omitted. Other sensitive primary producers are red and brown algae, which both change from a forecasted decrease to an increase when depth is omitted, and native eelgrass that increased by 42% when salinity was omitted.

Figure 3-4 Sensitivity of Species' Biomass Ratios due to Changes in Abiotic Factors for Birds



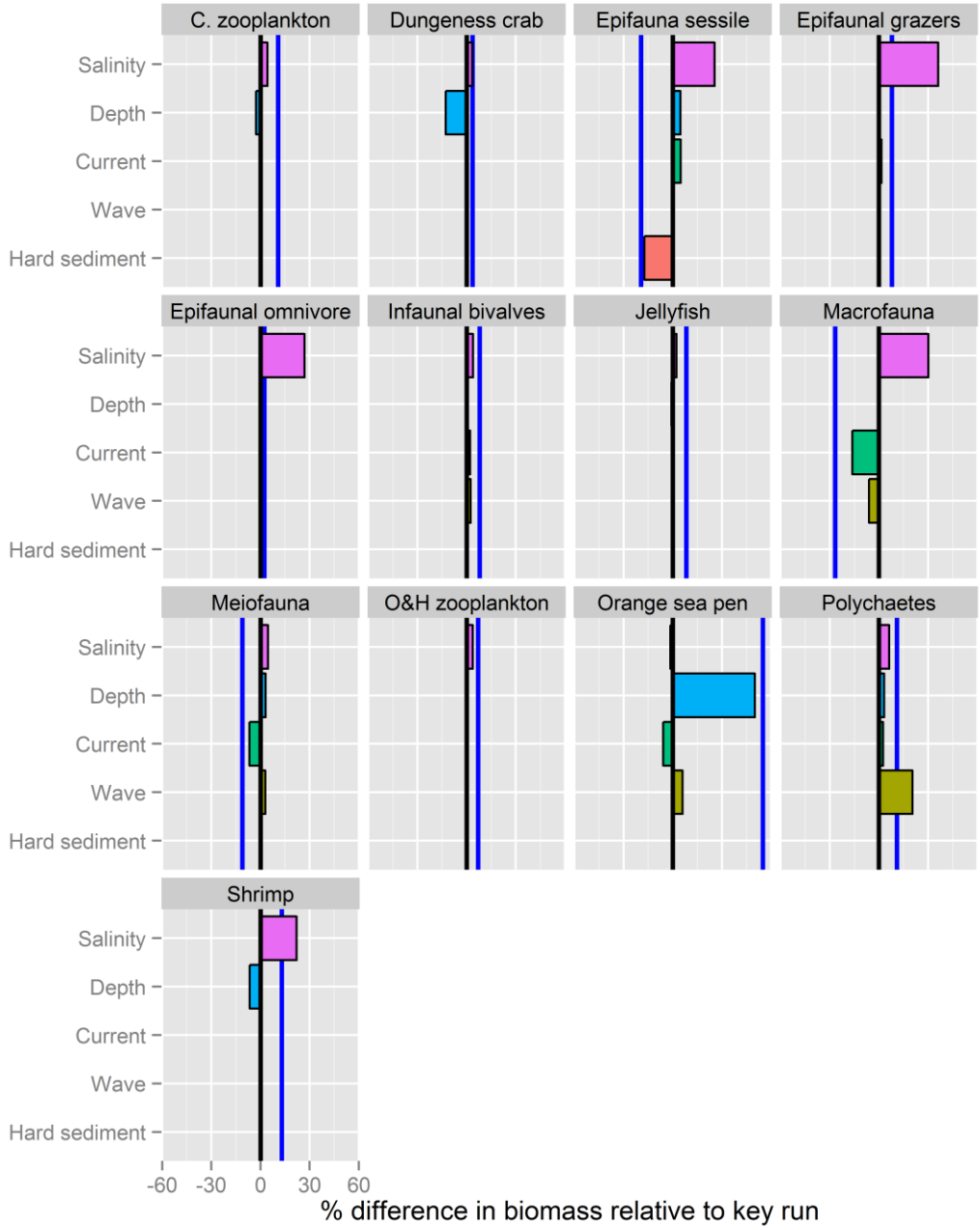
Note: The figure shows the maximum difference in biomass ratio relative to the key run, expressed as species biomass with Project divided by biomass without Project, when omitting each one of three abiotic factors. The blue lines show where there is no impact of the Project. Production ratio and biomass ratio are identical for individual functional groups. Note the different axis from previous figures of biomass and production ratios.

Figure 3-5 Sensitivity of Species' Biomass Ratios due to Changes in Abiotic Factors for Fish



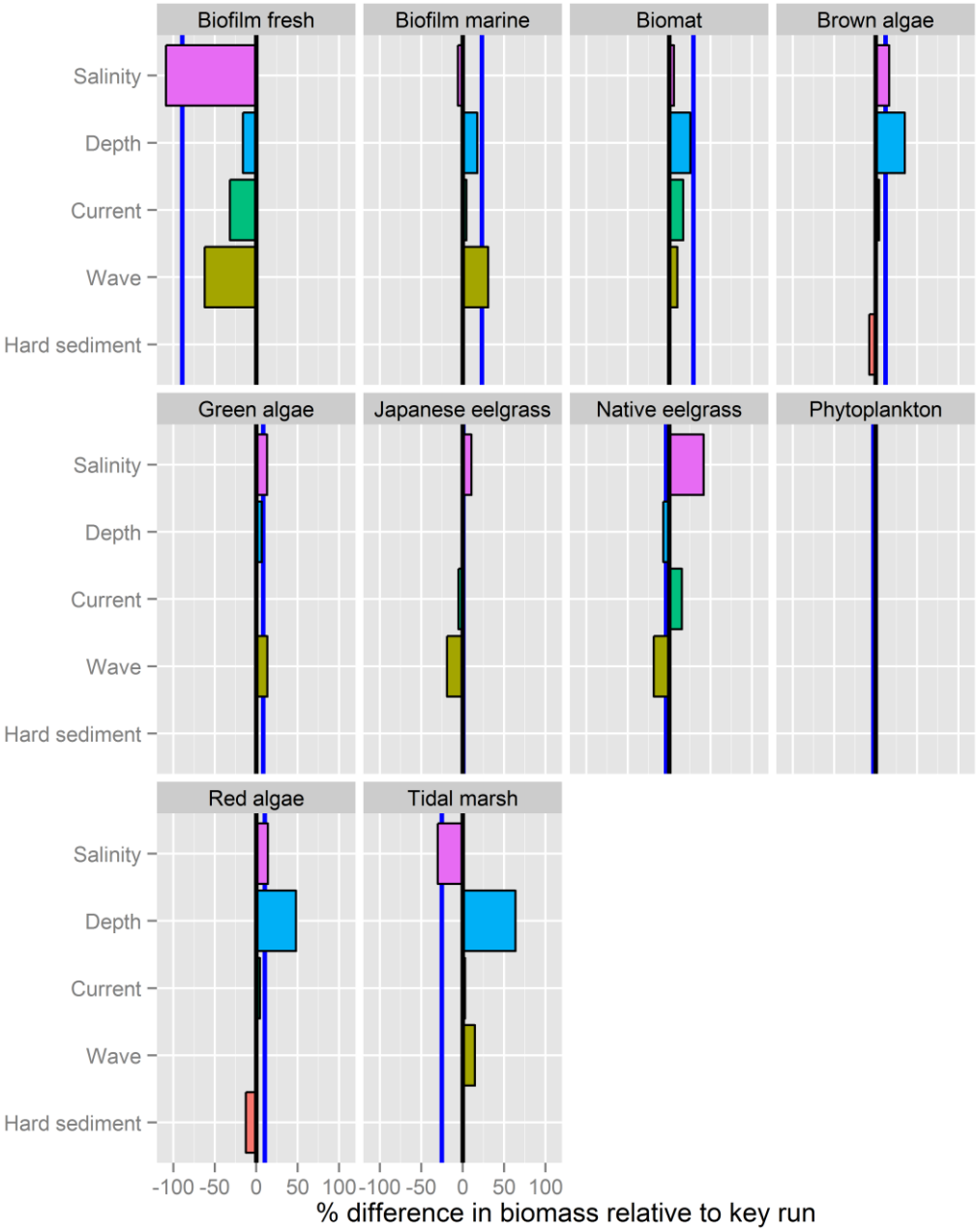
Note: The figure shows the maximum difference in biomass ratio relative to the key run, expressed as species biomass with Project divided by biomass without Project, when omitting each one of three abiotic factors. The blue lines show where there is no impact of the Project. Production ratio and biomass ratio are identical for individual functional groups. Note the different axis from previous figures of biomass and production ratios.

Figure 3-6 Sensitivity of Species' Biomass Ratios due to Changes in Abiotic Factors for Invertebrates



Note: The figure shows the maximum difference in biomass ratio relative to the key run, expressed as species biomass with Project divided by biomass without Project, when omitting each one of five abiotic factors. The blue lines show where there is no impact of the Project. Production ratio and biomass ratio are identical for individual functional groups. Note the different axis from previous figures of biomass and production ratios.

Figure 3-7 Sensitivity of Species' Biomass Ratios due to Changes in Abiotic Factors for Primary Producers



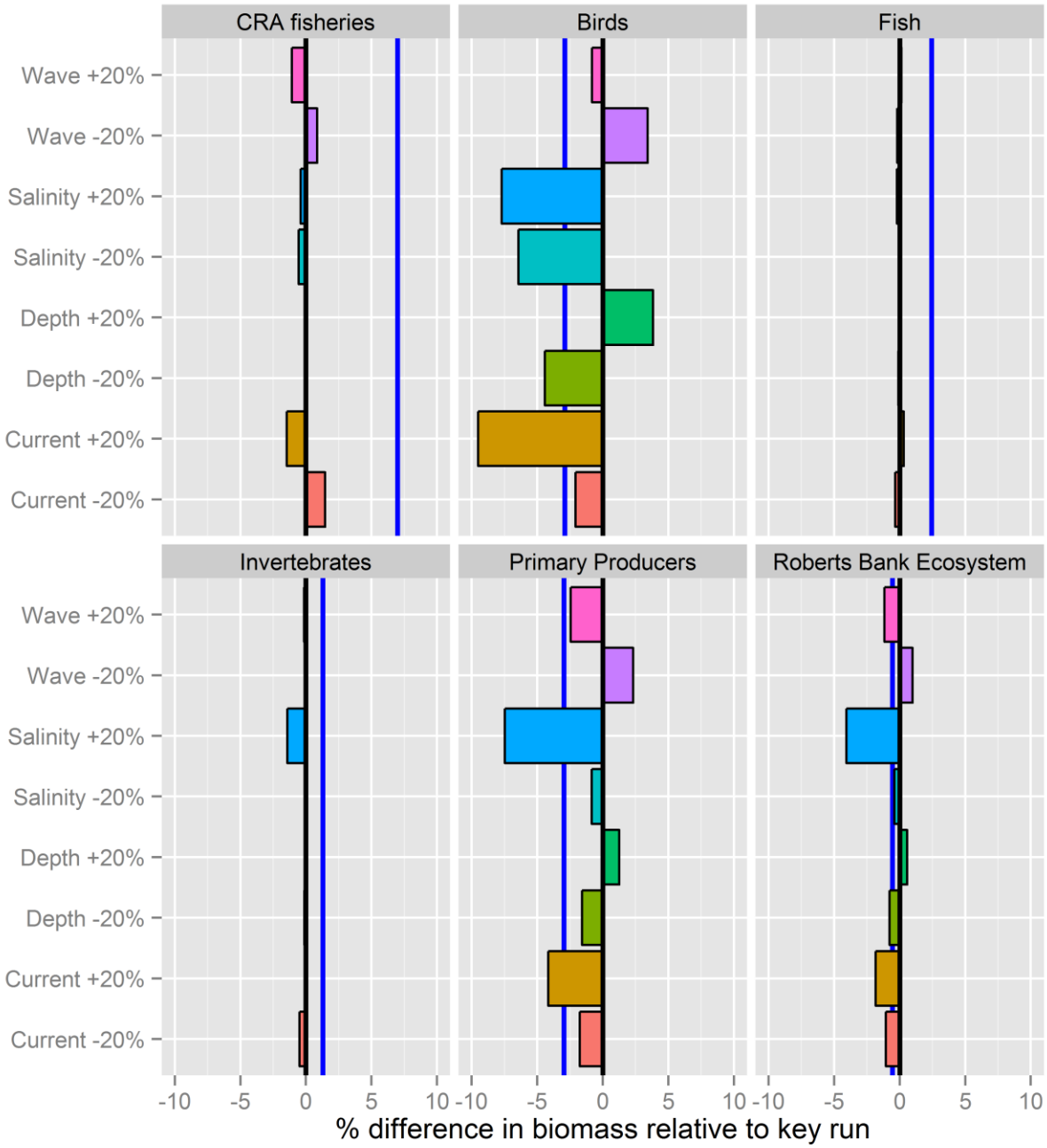
Note: The figure shows the maximum difference in biomass ratio relative to the key run, expressed as species biomass with Project divided by biomass without Project, when omitting each one of five abiotic factors. The blue lines show where there is no impact of the Project. Production ratio and biomass ratio are identical for individual functional groups. Note the different axis from previous figures of biomass and production ratios.

3.3 SENSITIVITY TO OVER- OR UNDERESTIMATION OF PROJECT EFFECTS

Biomass and production response of aggregated groups and functional groups were examined with variations in abiotic factors from -20% to +20% difference for salinity, bottom current, wave height, and depth relative to the values used for the key run (**Figure 3-8** and **Figure 3-9**). This is a range that represents a balance between the expected uncertainty for the coastal geomorphology model (<5%) and one large enough to allow a study of sensitivity for the ecosystem model. Hard substrate was not included in this analysis because unlike the other four abiotic factors, it doesn't represent a continuum but instead the discrete addition of hard substrate when the project is constructed, i.e. it is not possible to add or remove an additional 20% of hard substrate.

For the aggregated groupings examined, the gains by some groups counteracted the losses for other groups. Fish exhibited low sensitivity (less than 0.4% difference from the key run biomass ratio) and invertebrates were most sensitive to increases in salinity (i.e. underestimation), which decreased the biomass ratio for the group by 1.4% (**Figure 3-8**). **CRA fisheries** biomass ratio varied from -0.015 to +0.015 relative to the key run with changes in abiotic factors but decreased under all scenarios with project. The biomass ratio for birds increased when changes in wave heights decreased (i.e. overestimation) or when changes in depth increased (i.e. underestimation), and decreased for all other scenarios. For four of the scenarios (overestimated or underestimated changes in salinity, underestimated changes in depth and underestimated changes in bottom current) the model forecasted a decrease in biomass (biomass ratio < 1) whereas the key run forecasted an increase in biomass (biomass ratio > 1). Similar to the birds group, the biomass ratio for primary producers increased relative to the key run when changes in wave height were overestimated or changes in depth were underestimated and decreased for all other scenarios. Underestimation in salinity or bottom current resulted in biomass ratios below 1.0. The Roberts Bank ecosystem was overall forecasted to increase in biomass under the key run. The biomass is forecasted to increase further if changes in wave height are overestimated or changes in depths are underestimated. All other scenarios for the Roberts Bank ecosystem forecast either no change or a decrease in biomass (biomass ratio < 1.0).

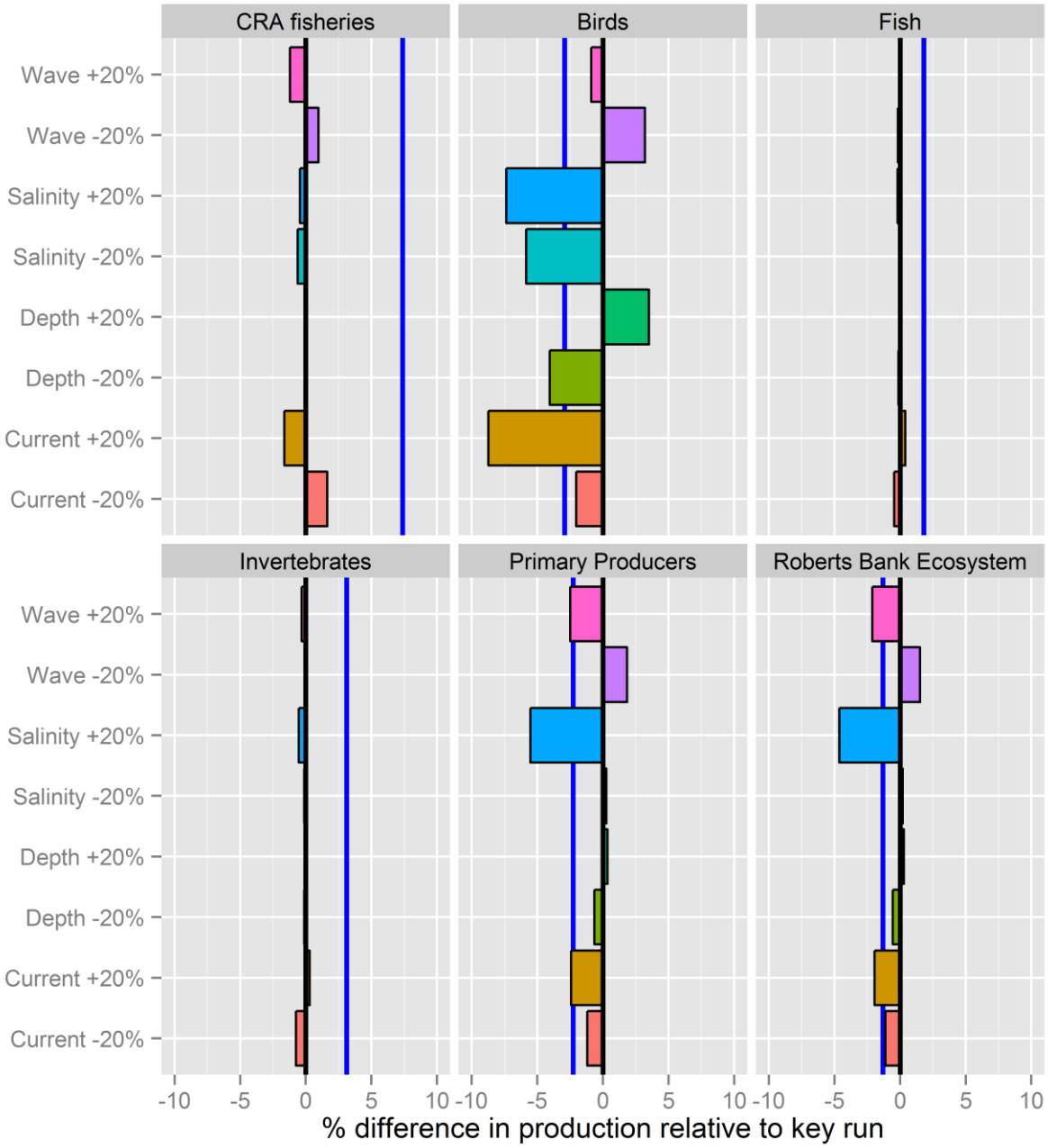
Figure 3-8 Sensitivity of Biomass Ratios to Over- or Underestimation of Changes in Abiotic Factors



Note: The difference in abiotic factors with and without Project was increased or decreased by 20% and the difference in biomass relative to the key run was calculated. Bars to the left of the black lines indicate that biomass would decrease under these scenarios. Similarly, bars to the right of the black line indicate an increase in biomass relative to the key run. The blue lines show where there is no impact of the Project. Bars that are entirely on one side of the blue line are considered robust to alternative scenarios for over- or underestimation of Project effect, i.e. the biomass ratio is higher or lower than 1 for all scenarios.

The ratio differed from the biomass ratio for aggregated groups because the biomass for component functional group was multiplied by their group-specific production over biomass ratio (P/B). The direction of change in **production ratios** was robust to over- or underestimation of Project effects up to 20% for four out of seven of the aggregated groups (**Figure 3-9**), i.e. an increase or a decrease in production relative to 'without project' was forecasted for all scenarios. The three aggregated groups that are not robust to over- or underestimation of Project effects are birds, primary producers and the Roberts Bank ecosystem. Bird production is forecasted to increase in the key run, but the sensitivity analysis indicates that the production could decrease if changes in current was 20% higher, changes in depth was 20% lower, or changes in salinity were either 20% higher or lower. The production for primary producers is forecast to decrease if the change in salinity was 20% higher, and remain unchanged or decrease slightly if the change in wave height or bottom currents was 20% higher. The production for the Roberts Bank ecosystem displays the same pattern as the primary producers because the primary producers are responsible for the majority of the production in the ecosystem.

Figure 3-9 Sensitivity of Production Ratios to Over- or Underestimation of Project Effects on Abiotic Factors



Note: The difference in abiotic factors with and without Project was increased or decreased by 20% and the difference in biomass relative to the key run was calculated. Bars to the left of the black lines indicate that biomass would decrease under these scenarios. Similarly, bars to the right of the black line indicate an increase in biomass relative to the key run. The blue lines show where there is no impact of the Project. Bars that are entirely on one side of the blue line are considered robust to alternative scenarios for over- or underestimation of Project effect, i.e. the biomass ratio is higher or lower than 1 for all scenarios.

Figure 3-10 to **Figure 3-13** shows how the biomass ratios of each functional group are affected by a 20% over or underestimation in abiotic factors.

Waterfowl was the only bird group to change from an increase to a decrease in biomass relative to 'without project' with changes in abiotic factors (**Figure 3-10**), however, Brant goose changed from a forecasted increase to no change. An increase in biomass was forecasted for the key run, however, a decrease was forecasted for both an over and underestimation in changes in salinity and for an underestimation in bottom currents. This was primarily due to the influence of tidal wetlands, a major part of waterfowl diet, which exhibits the same pattern. Brant goose biomass was forecasted to decline for all scenarios except when changes in waves are overestimated by 20% (i.e. a 20% decrease). This pattern is similar to the pattern for native eelgrass, which constitutes more than half of the diet of Brant goose.

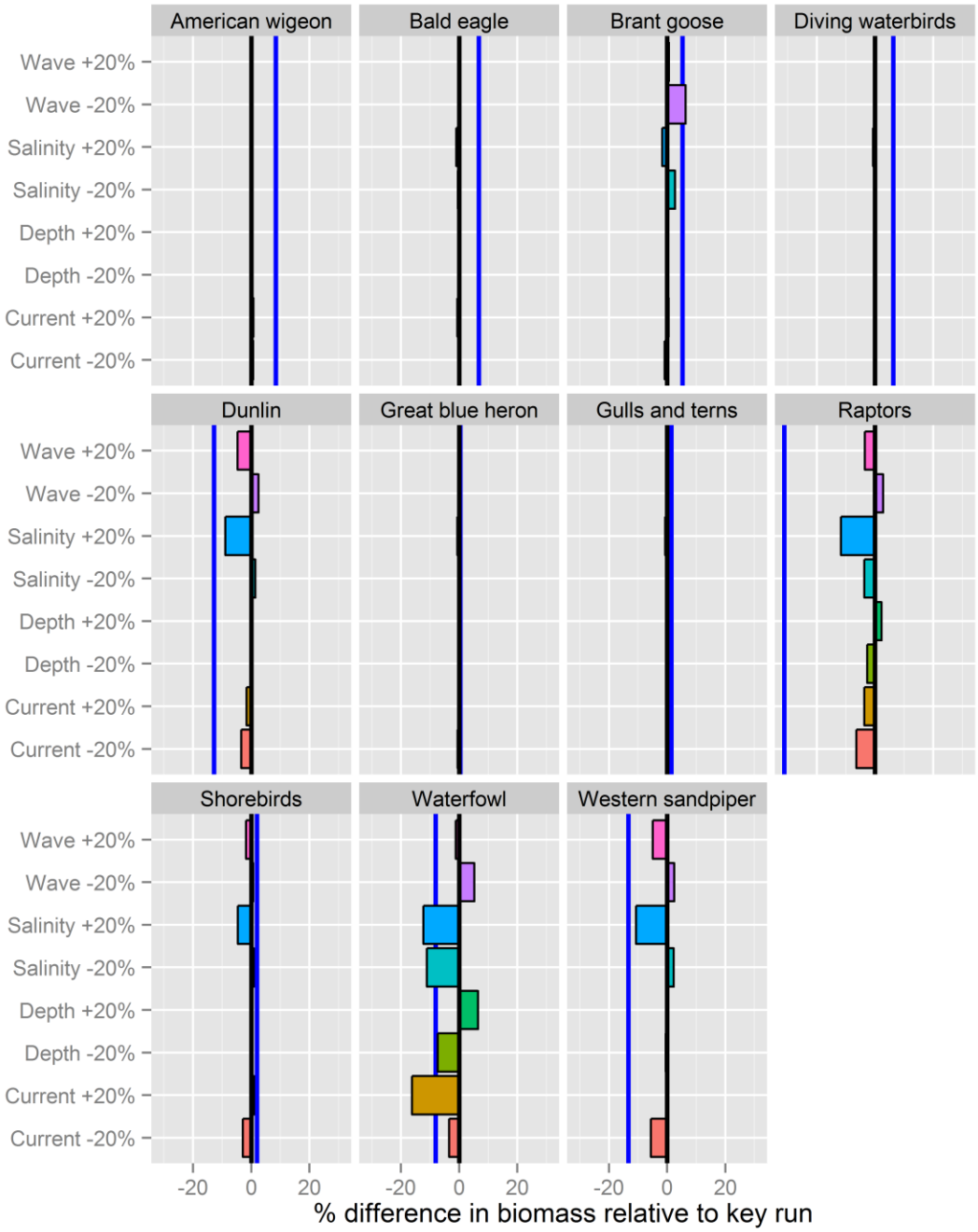
All fish functional groups were forecasted to consistently either increase or decrease for all scenarios (**Figure 3-11**). Both lingcod and rockfish showed an increase in biomass ratio relative to the key run when changes in salinity were overestimated or changes in waves were underestimated, however in both cases it was not enough for the biomass ratio to increase above one. Juvenile chinook, juvenile chum and shiner perch all exhibit the same pattern as they share a common prey, (macrofauna, which comprises approximately 40% of the diet for all three functional groups).

Similar to fish, the biomasses for all invertebrate functional groups were consistently forecasted to either increase or decrease for all scenarios (**Figure 3-12**). The most sensitive functional group is orange sea pens, which increased in biomass by more than 3% when changes in wave heights were overestimated and decreased by more than 7% when changes in salinity were overestimated. Macro- and meiofauna were also sensitive to abiotic factors and both displayed a similar response to changes in all abiotic factors except for changes to wave heights, which lead to an increase in macrofauna biomass with underestimation in wave height and a decrease in meiofauna biomass.

For primary producers, only two functional groups, tidal marsh and Japanese eelgrass, increased or decreased in biomass depending on changes in abiotic factors (**Figure 3-13**). Tidal marsh was forecasted to increase with project in the key run, but was forecasted to decrease when changes in bottom currents were underestimated by 20% or when changes

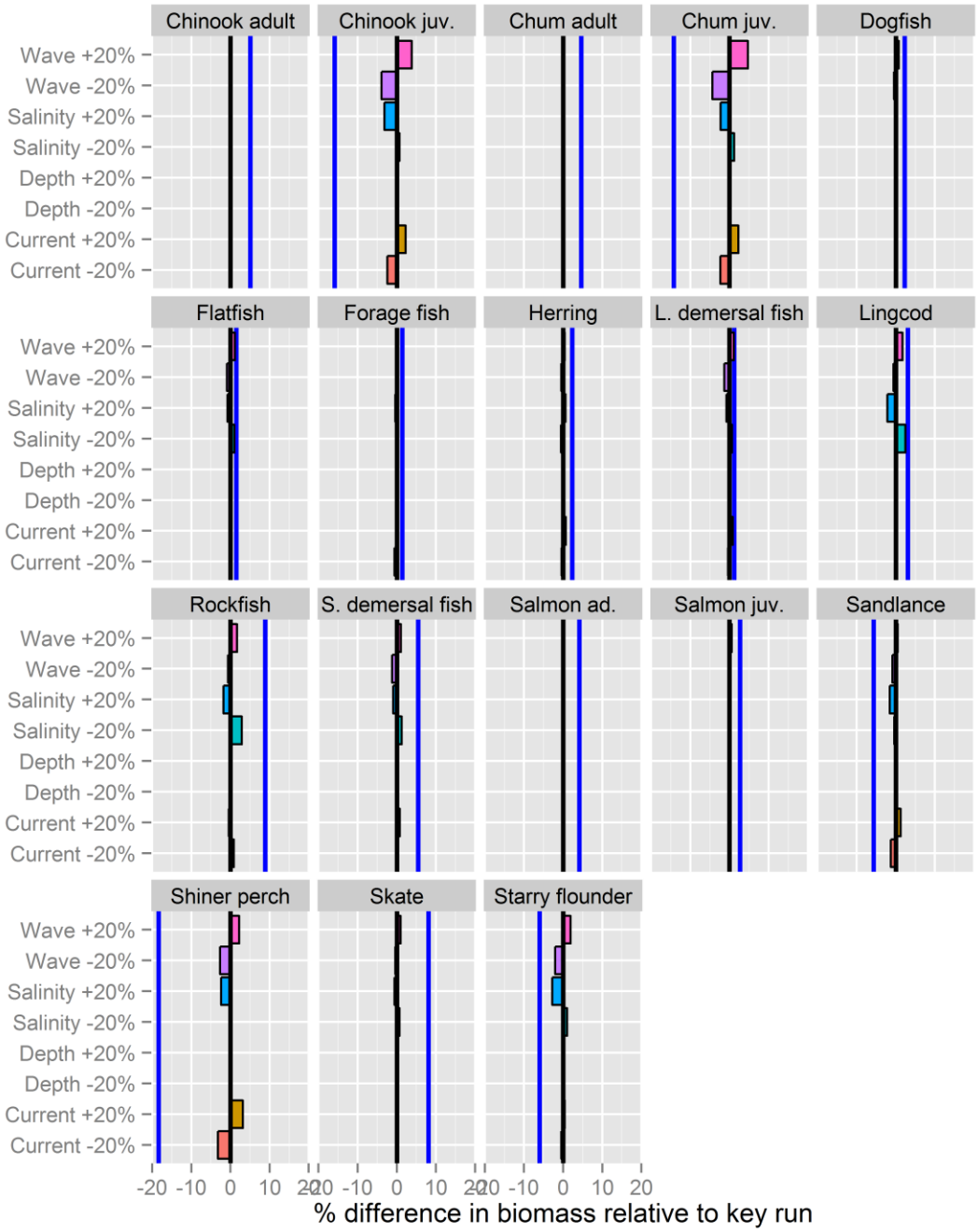
in salinity was either over or underestimated. Japanese eelgrass was not forecasted to change significantly in the key run but was forecasted to decrease by 10% if the change in salinity was overestimated by 20%. Decreased change in salinity was forecasted to simultaneously decrease Japanese eelgrass biomass and increase native eelgrass biomass. Smaller salinity changes also resulted in an 11% increase in marine biofilm, but only a 1% decrease in freshwater biofilm; however, the net results would remain a loss of marine biofilm and a net increase in combined biofilm biomass.

Figure 3-10 Sensitivity of Biomass Ratios to Over- or Underestimation of Project Effects on Abiotic Factors for Birds



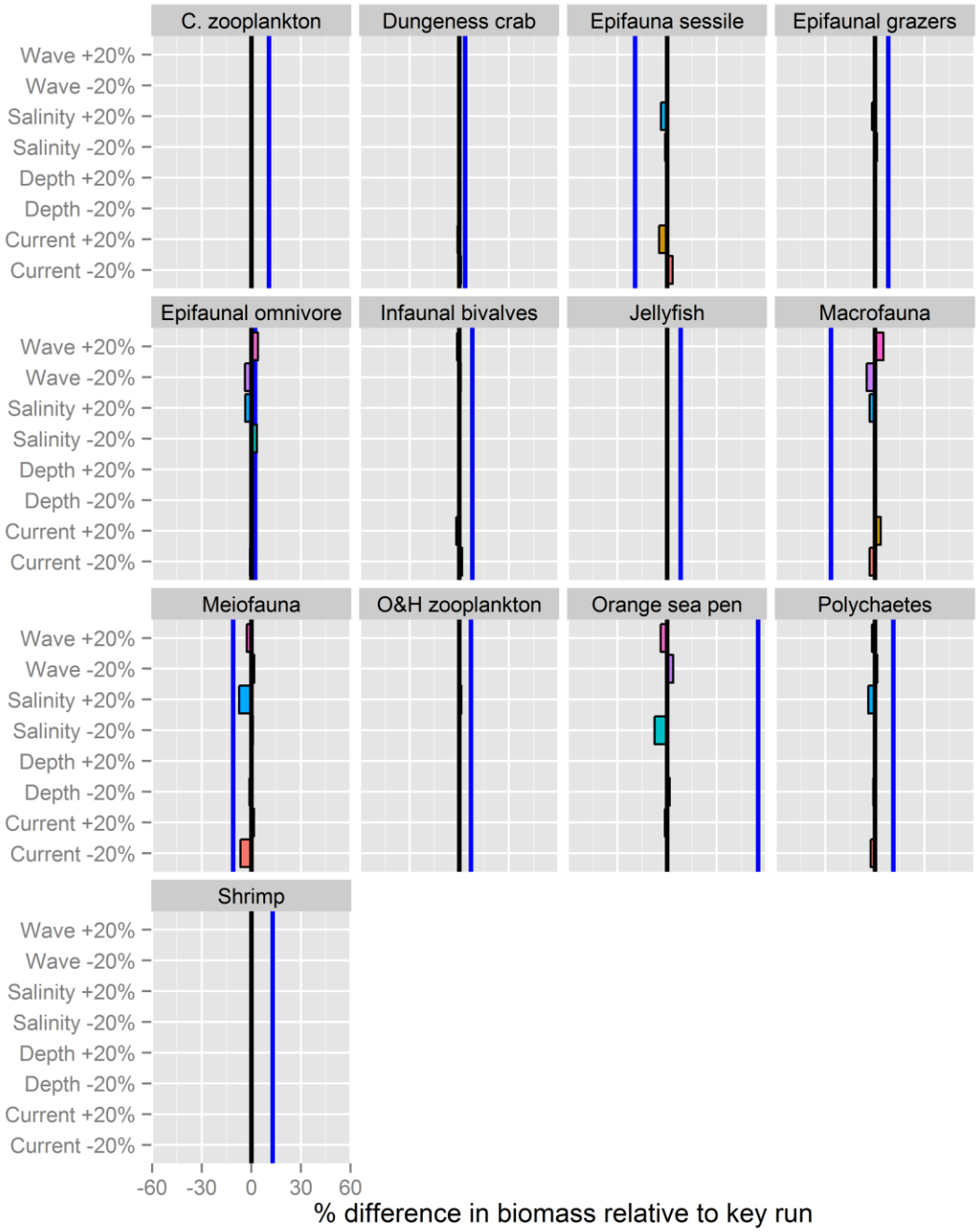
Note: The difference in abiotic factors with and without Project was increased or decreased by 20% and the % difference in biomass relative to the key run was calculated. Bars to the left of a black line indicate that biomass would decrease under these scenarios. Similarly, bars to the right of a black line indicate an increase in biomass relative to the key run. The blue lines show where there is no impact of the Project. Bars that are entirely on one side of the blue line are considered robust to alternative scenarios for over- or underestimation of Project effect, i.e. the biomass ratio is higher or lower than 1 for all scenarios.

Figure 3-11 Sensitivity of Biomass Ratios to Over- or Underestimation of Project Effects on Abiotic Factors for Fish



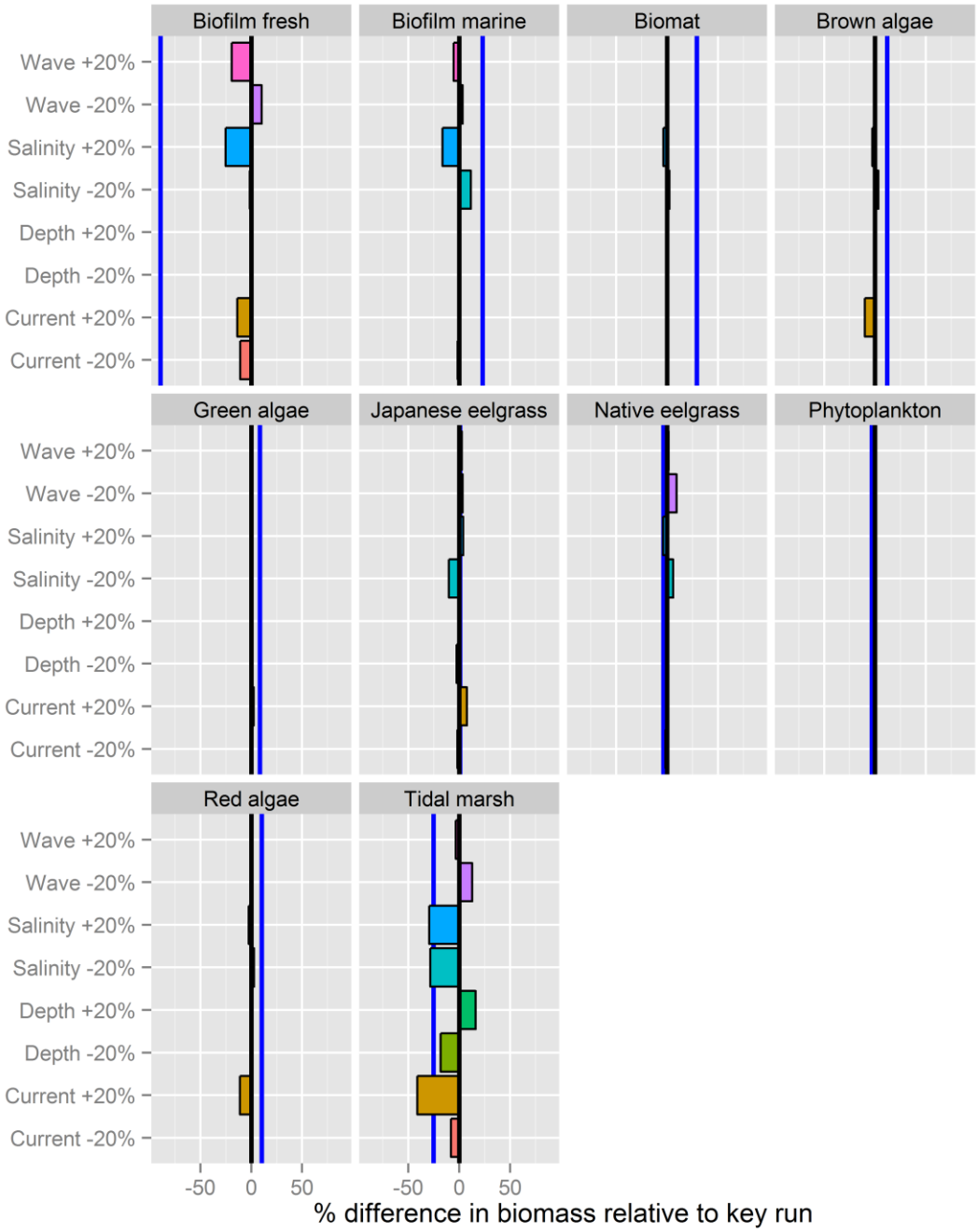
Note: The difference in abiotic factors with and without Project was increased or decreased by 20% and the % difference in biomass relative to the key run was calculated. Bars to the left of a black line indicate that biomass would decrease under these scenarios. Similarly, bars to the right of a black line indicate an increase in biomass relative to the key run. The blue lines show where there is no impact of the Project. Bars that are entirely on one side of a blue line are considered robust to alternative scenarios for over- or underestimation of Project effect, i.e. the biomass ratio is higher or lower than 1 for all scenarios.

Figure 3-12 Sensitivity of Biomass Ratios to Over- or Underestimation of Project Effects on Abiotic Factors for Invertebrates



Note: The difference in abiotic factors with and without Project was increased or decreased by 20% and the % difference in biomass relative to the key run was calculated. Bars to the left of a black line indicate that biomass would decrease under these scenarios. Similarly, bars to the right of a black line indicate an increase in biomass relative to the key run. The blue lines show where there is no impact of the Project. Bars that are entirely on one side of a blue line are considered robust to alternative scenarios for over- or underestimation of Project effect, i.e. the biomass ratio is higher or lower than 1 for all scenarios.

Figure 3-13 Sensitivity of Biomass Ratios to Over- or Underestimation of Project Effects on Abiotic Factors for Primary Producers



Note: The difference in abiotic factors with and without Project was increased or decreased by 20% and the % difference in biomass relative to the key run was calculated. Bars to the left of a black line indicate that biomass would decrease under these scenarios. Similarly, bars to the right of a black line indicate an increase in biomass relative to the key run. The blue lines show where there is no impact of the Project. Bars that are entirely on one side of a blue line are considered robust to alternative scenarios for over- or underestimation of Project effect, i.e. the biomass ratio is higher or lower than 1 for all scenarios.

3.4 SENSITIVITY TO INPUT ASSUMPTIONS

The evaluations above that describe the key run of the spatial Roberts Bank ecosystem model (ESSA 2014) were based on parameter input values described in an accompanying report (Hemmera 2014). Uncertainty associated with input parameters, here expressed as the forecasted biomass 'with Project' relative to the forecasted biomass 'without Project', was evaluated using a Monte Carlo (MC) approach as described earlier (see **Section 2.4**).

Distributions of the forecast biomass ratio (with/without Project) of functional groups in the Roberts Bank ecosystem model were generated by doing 4,000 runs with a procedure that involved: sampling input parameters with uncertainty (as specified from the pedigree module), evaluating mass-balance constraints (and re-sampling if these constraints were not met), and finally running the spatial model twice; once without the Project and once with the Project.

The results from this analysis are presented in **Figure 3-14** to **Figure 3-21**; the green solid vertical lines indicate the median (most likely) MC run, and the blue stippled lines show the key run. If the median MC run is to the left of the key run, it means that the key run likely overestimates the biomass ratio. Similarly, if the median MC run is to the right of the key run, it means that the key run likely underestimates the biomass ratio. In cases where the key run is outside the range of the MC runs, the combinations of parameters used in the key run for this functional group is highly unlikely.

Figure 3-14 Biomass Ratio With/Without Project for Bird Functional Groups, Based on 4,000 Evaluations of Input Parameter Uncertainty

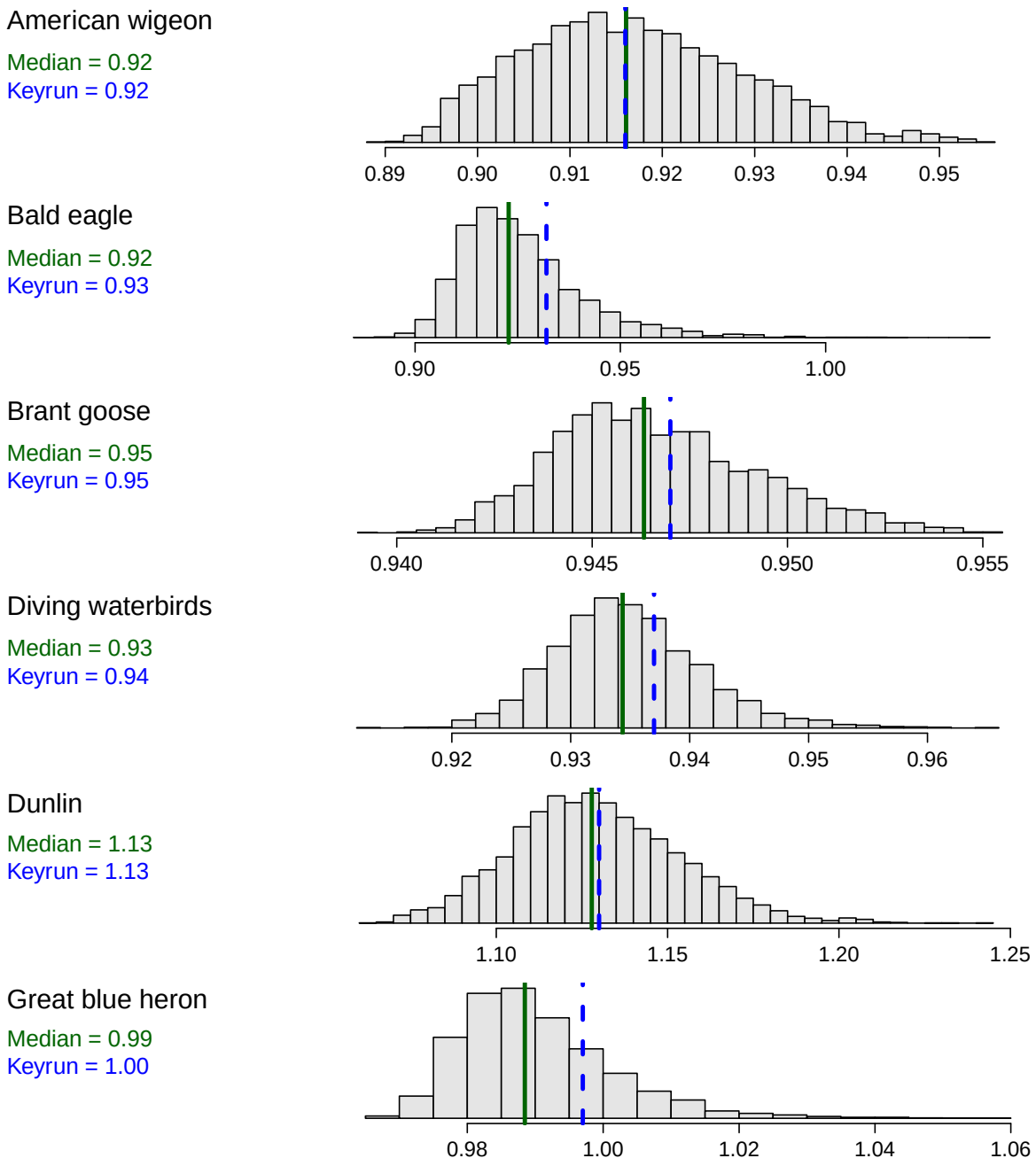
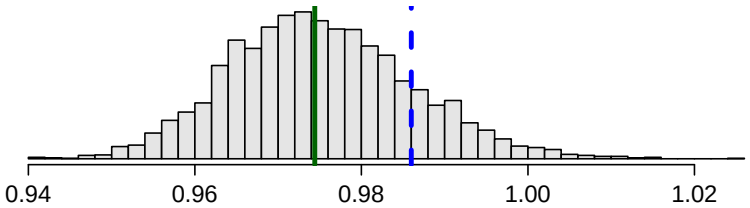


Figure 3-15 Biomass Ratio With/Without Project for Bird Functional Groups, Based on 4,000 Evaluations of Input Parameter Uncertainty (continued)

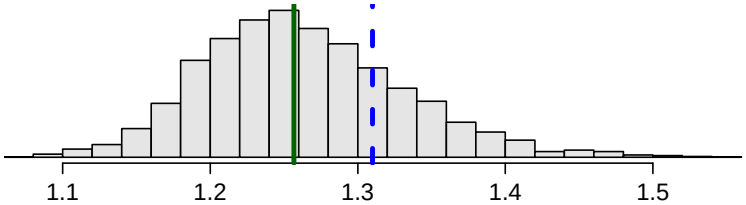
Gulls and terns

Median = 0.97
Keyrun = 0.99



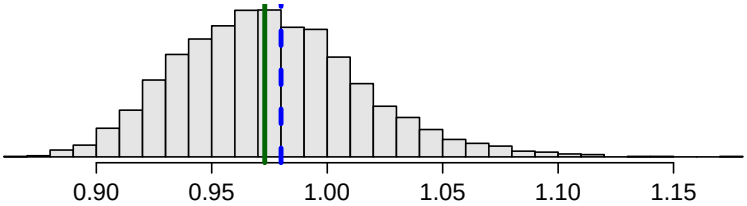
Raptors

Median = 1.26
Keyrun = 1.31



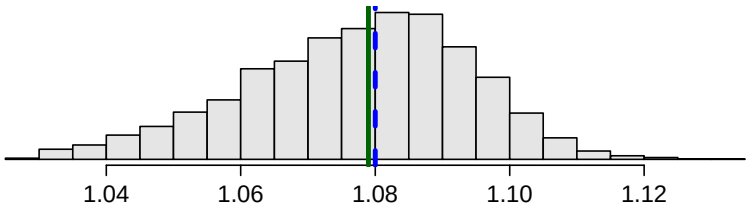
Shorebirds

Median = 0.97
Keyrun = 0.98



Waterfowl

Median = 1.08
Keyrun = 1.08



Western sandpiper

Median = 1.14
Keyrun = 1.13

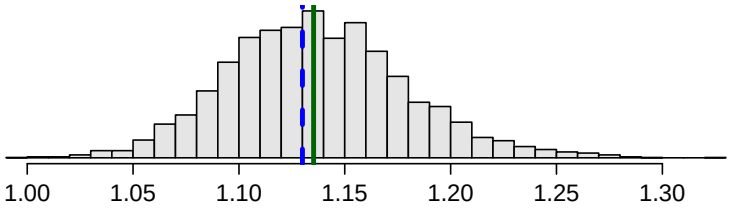


Figure 3-16 Biomass Ratio With/Without Project for Fish Functional Groups, Based on 4,000 Evaluations of Input Parameter Uncertainty

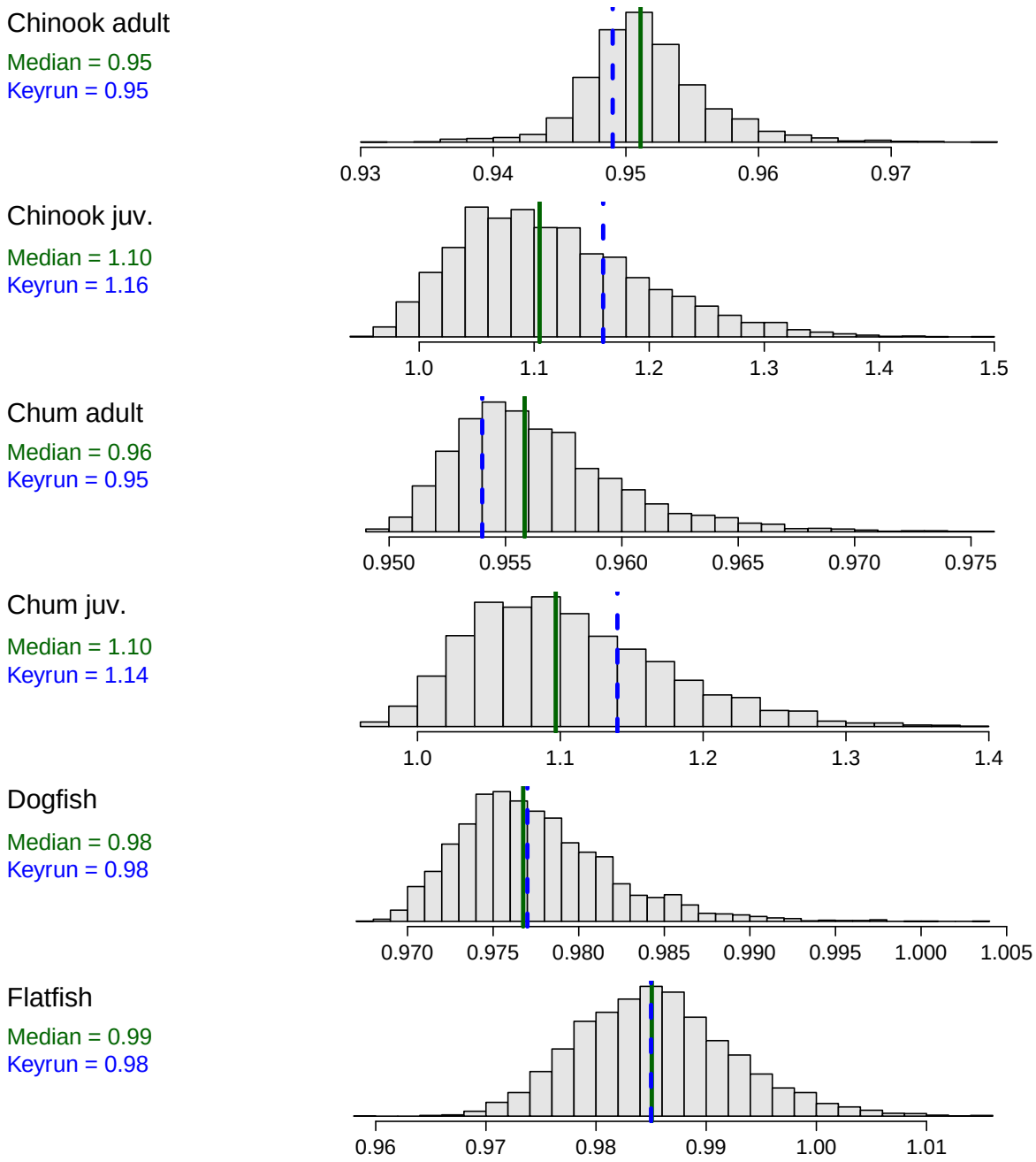


Figure 3-17 Biomass Ratio With/Without Project for Fish Functional Groups, Based on 4,000 Evaluations of Input Parameter Uncertainty (continued)

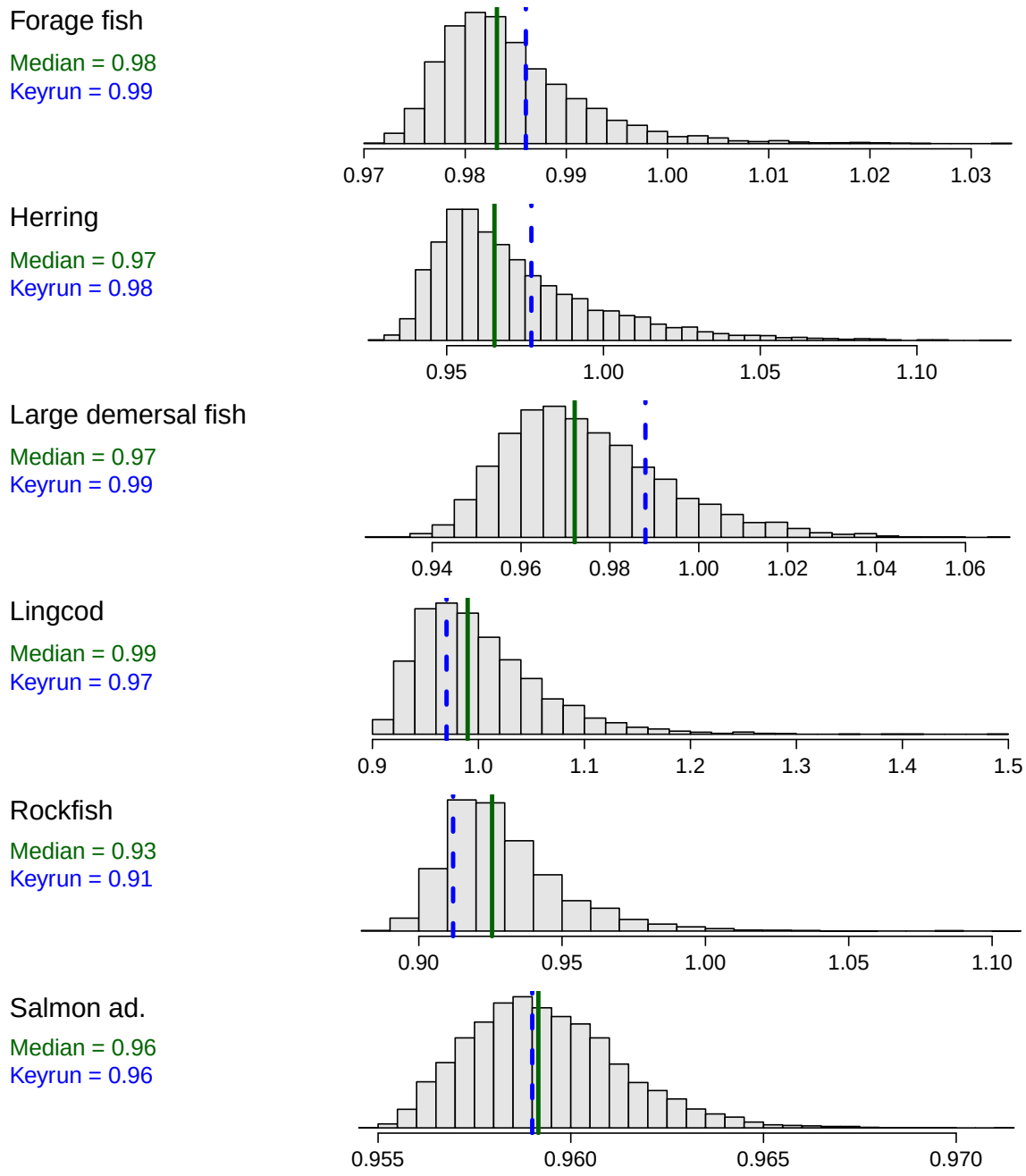


Figure 3-18 Biomass Ratio With/Without Project for Fish Functional Groups, Based on 4,000 Evaluations of Input Parameter Uncertainty (continued)

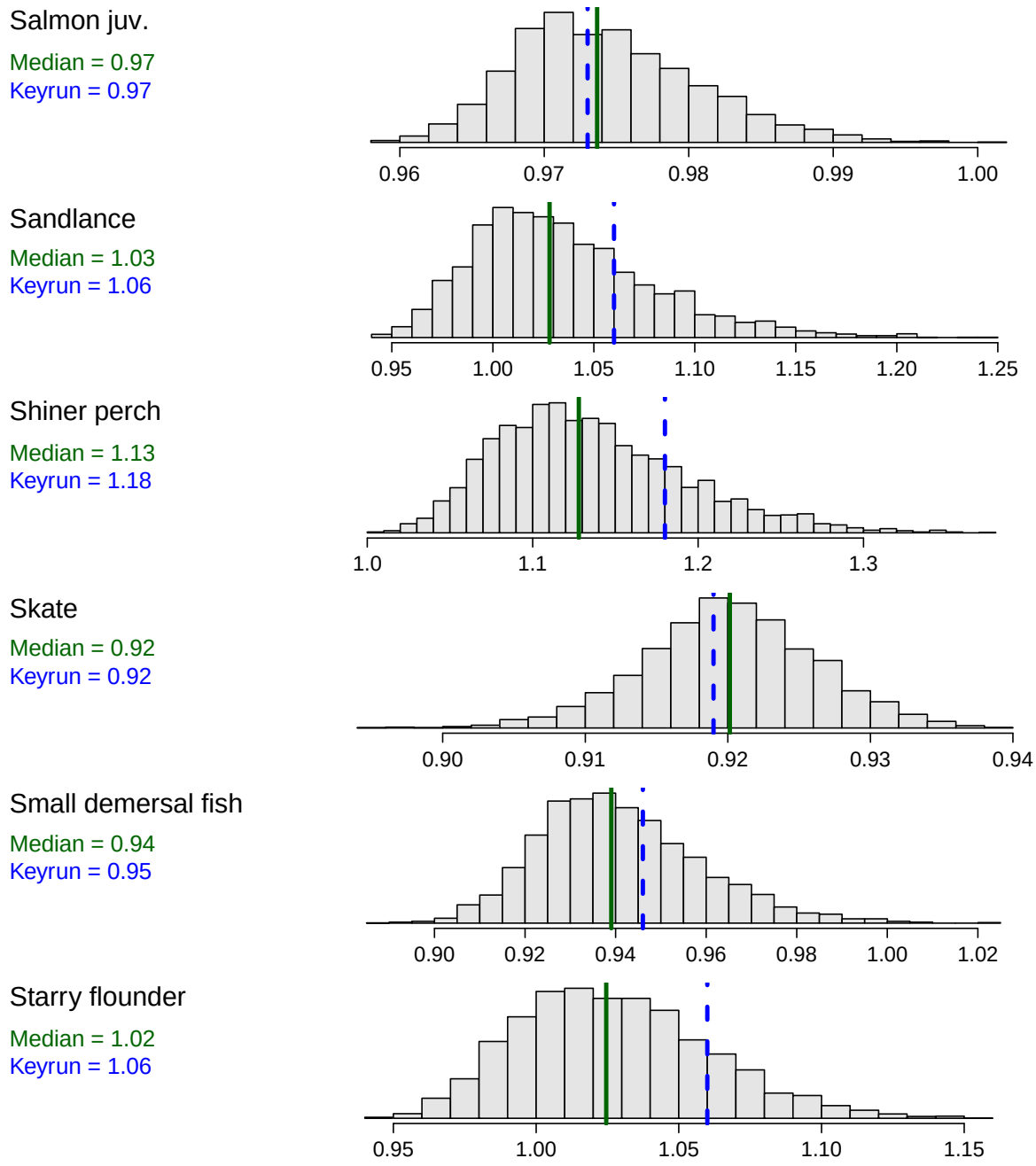


Figure 3-19 Biomass Ratio With/Without Project for Invertebrates Functional Groups, Based on 4,000 Evaluations of Input Parameter Uncertainty

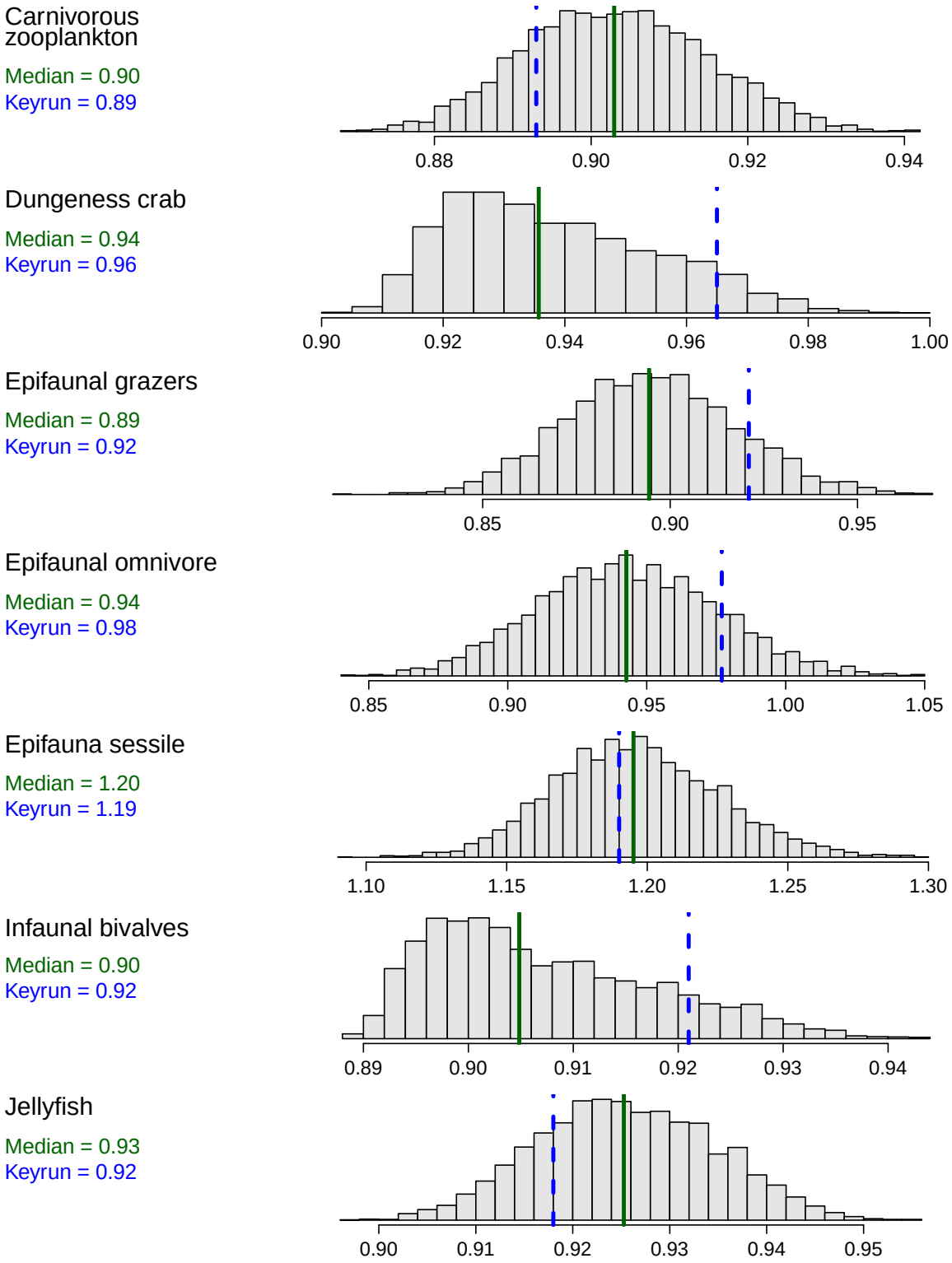
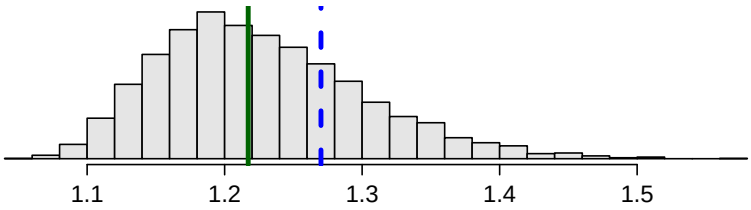


Figure 3-20 Biomass Ratio With/Without Project for Invertebrates Functional Groups, Based on 4,000 Evaluations (continued)

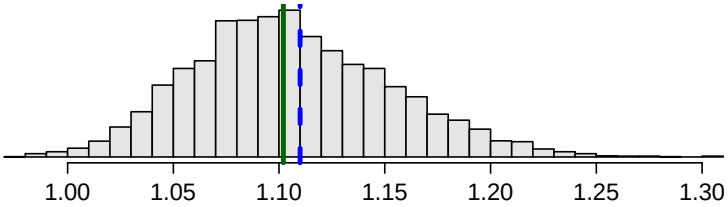
Macrofauna

Median = 1.22
Keyrun = 1.27



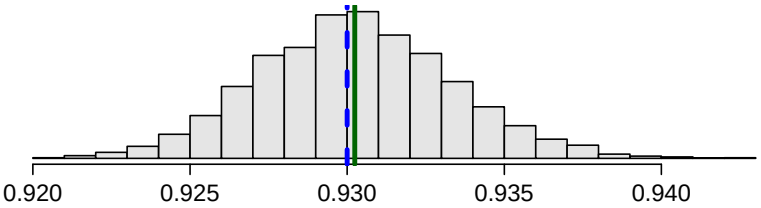
Meiofauna

Median = 1.10
Keyrun = 1.11



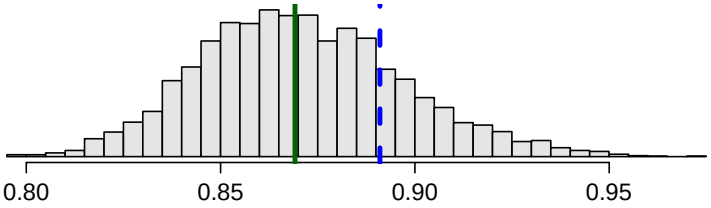
Omnivorous and herbivorous zooplankton

Median = 0.93
Keyrun = 0.93



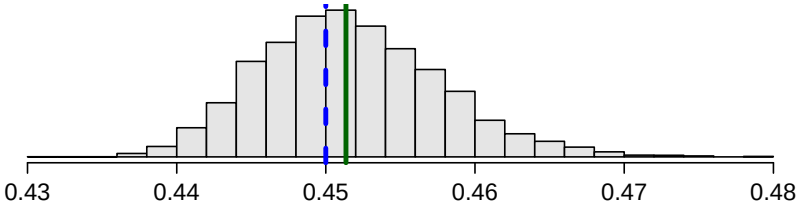
Polychaetes

Median = 0.87
Keyrun = 0.89



Orange sea pen

Median = 0.45
Keyrun = 0.45



Shrimp

Median = 0.88
Keyrun = 0.87

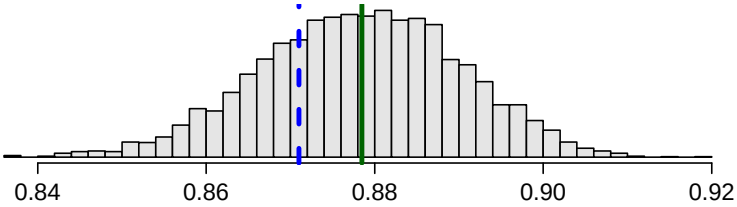


Figure 3-21 Biomass Ratio With/Without Project for Marine Vegetation Functional Groups, Based on 4,000 Evaluations

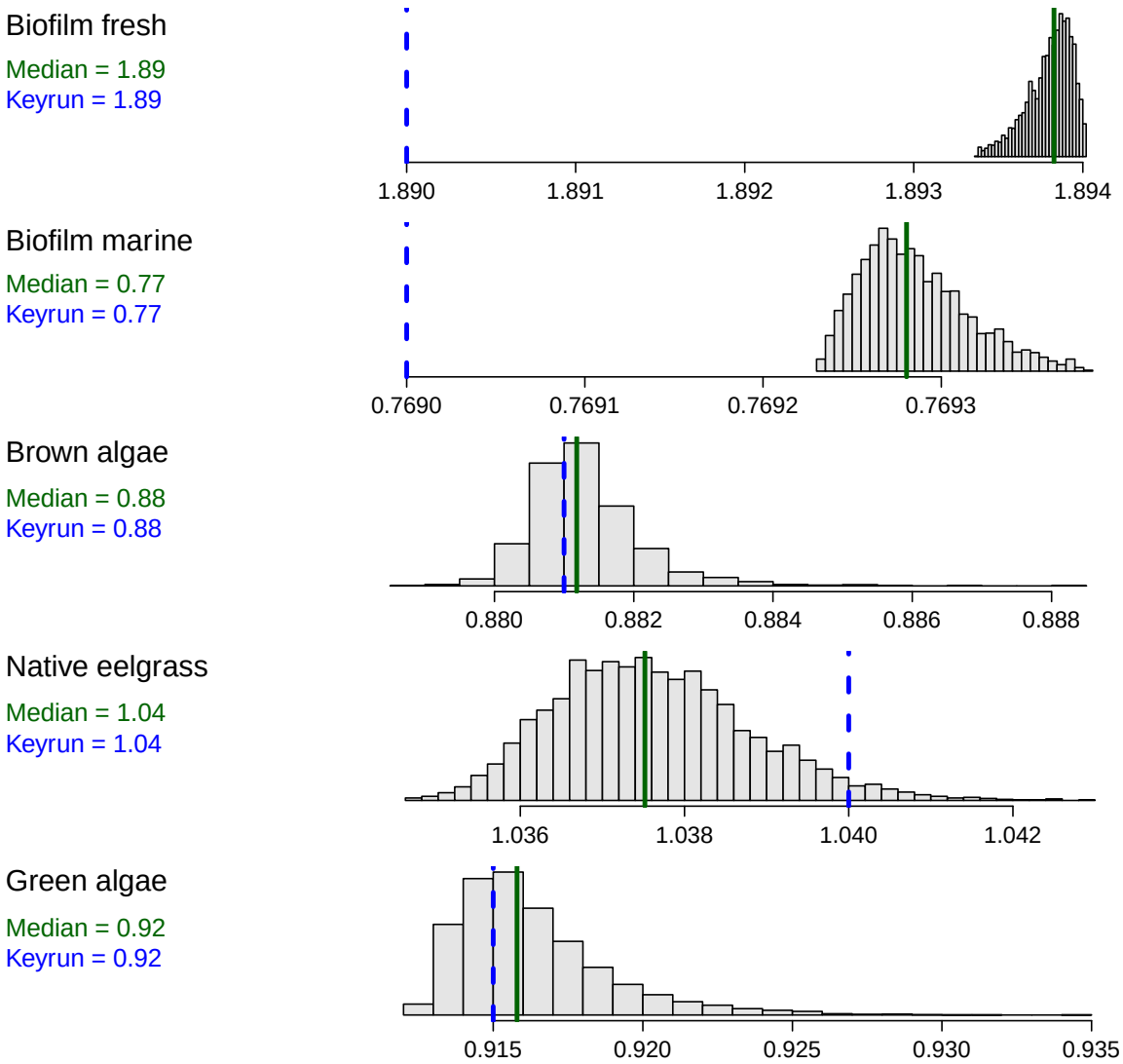
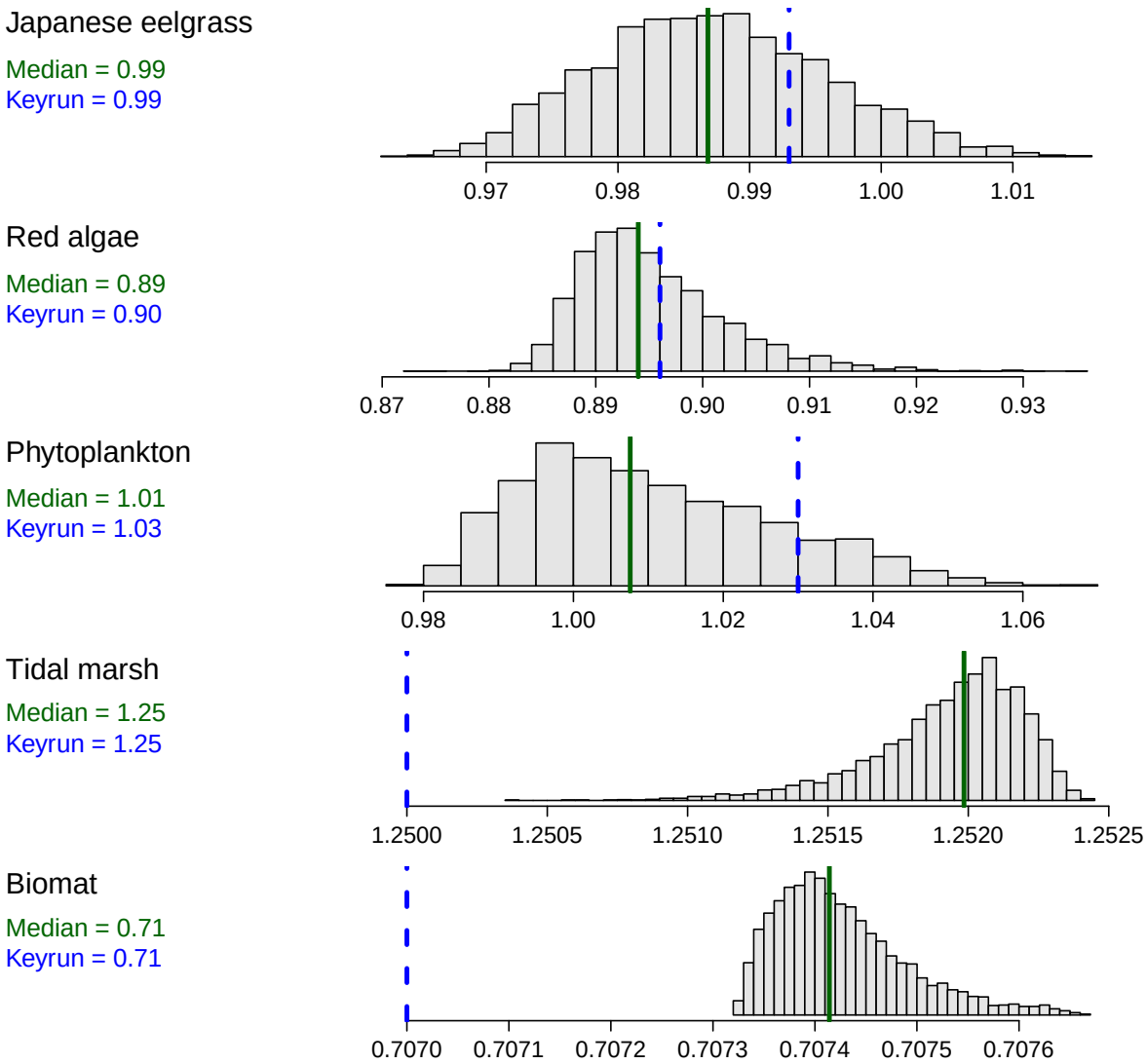


Figure 3-22 Biomass Ratio With/Without Project for Marine Vegetation Functional Groups, Based on 4,000 Evaluations of Input Parameter Uncertainty (continued)



The biomass ratios for the key run were generally similar to the median biomass ratios obtained from the 4,000 MC runs. Some noteworthy findings were that the median at the most exceeded the value from the key run by 2.0%, which was for lingcod, followed by rockfish with a 1.4% change. Further, there were four cases where the key run exceeded the median by more than 5%. These cases were:

- Shiner perch, in which the key run indicated a biomass ratio of 1.18, but was reduced to 1.13 in the MC results (for a difference of -5.6%)
- Raptors, in which the key run produced a biomass ratio of 1.31, while the median from the MC analysis was 1.26 (difference of -5.6%)
- Juvenile chinook salmon, in which the key run forecast a biomass ratio of 1.16, as opposed to 1.10 from the MC median run; a difference of -5.4%.
- Macrofauna, for which the key run yielded a biomass ratio of 1.27, and the MC median was 1.22 (difference of -5.0%).

Overall, 31 of 53 groups decreased more when input parameter uncertainty was considered compared to the key run, but for only 16 of these did the decrease exceed 1%. Also, the four most pronounced cases where the median was more than 5% lower than the key run (those listed above) were for groups forecasted to increase at least 10% with the Project.

In birds, the median MC biomass and key run ratios were very similar with the exception of raptors (-5.6%), as discussed above. The next largest deviation was for gulls and terns where the key run gave a biomass ratio of 0.99 and the key run 0.97.

For fish, half of 18 functional groups had increased biomass ratios in the MC analysis. For functional groups associated with hard bottom (lingcod and rockfish), the increase was most pronounced (at 2.0% and 1.4%, respectively). The biggest decreases in biomass ratio in the MC runs were for shiner perch and juvenile chinook salmon (as discussed above), followed by juvenile chum (-4.6%) and starry flounder (-3.6%).

The median of the MC analysis indicated a lower biomass ratio than for the key run for around half of the invertebrate functional groups. The largest decrease in the MC runs was for macrofauna (-5.0%), followed by epifaunal omnivores (-3.4%) and Dungeness crab (-2.9%).

Of the ten primary producer functional groups, five showed higher biomass ratios in the median of the MC analysis compared to the key run, but the difference was less than 1% in all cases apart from for phytoplankton (-2.4%). This means that the key run can be considered a “most likely run” for the important habitat-forming producer groups, i.e. for all producers apart from phytoplankton. It may be noted that the environmental preference functions for the habitat-forming producer groups were based on local sampling, whereas it

was based on literature information for the phytoplankton as this group was assumed to be less impacted by the Project due to its more planktonic life form.

The 4,000 MC runs made it possible to evaluate how input parameter uncertainty is distributed and how it may impact potential biomass changes as a result of the Project. The percentiles from the MC runs are summarized in **Table 3-1** for birds, in **Table 3-2** for fish, in **Table 3-3** for invertebrates, and in **Table 3-4** for primary producers. The percentile values were used to evaluate the uncertainty associated with the biomass ratio estimated for a functional group. For interpretation, the larger the range is for the 95% confidence interval (from the 0.025 percentile to the 0.975 percentile), the higher the uncertainty.

For birds, the 95% intervals (i.e., from 0.025 pct to 0.975 pct) are relatively wide for raptors (1.15 to 1.41), western sandpiper (1.06 to 1.23) and shorebirds (0.91 to 1.06) (**Table 3-1**).

Table 3-1 Biomass Ratio (pct, percentiles) With/Without Project by Functional Group of Birds Based on 4,000 Evaluations of Input Parameter Uncertainty

Group	0.01 pct	0.025 pct	0.05 pct	0.10 pct	0.50 pct	0.90 pct	0.95 pct	0.975 pct	0.99 pct
American wigeon	0.90	0.90	0.90	0.90	0.92	0.93	0.94	0.94	0.95
Bald eagle	0.90	0.90	0.91	0.91	0.92	0.95	0.96	0.96	0.98
Brant goose	0.94	0.94	0.94	0.94	0.95	0.95	0.95	0.95	0.95
Diving waterbirds	0.92	0.92	0.93	0.93	0.93	0.94	0.95	0.95	0.95
Dunlin	1.08	1.08	1.09	1.1	1.13	1.16	1.17	1.18	1.19
Great blue heron	0.97	0.97	0.98	0.98	0.99	1.01	1.01	1.02	1.03
Gulls and terns	0.95	0.95	0.96	0.96	0.97	0.99	0.99	1.00	1.00
Raptors	1.12	1.15	1.16	1.18	1.26	1.35	1.39	1.41	1.46
Shorebirds	0.90	0.91	0.92	0.93	0.97	1.03	1.05	1.06	1.08
Waterfowl	1.04	1.04	1.05	1.05	1.08	1.10	1.10	1.11	1.11
Western sandpiper	1.04	1.06	1.07	1.09	1.14	1.19	1.21	1.23	1.25

Note: The colours indicate conditional formatting with biomass ratios ranging from decreases in red to increases in green. A large range of values in the 95% confidence interval (from 0.025 pct to 0.975 pct) indicates high uncertainty.

For fish (**Table 3-2**), the 95% intervals are wide for juvenile chinook salmon (0.99 to 1.30), juvenile chum (1.00 to 1.27), shiner perch (1.05 to 1.27) , and lingcod (0.92 to 1.15).

Table 3-2 Biomass Ratio (pct, percentiles) With/Without Project by Functional Group of Fish Based on 4,000 Evaluations of Input Parameter Uncertainty

Group	0.01 pct	0.025 pct	0.05 pct	0.10 pct	0.50 pct	0.90 pct	0.95 pct	0.975 pct	0.99 pct
Chinook adult	0.94	0.94	0.95	0.95	0.95	0.96	0.96	0.96	0.97
Chinook juv.	0.98	0.99	1.01	1.02	1.10	1.23	1.27	1.30	1.34
Chum adult	0.95	0.95	0.95	0.95	0.96	0.96	0.96	0.97	0.97
Chum juv.	0.99	1.00	1.01	1.03	1.10	1.20	1.24	1.27	1.30
Dogfish	0.97	0.97	0.97	0.97	0.98	0.98	0.99	0.99	0.99
Flatfish	0.97	0.97	0.97	0.98	0.99	0.99	1.00	1.00	1.00
Forage fish	0.97	0.97	0.98	0.98	0.98	0.99	1.00	1.00	1.01
Herring	0.94	0.94	0.94	0.95	0.97	1.01	1.03	1.04	1.06
Large demersal fish	0.94	0.95	0.95	0.95	0.97	1.00	1.01	1.02	1.03
Lingcod	0.92	0.92	0.93	0.94	0.99	1.08	1.11	1.15	1.19
Rockfish	0.90	0.90	0.90	0.91	0.93	0.96	0.97	0.98	1.00
Salmon ad.	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.97
Salmon juv.	0.96	0.96	0.97	0.97	0.97	0.98	0.99	0.99	0.99
Sandlance	0.96	0.97	0.97	0.98	1.03	1.10	1.12	1.14	1.17
Shiner perch	1.03	1.05	1.06	1.07	1.13	1.21	1.24	1.27	1.29
Skate	0.91	0.91	0.91	0.91	0.92	0.93	0.93	0.93	0.93
Small demersal fish	0.91	0.91	0.92	0.92	0.94	0.97	0.97	0.98	0.99
Starry flounder	0.96	0.97	0.98	0.99	1.02	1.07	1.09	1.10	1.12

Note: The colours indicate conditional formatting with biomass ratios ranging from decreases in red to increases in green. A larger range of values in the 95% confidence interval (from 0.025 pct to 0.975 pct) indicates higher uncertainty.

The 95% intervals were generally narrow for invertebrates, with the exception of macrofauna (1.11 to 1.40), and meiofauna (1.02 to 1.21) (**Table 3-3**). This was even more pronounced for primary producers, with the largest 95% interval being that for phytoplankton (0.99 to 1.05) (**Table 3-4**).

Table 3-3 Biomass Ratio (pct, percentiles) With/Without Project by Functional Group of Invertebrates Based on 4,000 Evaluations of Input Parameter Uncertainty

Group	0.01 pct	0.025 pct	0.05 pct	0.10 pct	0.50 pct	0.90 pct	0.95 pct	0.975 pct	0.99 pct
Carnivorous zooplankton	0.88	0.88	0.88	0.89	0.90	0.92	0.92	0.93	0.93
Dungeness crab	0.91	0.91	0.92	0.92	0.94	0.96	0.97	0.97	0.98
Epifaunal grazers	0.85	0.85	0.86	0.87	0.89	0.93	0.93	0.94	0.95
Epifaunal omnivore	0.87	0.88	0.89	0.90	0.94	0.98	1.00	1.01	1.02
Epifauna sessile	1.13	1.14	1.15	1.16	1.20	1.23	1.25	1.26	1.27
Infaunal bivalves	0.89	0.89	0.89	0.90	0.90	0.92	0.93	0.93	0.93
Jellyfish	0.91	0.91	0.91	0.91	0.93	0.94	0.94	0.94	0.95
Macrofauna	1.10	1.11	1.12	1.14	1.22	1.33	1.36	1.40	1.43
Meiofauna	1.01	1.02	1.03	1.05	1.10	1.17	1.19	1.21	1.22
Omnivorous and herbivorous zooplankton	0.92	0.92	0.93	0.93	0.93	0.93	0.94	0.94	0.94
Polychaetes	0.82	0.82	0.83	0.84	0.87	0.91	0.92	0.93	0.94
Orange sea pen	0.44	0.44	0.44	0.44	0.45	0.46	0.46	0.46	0.47
Shrimp	0.85	0.85	0.86	0.86	0.88	0.89	0.90	0.90	0.90

Note: The colours indicate conditional formatting with biomass ratios ranging from decreases in red to increases in green. A larger range of values in the 95% confidence interval (from 0.025 pct to 0.975 pct) indicates higher uncertainty.

Table 3-4 Biomass Ratio (pct, percentiles) With/Without Project by Functional Group of Primary Producers Based on 5,000 Evaluations of Input Parameter Uncertainty

Group	0.01 pct	0.025 pct	0.05 pct	0.10 pct	0.50 pct	0.90 pct	0.95 pct	0.975 pct	0.99 pct
Biofilm fresh	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89
Biofilm marine	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77
Brown algae	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Native eelgrass	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
Green algae	0.91	0.91	0.91	0.91	0.92	0.92	0.92	0.92	0.93
Japanese eelgrass	0.97	0.97	0.97	0.98	0.99	1.00	1.00	1.00	1.01
Red algae	0.88	0.89	0.89	0.89	0.89	0.9	0.91	0.91	0.92
Phytoplankton	0.98	0.99	0.99	0.99	1.01	1.03	1.04	1.05	1.05
Tidal marsh	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Biomat	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71

Note: The colours indicate conditional formatting with production ratio ranging from decreases in red to increases in green. A larger range of values in the 95% confidence interval (from 0.025 pct to 0.975 pct) indicates higher uncertainty.

The proportion of MC runs where biomass was forecasted to increase is shown in **Table 3-5**.

Among birds, biomass increased in all MC runs for dunlin, raptors, waterfowl, and western sandpiper. In contrast, American wigeon, bald eagle, Brant goose, diving waterbirds, and gulls and terns never or almost never saw increases in biomass as a result of the proposed Project.

Among the fish, only shiner perch had increase in all runs, while juvenile chinook salmon, juvenile chum salmon, sandlance, and starry flounder had increases in most of the runs with the Project. Here, adult chinook salmon, adult chum salmon, dogfish, flatfish, forage fish, herring, large demersal fish, rockfish, adult salmon, juvenile salmon, skate and small demersal fish always or almost always decreased in the MC runs with the Project.

Only three invertebrate functional groups (epifauna sessile, macrofauna and meiofauna) showed increased biomass in the majority of the MC runs (>99%) while the remaining

invertebrate functional groups never or rarely (4% or less) showed cases with increased biomass.

Among the primary producers, biofilm fresh, native eelgrass, and tidal marsh always showed increases in biomass ratio with the Project, while biofilm marine, brown algae, green algae, red algae and biomat never showed higher biomass with the Project.

Table 3-5 Proportion of Monte Carlo Runs where the Biomass Ratio (With/Without Project) Indicated an Increase in Biomass 'with Project' for each Functional Group

	Group	Prop.		Group	Prop.		Group	Prop.
6	American wigeon	0.00	24	Herring	0.15	41	Jellyfish	0.00
7	Bald eagle	0.00	25	Large demersal fish	0.10	42	Macrofauna	1.00
8	Brant goose	0.00	26	Lingcod	0.42	43	Meiofauna	0.99
9	Diving waterbirds	0.00	27	Rockfish	0.01	44	Omnivorous and herbivorous zooplankton	0.00
10	Dunlin	1.00	28	Salmon ad.	0.00	45	Polychaetes	0.00
11	Great blue heron	0.17	29	Salmon juv.	0.00	46	Orange sea pen	0.00
12	Gulls and terns	0.02	30	Sandlance	0.78	47	Shrimp	0.00
13	Raptors	1.00	31	Shiner perch	1.00	48	Biofilm fresh	1.00
14	Shorebirds	0.24	32	Skate	0.00	49	Biofilm marine	0.00
15	Waterfowl	1.00	33	Small demersal fish	0.00	50	Brown algae	0.00
16	Western sandpiper	1.00	34	Starry flounder	0.78	51	Native eelgrass	1.00
17	Chinook adult	0.00	35	Carnivorous zooplankton	0.00	52	Green algae	0.00
18	Chinook juv.	0.96	36	Dungeness crab	0.00	53	Japanese eelgrass	0.08
19	Chum adult	0.00	37	Epifaunal grazers	0.00	54	Red algae	0.00
20	Chum juv.	0.98	38	Epifaunal omnivore	0.04	55	Phytoplankton	0.68
21	Dogfish	0.00	39	Epifauna sessile	1.00	56	Tidal marsh	1.00
22	Flatfish	0.03	40	Infaunal bivalves	0.00	57	Biomat	0.00
23	Forage fish	0.04						

Note: The detritus functional group was excluded from this table

4.0 DISCUSSION

In the face of uncertainty, ecosystem modelling and associated sensitivity analyses are reasonable means to forecast changes related to complex scenarios. In this report, the question of the uncertainty of the forecasts about the proposed Project's effects has been addressed in several ways. The present report was designed to comprehensively and transparently evaluate the most immediate questions about uncertainty.

The overall result from the study was that the results from the Roberts Bank ecosystem model were generally consistent among scenarios. The key run of the Roberts Bank ecosystem model (ESSA 2014) forecasted that the proposed Project would result in variable changes to biomass and production, but that for most functional groups these changes (either positive or negative) would be of limited magnitude. The evaluations of uncertainty in this report did not substantively change the findings in the key run. A notable exception was for orange sea pen, which in the key run was forecasted to see a marked decrease in biomass associated with the proposed Project. This decrease was due to loss of their primary habitat area, where the proposed terminal is to be situated. In the scenario where the environmental preference for depth was removed for orange sea pens, the decrease was less pronounced – as a function of orange sea pens being spread out over a larger habitat area. For other groups, there was general consistency among results of different uncertainty scenarios, indicating a considerable degree of robustness for the model findings.

The sensitivity analysis also demonstrated that the Roberts Bank ecosystem model is not sensitive to over or underestimation of Project effects. The analysis looked at 20% variance in abiotic factors relative to key run, however uncertainty for the coastal geomorphology model is likely less than 5%. Most aggregated groups showed what is considered an insignificant change (i.e. less than 5% difference) as biomass response to the proposed Project when abiotic factors were varied. However, larger responses were observed for the Roberts Bank ecosystem (≤7%), birds (≤12%), and primary producers (≤12%).

The MC analysis indicated that the biomass ratio for shiner perch juvenile, raptors, chinook salmon, and macrofauna were potentially overestimated. Out of these four functional groups, none changed from increasing with Project to decreasing with Project, indeed all were projected to increase with more than 10%. The dozen functional groups with the largest uncertainty in biomass ratio from the 95% confidence interval of the MC runs were juvenile chinook (0.99 to 1.30), macrofauna (1.11 to 1.40), raptors (1.15 to 1.41), juvenile chum (1.00 to 1.27), lingcod (0.92 to 1.15), shiner perch (1.05 to 1.27), meiofauna (1.02

to 1.21), sandlance (0.97 to 1.14), western sandpiper (1.06 to 1.23, shorebirds (0.91 to 1.06), starry flounder (0.97 to 1.10) and epifaunal omnivore (0.88 to 1.01). These species are therefore good candidates for monitoring, should the proposed Project proceed. Other factors that could be included in a more exhaustive study include the combined effects of temperature and oxygen, which were not examined due to lack of data.

Another limitation was the degree to which forecasts rely on the choice of modelling approach. An assumption in the Roberts Bank ecosystem model was that the species' geographic distributions reflected their environmental preferences, and that this was directly linked to their potential productivity in the study area. For instance, if native eelgrass was mostly found in locations with an average salinity of 25 psu, this was assumed to be their preferred environment. Similarly, if dunlin is primarily found at 0-5m depth below the high tide level, this was assumed to be their environmental preference. This is especially a limitation where the local conditions do not cover the potential distribution range for a species.

Further, it was assumed that environmental factors obtained from the Roberts Bank coastal geomorphology model, i.e., depth, salinity, bottom current, and wave height (NHC 2014), combined with hard/soft bottom (Hemmera 2014, ESSA 2014), were sufficient to forecast changes in productivity as a result of the Project. These are assumptions that reflect lack of alternative data and information sources, but they do not in any way invalidate the results. Rather, the sensitivity tests that are reported here indicate that the forecasts were robust, regardless of limitations. For example, while it was not feasible to forecast changes in grain size distributions due to the proposed Project, analyses indicated that percent sand is positively correlated with wave height and current velocities (see **Appendix B**), factors that were considered in the coastal geomorphology model and Roberts Bank ecosystem model. Similarly, while it was not feasible to forecast changes in turbidity due to the proposed Project, turbidity in the Fraser River estuary is likely to be inversely correlated with salinity, as shown elsewhere (Marshall and Elliott 1998). The sediment supply to the southern Roberts Bank tidal flats is primarily fine suspended sediments from the Fraser River plume. The proposed terminal pad will increase the residence time of lower salinity Fraser River water in the region shoreward of the terminal pad and north of the causeway (NHC 2014). Since salinity was considered in the coastal geomorphology model and Roberts Bank ecosystem model, it is likely that the environmental preferences for salinity that were incorporated at least partially covers the turbidity preferences, even if by proxy.

Finally, while it might be argued that biomass and production are more closely correlated to seasonal values of abiotic factors, it was not possible to develop an ecological model on such fine temporal scales, given the lack of information on seasonal or monthly variability in the distribution and abundance of biota (see **Appendix C**). The ecological model used here makes forecasts that can be tested during post-construction monitoring, should the proposed Project proceed. The proposed Project would also include onsite mitigation of potential loss of productive potential (see **Appendix D**).

Table 4-1 shows the expected change for each functional group as identified by the PC-TAG based on weight of evidence from the key run and the Monte Carlo analysis. Twelve focal species are expected to increase in biomass with Project relative to without Project. The biomass ratio for the lower end of the 95% confidence from the Monte Carlo analysis is above one for all species except juvenile chinook and chum. Both species are expected to increase because the median of the MC runs is 10%. The lowest increase is 4% for Native eelgrass, but the forecasted increase is consistent for both the key run and the Monte Carlo analysis. The mean increase for the focal species that are expected to increase in biomass is 20% and 22% for the key run and the median of the Monte Carlo runs respectively. Ten focal species are not expected to change. The 95% confidence interval for all these focal species include biomass ratios above and below one. The mean change for these focal species are 0% and -1% for the key run and the median of the Monte Carlo runs respectively. Sixteen focal species are forecasted to decrease. The biomass ratio for the upper end of the 95% confidence from the Monte Carlo analysis is one or below for all species. The mean decrease in biomass is 13% and 17% for the key run and the median of the Monte Carlo runs respectively.

Table 4-1 Expected Change for Each Functional Group Based on Weight of Evidence

Functional group	Key run	MC min	MC median	MC max	Weight of evidence
Biofilm freshwater	1.89	1.89	1.89	1.89	Increase
Other raptors	1.31	1.12	1.26	1.46	Increase
Intertidal marsh	1.25	1.25	1.25	1.25	Increase
Macrofauna	1.27	1.10	1.22	1.43	Increase
Western sandpiper	1.13	1.04	1.14	1.25	Increase
Shiner perch	1.18	1.03	1.13	1.29	Increase
Pacific dunlin	1.13	1.08	1.13	1.19	Increase
Meiofauna	1.11	1.01	1.10	1.22	Increase
Chinook (juvenile)	1.16	0.98	1.10	1.34	Increase
Chum (juvenile)	1.14	0.99	1.10	1.30	Increase
Other waterfowl	1.08	1.04	1.08	1.11	Increase
Native eelgrass	1.04	1.04	1.04	1.04	Increase
Pacific sandlance	1.06	0.96	1.03	1.17	No change
Starry flounder	1.06	0.95	1.02	1.15	No change
Non-native eelgrass	0.99	0.97	0.99	1.01	No change
Lingcod	0.97	0.92	0.99	1.19	No change
Other flatfish	0.98	0.97	0.99	1.00	No change
Great blue heron	1.00	0.97	0.99	1.03	No change

Other forage fish	0.99	0.97	0.98	1.01	No change
Pacific herring	0.98	0.94	0.97	1.06	No change
Other shorebirds	0.98	0.90	0.97	1.08	No change
Gulls and terns	0.99	0.95	0.97	1.00	No change
Chum (adult)	0.95	0.95	0.96	0.97	Decrease
Chinook (adult)	0.95	0.94	0.95	0.97	Decrease
Brant	0.95	0.94	0.95	0.95	Decrease
Dungeness crabs	0.97	0.91	0.94	0.98	Decrease
Small demersals	0.95	0.91	0.94	0.99	Decrease
Rockfish	0.91	0.90	0.93	1.00	Decrease
Diving birds	0.94	0.92	0.93	0.95	Decrease
Green algae	0.92	0.91	0.92	0.93	Decrease
American wigeon	0.92	0.90	0.92	0.95	Decrease
Bald eagle	0.93	0.90	0.92	0.98	Decrease
Bivalve shellfish	0.92	0.89	0.90	0.93	Decrease
Brown algae	0.88	0.88	0.88	0.88	Decrease
Polychaetes	0.89	0.82	0.87	0.94	Decrease
Biofilm marine	0.77	0.77	0.77	0.77	Decrease
Biomat	0.71	0.71	0.71	0.71	Decrease
Orange sea pens	0.45	0.44	0.45	0.47	Decrease

5.0 CLOSURE

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7.0 STATEMENT OF LIMITATIONS

This report was prepared by ESSA Technologies Ltd., based on information supplied by Hemmera and NHC, for the sole benefit and exclusive use of Port Metro Vancouver. The material in it reflects the best judgment by ESSA Technologies and its sub-contractors in light of information available to it at the time of preparing this report. Any use that a third party makes of this report, or any reliance on or decision made based on it, is the responsibility of such third parties. ESSA Technologies and its sub-contractors accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on this Report.

ESSA Technologies and its sub-contractors have performed the work as described above and made the findings and conclusions set out in this report in a manner consistent with the level of care and skill normally exercised by members of the environmental science profession practicing under similar conditions at the time the work was performed.

This report represents a reasonable analysis based on the information and methodologies available to ESSA Technologies and its sub-contractors within the established scope, work schedule and budgetary constraints. It is possible that there are effects that have not considered in this report because of lack of information, and hence currently unrecognised factors. No warranty, expressed or implied, is given concerning the impact of unrecognised factors, expect as specifically noted in this report.

The conclusions and recommendations contained in the report were based on applicable legislation existing at the time the report was drafted. Any changes in the legislation may alter the conclusions and/or recommendations contained in this report. Regulatory implications discussed in this report were based on the applicable legislation existing at the time this report was written.

In preparing this report, ESSA Technologies and its sub-contractors have relied in good faith on information provided by others as noted in this report, and have assumed that the information provided by those individuals and organizations is both factual and accurate. ESSA Technologies and its sub-contractors accept no responsibility for any deficiency, misstatement or inaccuracy in the report resulting from the information provided by those individuals or organizations.

The liability of ESSA Technologies to Port Metro Vancouver shall be limited to injury or loss caused by negligent acts of ESSA Technologies. The total aggregate liability of ESSA Technologies related to this agreement shall not exceed the lesser of the actual damages incurred, or the total fee of ESSA Technologies for services rendered on the project.

APPENDIX A:

TABLES REPRODUCED FROM ESSA 2014

Table A-1 Functional Group Abbreviations

Functional groups					
Marine mammals		19	Chum salmon* juvenile (CM-A)	39	Epifaunal sessile suspension feeders (ES)
1	Baleen whales (BW)	20	Chum salmon* juvenile (CM-J)	40	Infaunal bivalve* (IB)
2	Dolphins and porpoises (D&P)	21	Dogfish (DF)	41	Jellyfish (J)
3	Pinnipeds (P)	22	Flatfish (FL)	42	Macrofauna* (MaF)
4	Southern resident killer whales* (SRKW)	23	Forage fish (FF)	43	Meiofauna (MeF)
5	Transient killer whales* (KW)	24	Herring (H)	44	Omnivorous and herbivorous zooplankton (OHZ)
Birds		25	Large demersal fish (LDF)	45	Polychaetes* (P)
6	American wigeon* (AW)	26	Lingcod* (LC)	46	Orange sea pen (OSP)
7	Bald eagle* (BE)	27	Rockfish* (RF)	47	Shrimp (SHP)
8	Brant goose* (BG)	28	Salmon adult (S-A)	Primary producers	
9	Diving waterbirds (DW)	29	Salmon juvenile (S-J)	48	Biofilm fresh* (BF)
10	Dunlin* (DN)	30	Sandlance* (SL)	49	Biofilm marine* (BM)
11	Great blue heron* (GBH)	31	Shiner perch* (SP)	50	Brown algae* (BA)
12	Gulls and terns (G&T)	32	Skate (SK)	51	Eelgrass (native)* (NE)
13	Raptors (R)	33	Small demersal fish (SDF)	52	Green algae* (GA)
14	Shorebirds (S)	34	Starry flounder* (SF)	53	Japanese eelgrass (non-native)* (JE)
15	Waterfowl (W)			54	Red algae (RA)
16	Western sandpiper* (WS)	Invertebrates		55	Phytoplankton (PP)
		35	Carnivorous zooplankton (CZ)	56	Tidal marsh* (TM)
Fish		36	Dungeness crab* (DC)	57	Biomat (BM)
17	Chinook salmon* adult (CK-A)	37	Epifaunal grazer (EG)	Detritus	
18	Chinook salmon* juvenile (CK-J)	38	Epifaunal omnivore (EO)	58	Detritus (DET)

Note: * indicates focal species as identified by the PC-TAG; abbreviations are shown in bracket after the functional group name

Table A1.1 Model Pedigree Definitions for Biomasses

No	Parameter	Index	CI (%)
1	'Missing' parameter (estimated by Ecopath)	0.0	n.a.
2	From other model	0.0	80
3	Based on Professional judgement	0.0	80
4	Approximate or indirect method	0.4	50
5	Sampling based, low precision	0.7	30
6	Sampling based, high precision	1.0	10

Note: The pedigree is a measure of data source quality. The index value is used to estimate the overall pedigree index of the Roberts Bank ecosystem model. CI indicates the 95% confidence interval as percentage of the mean.

Table A1.2 Model Pedigree Definitions for Production/Biomass and Consumption/Biomass Ratios

No	Parameter	Index	CI (%)
1	'Missing' parameter (estimated by Ecopath)	0.0	n.a.
2	Professional judgement	0.1	70
3	From other model	0.2	60
4	Empirical relationships	0.5	50
5	Similar group/species, similar system	0.6	40
6	Similar group/species, same system	0.7	30
7	Same group/species, similar system	0.8	20
8	Same group/species, same system	1.0	10

Note: The pedigree is a measure of data source quality. The index value is used for estimating the overall pedigree index of the Roberts Bank ecosystem model. CI indicates the 95% confidence interval as percentage of the mean.

Table A1.3 Model Pedigree Definitions for Diet Compositions

No	Parameter	Index	CI (%)
1	General knowledge of related group/species	0.0	100
2	From other model	0.0	100
3	General knowledge for same group/species	0.2	80
4	Qualitative diet composition study	0.5	50
5	Quantitative but limited diet composition study	0.7	40
6	Quantitative, detailed, diet composition study	1.0	30

Note: The pedigree is a measure of data source quality. The index value is used for estimating the overall pedigree index of the Roberts Bank ecosystem. CI indicates the 95% confidence interval as percentage of the mean.

Table A1.4 Model Pedigree Illustrating How Well Rooted the Roberts Bank Ecopath Model Is in Local Data

No	Group name	Biomass	P/B	Q/B	Diet
1	Baleen whales	4	3	3	3
2	Dolphins and porpoises	4	3	3	5
3	Pinnipeds	5	3	3	5
4	Southern resident killer whales	5	7	4	5
5	Transient killer whales	5	7	4	5
6	American wigeon	6	4	4	4
7	Bald eagle	6	4	4	4
8	Brant goose	6	4	4	4
9	Diving waterfowl	6	4	4	4
10	Dunlin	6	4	4	4
11	Great blue heron	6	4	4	4
12	Gulls and terns	6	4	4	4
13	Raptors	6	4	4	4
14	Shorebirds	6	4	4	4
15	Waterfowl	6	4	4	4
16	Western sandpiper	6	4	4	4
17	Chinook adult	4	7	4	3
18	Chinook juvenile	5	2	3	3
19	Chum adult	3	4	4	3
20	Chum juvenile	5	2	3	3
21	Dogfish	3	4	4	3
22	Flatfish	5	4	4	3
23	Forage fish	5	4	4	3
24	Herring	5	4	4	3
25	Large demersal fish	5	4	4	3

No	Group name	Biomass	P/B	Q/B	Diet
26	Lingcod	5	4	4	3
27	Rockfish	5	4	4	3
28	Salmon adult	1	4	4	3
29	Salmon juvenile	5	4	4	3
30	Sandlance	5	4	4	3
31	Shiner perch	5	4	4	3
32	Skate	3	4	4	3
33	Small demersal fish	5	4	4	3
34	Starry flounder	5	4	4	3
35	Carnivorous zooplankton	4	3	3	3
36	Dungeness crab	5	6	3	3
37	Epifaunal grazers	4	3	3	3
38	Epifaunal omnivore	4	3	3	3
39	Epifauna sessile	1	4	3	3
40	Infaunal bivalves	5	3	4	3
41	Jellyfish	4	3	3	3
42	Macrofauna	6	3	4	3
43	Meiofauna	6	3	4	3
44	Omnivorous and herbivorous zooplankton	5	3	4	3
45	Polychaetes	6	5	4	3
46	Orange sea pen	6	4	4	3
47	Shrimp	4	3	3	3
48	Biofilm fresh	6	2		
49	Biofilm marine	6	2		
50	Brown algae	5	3		
51	Native eelgrass	6	3		
52	Green algae	5	3		

No	Group name	Biomass	P/B	Q/B	Diet
53	Japanese eelgrass	6	3		
54	Red algae	5	3		
55	Phytoplankton	2	3		
56	Tidal marsh	6	3		
57	Biomat	6	2		

Note: P/B is the Production/Biomass ratio, and Q/B the Consumption/Biomass ratio. Numbers in the table refer to pedigree grades. For interpretation of colours/grades, see **Table A1.1** to **Table A1.2**. The colour scale ranges from green (low pedigree) to red (high pedigree).

APPENDIX B:

SEDIMENT PARTICLE SIZE DISTRIBUTION SCENARIOS MEMO

MEMORANDUM

Date:	September 23, 2014
To:	Villy Christiansen (UBC), David Marmorek (ESSA)
From:	Scott Toews (Hemmera), Reviewed by Doug Bright (Hemmera)
Re:	Roberts Bank ecosystem model: Sediment particle size distribution scenarios

1.0 OBJECTIVE

- To provide technical advice on methods to represent sediment particle size distribution changes over time using current sediment particle size distribution and environmental correlates.
- To provide methods to UBC/ESSA regarding inputs into the Roberts Bank ecosystem model to account for sediment particle size distribution changes over time.

2.0 BACKGROUND

The Roberts Bank ecosystem model assists in evaluating potential effects to productivity associated with the proposed Roberts Bank Terminal 2 project. Input to this model included information on biomass, production and consumption parameters, diet composition, environmental preferences and abiotic characteristics (current, wave height, salinity, depth and hard/soft substrate) (ESSA 2014*a*, *b*, Hemmera 2014). Environmental preferences were chosen for ecological significance and the availability of maps of modelled data showing Project-related change for the study area. Sediment particle size distribution was not available as a modeled surface and was not included in the Roberts Bank model.

Sediment particle size composition is an important habitat component that may drive differences among nearshore marine communities (Gray 1981, Burd et al. 2008). While sediment texture can be viewed as a secondary outcome of physical oceanographic and geomorphic processes, it is likely a primary determinant for the presence, fitness, and productivity of sediment-associated marine species and communities. Sediment texture and porosity at the sediment-water interface controls the degree of interchange between sediment interstitial water and the lower portion of the water column via advection and diffusion. Advection and diffusion control the degree of oxygenation of the upper sediments versus concentrations of potentially toxic metabolites produced through the heterotrophic microbial decomposition of detrital organic matter, including sulfide and ammonia. Sediment texture reflects the tendency for less dense and smaller particles to be retained or scoured and removed to other areas. Areas with finer textured sediments (i.e., silts and clays) capture greater amounts of detrital organic

matter (typically measured as TOC), and nutrients, and tend to sorb various trace elements and organic compounds. Sediment-associated flora and fauna, in turn, are adapted to sediment geochemical conditions associated with sediment texture.

Some sediment-associated fauna may respond to bottom currents more directly, especially those that are filter feeders, so effects associated with altered bottom currents may occur independent of effects on sediment texture.

To analyze information on sediment particle size distribution and how it may influence the Roberts Bank ecosystem model, a predictive model of sediment particle size distribution for Project-related change was required. Sediment particle size distribution was not included in the coastal geomorphology model (NHC 2013) based on the premise that sediment particle size distribution is determined by the dynamic influences of tidal currents at the sediment-water interface, and wind-generated wave movements, which were assessed directly in the coastal geomorphology model. Thus, sediment particle size distribution was not available for both with-project and without-project conditions to be incorporated into the ecosystem model. Wave action and current velocity are the two most important factors determining particle size distribution and sorting of nearshore sediments following the initial sediment deposition (Gray 1981, McCave et al. 1995). The coastal geomorphology model provided spatially explicit predictions of wave height, bottom current velocity, and salinity outputs under both with-project and without-project conditions.

The initial settlement rates and potential of sediment need to be considered within an estuarine setting. Annual sedimentation rates on Roberts Bank probably fall within the range of approximately 2 to 30 mm/year, based on published studies using sediment traps and/or radiodated sediment cores (NHC 2014). Newly deposited sediments on Roberts Bank are predominantly eroded materials discharged from the Fraser River watershed, with minor contributions from detrital organic matter (dead phytoplankton, zooplankton, faecal pellets, etc.) (McLean et al. 1999). Based on the historical construction of entrainment structures on the North Arm and South Arm of the Fraser River, the major portion of sands discharged by the Fraser River settle beyond the topset sediments of the Fraser River Delta, being deposited on and beyond the foreslope sediments at the end of the major channels (McLaren and Tuominen 1999, Hill et al. 2008). Finer silt-clay sediments, however, remain in suspension longer, resulting in a visually obvious turbid plume at the water surface in outflowing brackish water as part of the dynamic salt wedge (Hill et al. 2008). These finer sediments are available for settling on the Sturgeon Bank and Roberts Bank mudflats and sandflats, and the initial rate of fines settlement is correlated with the proportion of time annually that these flats are inundated with brackish and turbid Fraser River discharge water versus low turbidity and saline marine waters that enter the Strait of Georgia from the North Pacific Ocean through the Strait of Juan de Fuca (McLaren and Tuominen 1999). The initial settlement rates of fines on the tidal flats are expected to be correlated with average salinity of the water that inundates the flats. The degree of

influence of salinity, however, could be small as current regimes rapidly re-suspend and transport finer sediments to more quiescent areas.

To assess potential sediment distribution correlations with bottom current, wave height, and salinity, a predictive correlational surface interpolate predicted sediment texture from wave height and bottom current velocity changes due to the Project. Since extensive data have been gathered on the existing tideflat sediment texture based on 2012 and 2013, the predicted sediment texture surfaces can then be used to verify that the variability created by sediment particle size distribution is adequately captured with the inclusion of wave height and bottom current velocity.

3.0 METHODS

The existing sediment particle size distribution is defined based on the percent sand data (> 63 µm effective particle size) from 380 mini-core or trowel-collected samples taken across the study site. The samples comprised the upper 10 cm of sediment. Percent sand was chosen as the dependent variable for sediment particle size distribution as it is consistently distributed across the site with few zero data points (percent clay was virtually negligible over much of the Roberts Bank tideflat). Increases in percent sand were inferred to indicate increasing sediment particle size while a decrease in percent sand inferred the inverse. Percent gravel and percent fines maps were used to compare and verify the inferences made about percent sand distributions.

The mapped sediment sampling points, corresponding to the field study sampling locations, were used to sample nhc's wave height, bottom current velocity, and salinity model values for without-project using the extract to multipoint tool in ArcGIS. The values for percent sand and all environmental variables were extracted into a table and imported into R statistical package (R Core Team 2014). Data for percent sand were $\log_{10}$ transformed to normalize residual output of the proportional data. The log of percent sand was used as the dependent variable with wave height, bottom current velocity and salinity all predictor variables. An interaction term between wave height and bottom current velocity was included in the full model.

Linear model comparisons for all model combinations were used to determine the final best model using corrected AIC values (Burnham and Anderson 2002). The best fit model from the AIC comparison was used to create a spatially explicit regression model. This model was then used to create a predictive kriged surface of sediment distribution. The without-project scenario required the use of the without-project environmental inputs from the best regression model while the predictive with-project scenario required using the without-project model to estimate a predictive surface using the with-project environmental layers. The final kriged model was validated using surface map comparisons and cross validation.

To further examine the relationship of salinity to sediment particle size distribution, percent fines (combination of percent clay and percent silt) were modeled with all the environmental variables. As there are more zeroes with this data, silt (particles in the size range of 4 to 63 µm) and clay (particles < 4 µm) were combined (i.e., as percent fines) and only used to examine salinity as a potential predictor. The same data transformations and model comparison approach was taken with fines as was done with sand.

4.0 RESULTS

Model results confirmed that at Roberts Bank there is a strong correlation between sediment particle size distribution and wave height, bottom current velocity, and salinity. The full model with wave height (wave), bottom current velocity (ubot), salinity and an interaction term (ubot:wave) was the winning model when compared with the all combinations of model parameters (**Table B-1**).

Sand Model equation:

$$\%\,Sand \sim -9.16 + 12.30 * ubot + 6.78 * wave + 0.23 * salinity - 18.88 * ubot{:}wave$$

The model parameters for bottom current velocity, wave height, and salinity all had a positive relationship with size distribution of sand (**Table B-2**). However, the interaction term between bottom current velocity and wave height was negative. This fits with theoretical understanding: in intertidal areas and shallow subtidal areas where wind waves can interact with the seabed, an increase wave height, steepening of the wave front and eventual wave crash on the beach tend to direct local wave energies downward, thus maximizing scour potential, especially near the tideline. The simultaneous presence of tidal flows would result in laminar flows at the sediment water interface, and turbulent flows at higher velocities. In either case, super-imposition of breaking waves and tidal flows would result in re-direction of the downward vector of wave energies near the sediment water interface.

An adjusted R-squared of 0.52 and a model validation correlation coefficient of 0.814 was estimated by the cross validation suggesting a high degree of correlation between the predicted model values and observed values of percent sand on Roberts Bank.

The kriged model surfaces for both with and without-project scenarios show similar patterns of sediment particle size distribution (**Figure B-1**). However, the with-project scenario does show decreasing percent sand behind the new terminal and in the shadow of the terminal near shore against the causeway, indicating a decrease in sediment particle size.

Regression models for predictions of (log-transformed) percent fine sediment as the dependent variable were similar to the results presented in Table B-1 for the sand model, though the choice of the best model was split among the top two models (

Table B-3). The pattern of distribution was complimentary to the predictive sand surfaces, with increases in fine sediment occurring in areas with predicted decreases in sand (**Figure B-2**). Parameter estimates for the fine sediment model also show the opposite pattern to the sand model in terms of direction of the parameter estimate (**Table B-4**).

Fine Sediment Model equation:

$$\%\,Fines \sim 7.47 - 4.21 * ubot - 2.64 * wave - 0.10 * salinity + 13.79 * ubot{:}wave$$

5.0 CONCLUSIONS

Regression models developed to predict either percent sand or percent fines as measures of Roberts Bank tideflat sediment texture based on predictive estimates of tidal current velocities, wave heights, and average salinity were effective in reproducing the known sediment texture based on data collected in 2012 and 2013.

The ecosystem model is deemed to have adequate utility to predict future sediment particle size distribution on the Roberts Bank tideflat from predictive estimates of altered physical oceanographic processes.

The selected regression model predicted that Project-related changes to sediment particle size distribution are localized at the RBT2 study site, driven by shadowing effects created by the new terminal. Reduced wave height and bottom current velocities will create conditions for increased suspended sediment deposition, leading to a higher percent composition of fine sediments with the Project. The predicted area of influence is localised, which suggests that effects on marine benthic communities will also be localised. There were no identifiable areas where percent sand increased. The modelling results suggest that tidal water movement will slow behind the new terminal, leading to increased sedimentation, especially of finer sediment fractions. The sediment load of the tidal flows that inundate the tideflat is measurably low (total suspended solids estimated to range from 2 mg/L to 50 mg/L), and this will impose limits on accretion rates. Local sediment supply is low for sand in most years and negligible for fine sediment for the study site (NHC 2013).

Overall, spatial variations in sediment particle size distribution strongly correlated with the major physical oceanographic variables that control sediment deposition and re-distribution (i.e., wave height, bottom current velocity, and salinity). Including these environmental parameters in the Roberts Bank ecosystem model help account for potential indirect changes in sediment particle size distribution.

6.0 TABLES

Table B-1 Sand Regression Model Comparison Table

Models	Number of Parameters (K)	AICc	Delta AICc	AICc Weight	Log-likelihood
ubot + wave + salinity + ubot:wave	6	1284.34	0	1	-636.06
ubot + wave + salinity	5	1329.19	44.85	0	-659.51
ubot + wave + ubot:wave	5	1331.87	47.52	0	-660.85
ubot + salinity	4	1335.37	51.02	0	-663.63
ubot + wave	4	1355.3	70.95	0	-673.59
wave + salinity	4	1356.13	71.79	0	-674.01
wave	3	1362.77	78.42	0	-678.35
ubot	3	1402.03	117.68	0	-697.98
salinity	3	1515.33	230.99	0	-754.63
Null	2	1558.82	274.47	0	-777.39

Note: ubot = bottom current velocity (cm/s), wave = wave height (m), salinity = practical salinity units (psu)

Table B-2 Parameter Estimates for the Best Sand Regression Model

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-9.1552	0.9888	-9.26	< 0.0001
ubot	12.3017	1.3512	9.10	< 0.0001
wave	6.7805	1.0130	6.69	< 0.0001
salinity	0.2264	0.0313	7.23	< 0.0001
ubot:wave	-18.8838	2.6902	-7.02	< 0.0001

Table B-3 Fine Sediment Regression Comparison Table

Models	Number of Parameters (K)	AICc	Delta AICc	AICc Weight	Log-likelihood
ubot + wave + salinity + ubot:wave	6	897.21	0	0.85	-442.49
ubot + wave + salinity	5	900.68	3.48	0.15	-445.26
ubot + salinity	4	911.82	14.61	0	-451.86
ubot + wave	4	921.33	24.13	0	-456.61
ubot + wave + ubot:wave	5	922.21	25	0	-456.03
wave + salinity	4	925.11	27.9	0	-458.5
wave	3	929.16	31.95	0	-461.55
ubot	3	975.72	78.51	0	-484.83
salinity	3	1104.96	207.75	0	-549.45
Null	2	1145.25	248.04	0	-570.61

Table B-4 Parameter Estimates for the Best Fine Sediment Regression Model

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	7.4677	0.5941	12.57	< 0.0001
ubot	-4.2140	0.8119	-5.19	< 0.0001
wave	-2.6398	0.6087	-4.34	< 0.0001
salinity	-0.0990	0.0188	-5.26	< 0.0001
ubot:wave	3.7937	1.6165	2.35	0.0194

7.0 FIGURES

Figure B-1 Sediment Distribution Surfaces for Without-Project Scenario

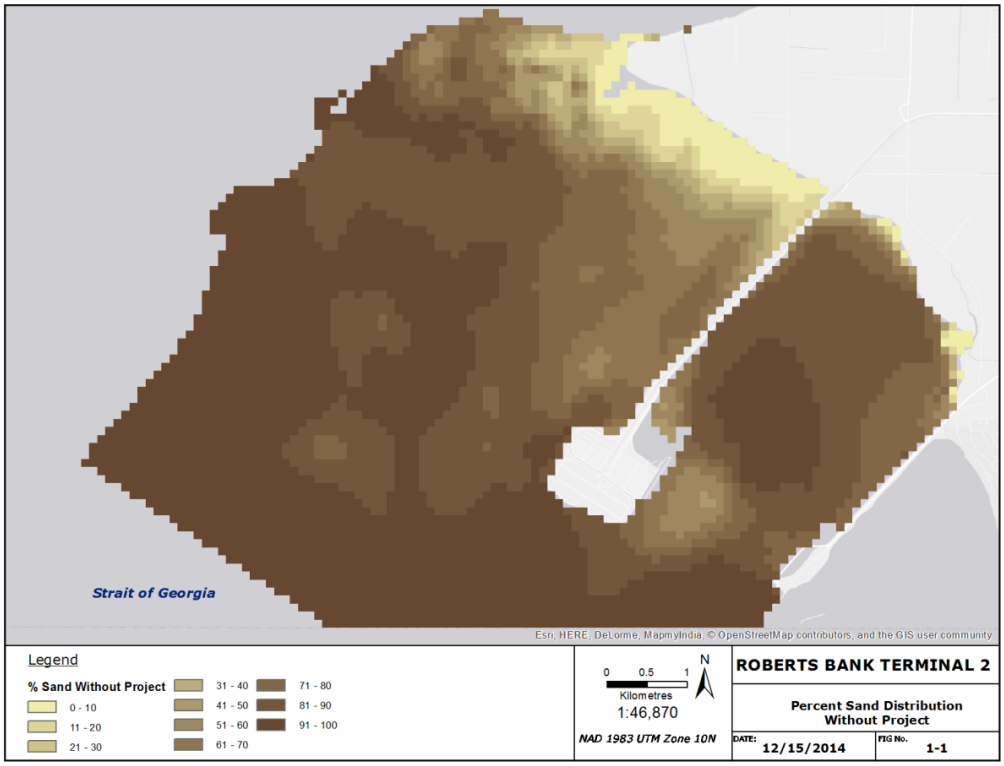


Figure B-2 Percent Sand Distribution Surfaces for With-Project Scenario

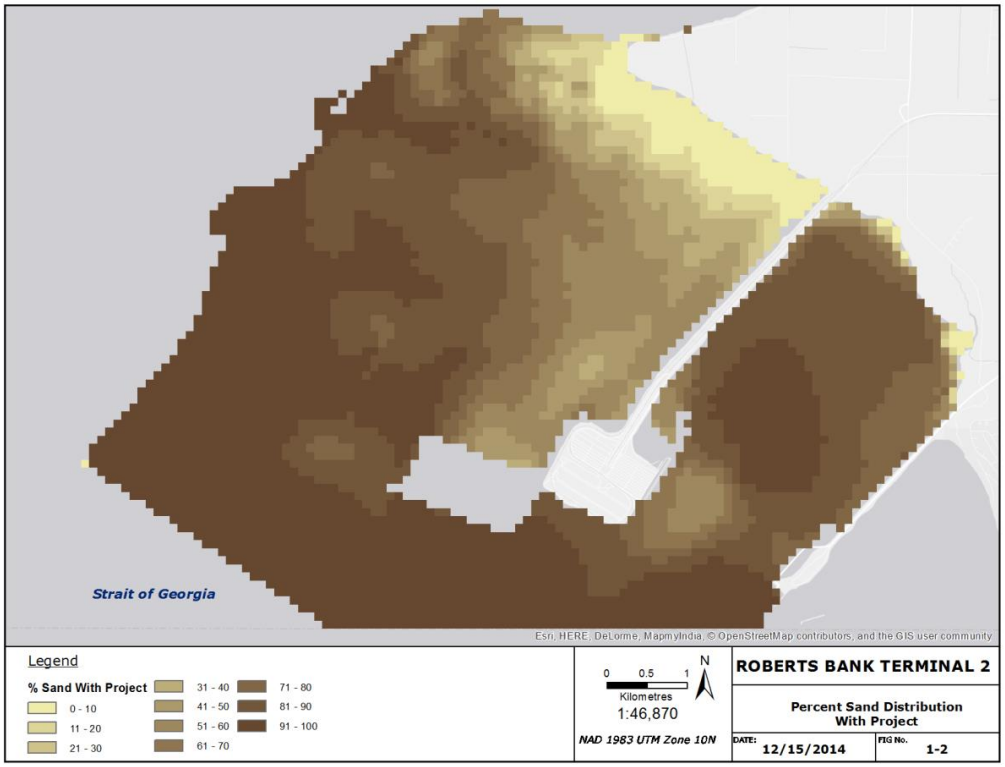


Figure B-3 Fine Sediment Distribution Surface for Without-Project Scenario

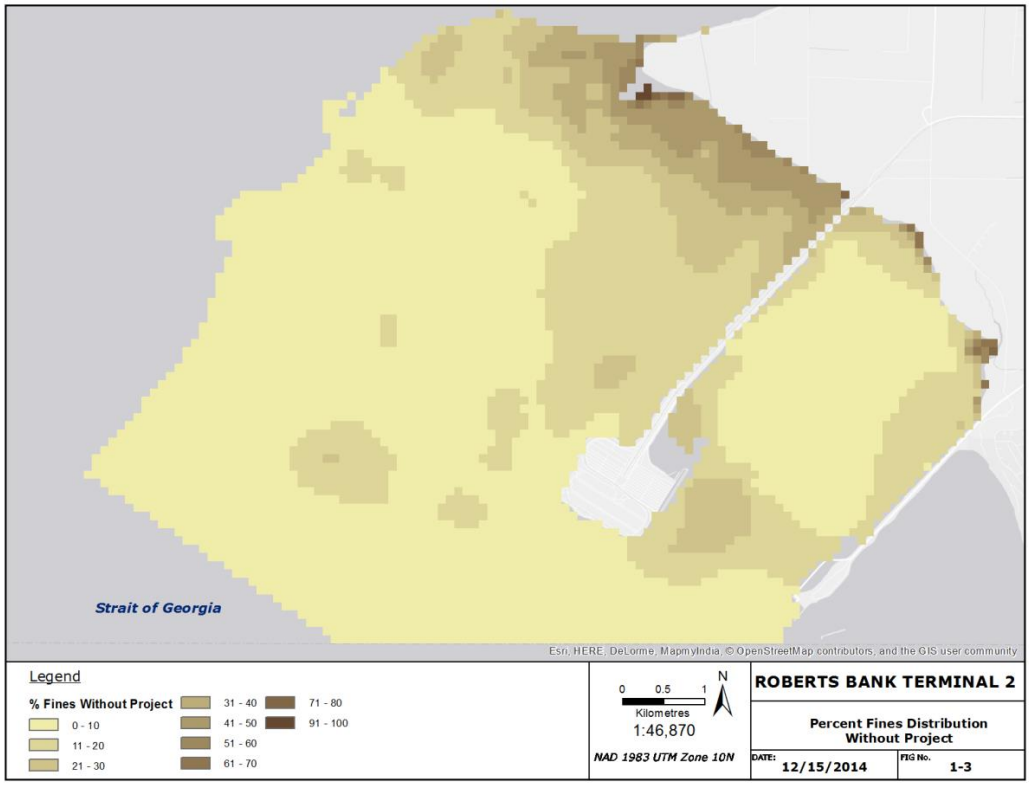
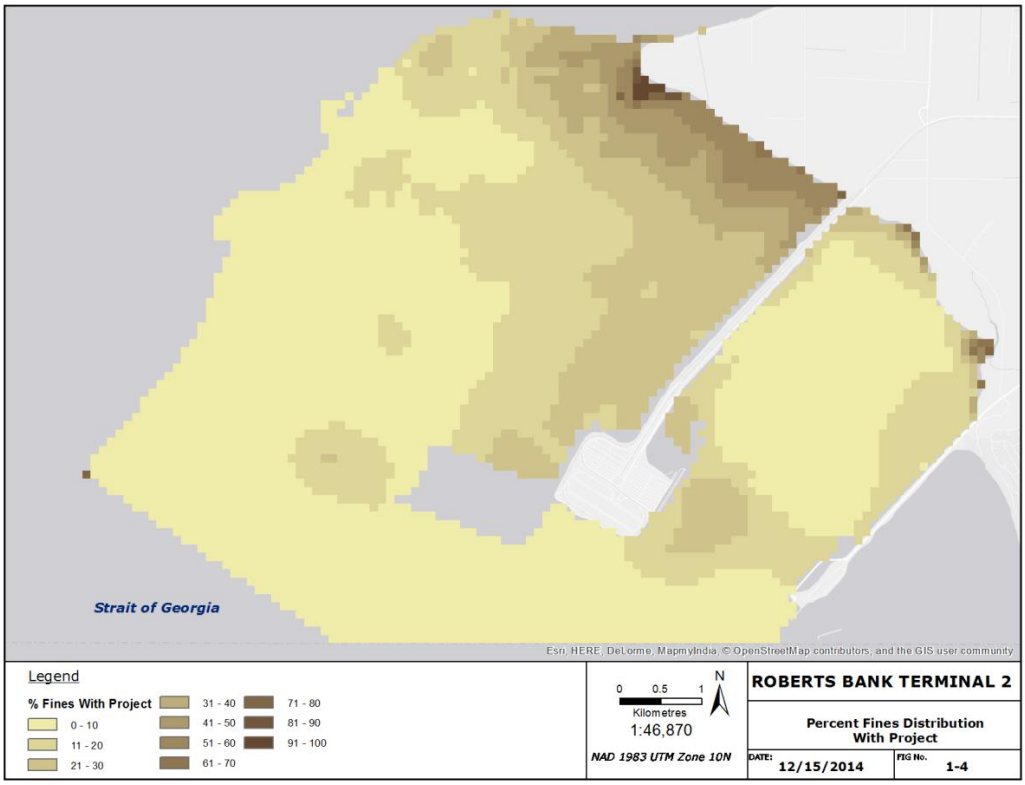


Figure B-4 Fine Sediment Distribution Surface for With-Project Scenario



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APPENDIX C:

SEASONALITY MEMO

Date: February 3, 2015
To: Robin Taylor
From: Frank Poulsen, Villy Christensen
RE: *Seasonality in Ecopath with Ecosim*

1.0 **Introduction**

The Roberts Bank ecosystem model assists in evaluating potential effects to productivity associated with the proposed Roberts Bank Terminal 2 project. This memo describes some of the technical details and challenges of incorporating seasonality in the EwE modeling complex, and the technical feasibility of incorporating seasonality into the ecosystem model.

2.0 **Seasonality in EwE**

EwE models can be run with time steps of any length, with the default being monthly time steps. The vast majority of EwE models, while run with monthly time steps, do not explicitly model seasonality (i.e. model parameters and abiotic factors are kept constant throughout the year). Many studies have successfully applied annually integrated models (i.e. models without seasonally-varying parameters) to track long-term changes. For instance, Preikshot et al. (2013) used an annual Ecosim model to emulate biomass and mortality changes in the Strait of Georgia from 1960 to 2009. In annual models, seasonal cycles in biomass, production per biomass, consumption per biomass and/or diet composition are represented by appropriately integrated rates that ensure that the overall mass balance is maintained, typically using the same parameter values for all time steps in any given year (Pauly et al. 2000).

The use of annually integrated rates can be illustrated using the interaction between Brant geese and eelgrass, which both exhibit strong seasonality. Eelgrass grows primarily from May to September, and Brant geese arrive in November to feed on eelgrass before leaving again in April. During the growing season, eelgrass mortality is primarily due to sloughed biomass, which accounts for at least 50% of the shoot net primary production (Baldwin and Lovvorn 1994). Brant geese and dabbling ducks

consume approximately 50% of the biomass remaining at the end of the growing season between September and March (Baldwin and Lovvorn 1994). This system can be modelled using monthly production, mortality, and consumption rates for both Brant geese and eelgrass, or using total (summed) annual rates. In both models, a change in production of eelgrass due to habitat changes would result in a higher or lower biomass of eelgrass. This change in biomass then affects the productivity for Brant geese due to alterations in food availability.

Seasonal variations are generally most important in the short term for lower trophic species, e.g. phytoplankton. For instance, a seasonal model of Weeks Bay, Alabama, USA, exhibited cyclic behaviour at the lowest trophic levels, but the effect was gradually dampened as one moved up the food chain. At the highest trophic level, the top predators did not display any seasonal cycling (Althauser 2003). Furthermore, seasonal variations generally have very little impact on predicted long term patterns of system change (Christensen and Walters 2004) making an annual model appropriate for evaluating long-term changes to productivity.

Where seasonal considerations are especially important is in connection with the match-mismatch hypothesis. Cushing (1975) postulated that the seasonal timing of zooplankton and fish larvae production would be a determinant factor for year class strength, and while it indeed is a plausible hypothesis, it has shown to be very difficult (perhaps impossible) to actually obtain empirical information to demonstrate the hypothesis.

The Roberts Bank ecosystem model was reviewed to ensure that there is no match-mismatch between predators and prey, i.e. each predator only feeds on prey that is present at the same time. A seasonal biomass matrix (Table C-1) was constructed based on a detailed review of each functional group (Hemmera 2014). In the matrix, the biomass for each month was classified as either high (peak season), low, or no (absent) biomass for all functional groups. The seasonal biomass was then compared

to the Roberts Bank ecosystem diet matrix (Hemmera 2014) to ensure predator and prey were present at the same time for at least a month every year. While there were no instances of a match-mismatch between predators and their prey, some instances were identified where predators were feeding on prey outside of the prey's peak season. For example Brant goose was not present during peak availability of eelgrass but was still able to consume its prey during months with lower biomass. Similarly, juvenile chum had three months where it could eat only one particular prey item, however other prey items were available during the rest of the year.

3.0 **Technical feasibility**

For the Roberts Bank study area, the match-mismatch hypothesis can be extended to apply to the timing of seasonal bird migrants and their food production in the study area, but as discussed above for Brant geese and eelgrass, it is unlikely that the differences in production timing will have an impact for the Brant geese.

Another, and potentially more important, example is for migrant birds that obtain a major part of their food from biofilm, notably dunlin and Western sandpiper. Biofilm shows a strong seasonal variation, as do the birds. One, might, as an example, speculate that the proposed Project could impact the timing of biofilm production. Such hypothetical qustions have, however, not been addressed with the ecosystem modelling due to lack of information about what drives the seasonal productivity of primary producers (e.g. temperature and light) and quantifiable relationships between these factors and the productivity. Without such information, including how the factors may change with the proposed Project, it will be non-informative to use seasonal ecosystem modelling to address this specific question.

As the examples show, the data requirements for a seasonal ecosystem model of productivity are significantly higher than for an annual model. A seasonal model would require monthly estimates of biomass, production per biomass, consumption per biomass and diet composition, as well as monthly estimates of physical factors

(depth, salinity, bottom current and wave height) to develop environmental preferences for each month. Not only would these additional parameters potentially introduce new sources of errors, they would also create a model that is likely to be unnecessarily complex.

4.0 **Discussion**

Annual models have been demonstrated to be well-suited for modeling long-term trends, which is the purpose of this ecosystem model, whereas seasonal models are better at modeling seasonal cyclic behaviour at the lowest trophic levels. One exception is the match-mismatch hypothesis. In this memo, The Roberts Bank ecosystem model was reviewed to ensure that there is no match-mismatch between predators and prey. For the purpose of the Roberts Bank ecosystem model, we conclude that an annual model is an appropriate choice and that a seasonal approach would add unnecessary complexity without providing additional information on how the proposed project will impact productivity at Roberts bank.

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Appendix C-1: Seasonal biomass matrix

Table C-1: Seasonal biomass matrix. The colours denote peak season with high biomass (green), low biomass (yellow) and biomass absent (red). The seasonal biomass was reviewed together with the Roberts Bank ecosystem model diet matrix (Hemmera 2014) to ensure that there was no match-mismatch between all predators and their prey, i.e. predators only feed on prey that is present at the same time (in high or low biomass).

Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baleen whales												
Dolphins and porpoises												
Pinnipeds												
Southern resident killer whales												
Transient killer whales												
American wigeon												
Bald eagle												
Brant goose												
Diving waterbirds												
Dunlin												
Great blue heron												
Gulls and terns												
Raptors												
Shorebirds												
Waterfowl												
Western sandpiper												
Chinook adult												
Chinook juvenile												
Chum adult												
Chum juvenile												
Dogfish												
Flatfish												
Forage fish												
Herring												

Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Large demersal fish												
Lingcod												
Rockfish												
Salmon adult												
Salmon juvenile												
Sandlance												
Shiner perch												
Skate												
Small demersal fish												
Starry flounder												
Carnivorous zooplankton												
Dungeness crab												
Epifaunal grazers												
Epifaunal omnivore												
Epifauna sessile												
Infaunal bivalves												
Jellyfish												
Macrofauna												
Meiofauna												
Omnivorous and herbivorous zooplankton												
Polychaetes												
Orange sea pen												
Shrimp												
Biofilm												
Brown algae												
Native eelgrass												
Green algae												
Japanese eelgrass												
Red algae												

Group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Phytoplankton												
Tidal marsh												
Biomat												
Detritus												

Note: Detritus is present all year-round but during the winter at concentrations of 0 to 1 ug/L, which is relatively low.

APPENDIX D:

HABITAT PRODUCTIVITY MEMO

Date: January 27, 2015
To: Robin Taylor
From: Frank Poulsen, Villy Christensen
RE: ***Roberts Bank Ecosystem Habitat Productivity***

1.0 Introduction

Port Metro Vancouver (PMV) is developing offsetting concepts for the proposed Roberts Bank Terminal 2 Project (RBT2) to mitigate potential Project-related effects to marine biophysical valued components (VCs) such as fish, wildlife and their habitat. A Technical Advisory Group on Productive Capacity (PC-TAG) recommended that PMV use productivity to quantify Project effects. The PC-TAG selected the Ecopath with Ecosim model (EwE) as an approach for measuring changes in: (1) overall productivity across an ecosystem, and (2) the productive capacity of functional groups. Biomass, measured in tonnes, is used as the metric of productivity in the model. This ecosystem modelling method has further been supported by Fisheries and Oceans Canada (DFO) in recent publications recommending an ecosystem-based approach to management (DFO 2007, 2013). In addition to assessing unmitigated Project-related change, this productivity assessment technique can be used to determine the overall amount and type of offsetting required by the Project and how each offsetting concept will contribute to the offsetting plan. Productivity values for the RBT2 onsite habitat concepts presented below are based on input values to the ecosystem model.

Onsite habitat offsetting concepts include sites that are located within the 54.6 km^2 Roberts Bank study area. Currently, five onsite habitat concepts are proposed. To provide an equivalent measure of the associated productivity of these offsetting concepts with the EwE model effects assessment, estimates of the forecast biomass in tonnes per square kilometre (t/km^2) are presented.

Table D-1. List of onsite habitat concepts for Roberts Bank Terminal 2

Offsetting concepts	
Tidal marsh	Mudflat bench
Sandy gravel beach	Subtidal rock reef
Eelgrass	

In addition, a productivity value for intertidal sandflat (based on intertidal soft bottom habitat areas), which is typically the habitat on which the proposed onsite concepts will be constructed, was calculated. Thus, the relative difference in productivity can be estimated by subtracting the productivity associated with the sandflat from the productivity associated with the proposed onsite concept. However, this memo presents absolute values associated with each habitat type. This memo provides a description of methods and an initial estimate of productivity calculations for each of the onsite habitat concepts (**Table D-1**).

2.0 Objective

The objective of this memo is to present how the Roberts Bank ecosystem model was used to estimate biomass (t/km^2) of habitat types that are representative of each proposed onsite offsetting habitat concept (e.g., tidal marsh).

3.0 Methodology

Habitats were not pre-defined as input parameters in the Roberts Bank ecosystem model (ESSA 2014a). Rather, habitats emerge as properties based on environmental conditions and group-specific environmental preference function inputs combined with effects of food web dynamics. Therefore, to evaluate habitat productivity, it was necessary to identify cells by habitat type after the model runs. Each habitat type was extracted from the "Without Project" key run of the Roberts Bank ecosystem model (ESSA 2014a), and it was assumed that the cells that were most abundant for the indicator groups (**Table D-2**) could be used to characterize the productivity patterns of each habitat type.

To balance between sample size and productivity values, a 99.8 percentile threshold was used to select for these habitat types. This resulted in 11 cells used in the analysis; each cell 1 hectare in size. More than 11 cells would "dilute" or underestimate the productivity and less than 11 cells would "concentrate" or overestimate the productivity. For rock reefs, only 8 of the 11 cells were in the subtidal zone (**Table D-2**). **Figure D-7** in **Appendix D-1** shows the exceedance plots for each habitat type that were used to decide on a percentile cut-off limit. Exceedance plots illustrate total biomass of a cell against the percentile of cells used.

Table D-2. Criteria used for selecting cells1 for evaluation of habitat productivity

Habitat	Indicator group	Percentile	Depth (m)	Considerations
Mudflat bench	Marine biofilm	99.8	All	
Subtidal rock reef	Brown algae	99.8	≥ 5	
Eelgrass	Native eelgrass	99.8	All	
Tidal marsh	Tidal marsh	99.8	All	
Sandy gravel beach	10-20% hard bottom	n.a.	< 5	Limited tidal marsh
Sandflats[2]	No hard bottom	n.a.	< 5	Limited native eelgrass, Japanese eelgrass, tidal marsh, freshwater biofilm, marine biofilm

Note: Depths are relative to the high water level or 5 m above chart datum, therefore a depth of 5 equals 0 m CD.

[1] For the EwE model, the Roberts Bank study area was comprised of a grid of 1 ha cells (100m x 100m).

[2] Habitat type that the onsite concepts will be constructed over and used for relative difference in productivity calculations.

Cells representing sand flat, represented by intertidal soft bottom, were selected to include only limited abundances (i.e., less than 10% of the maximum value) of native eelgrass, Japanese eelgrass, tidal marsh, freshwater biofilm, and marine biofilm. For the sandy gravel beach, only cells with less than 10% of the maximum tidal marsh biomass were included. The approach was required due to the size of the sample cell (1 ha) and the low number 100% pure sand flat habitat cells.

Food webs were developed for each habitat by:

- Constructing an initial food web based on the diet compositions from the key run. The initial food web only included functional groups that obtain >1% of their diets from the functional groups associated with the habitat type. For example, the initial food web for eelgrass consisted of American wigeon, brant goose, waterfowl and shiner perch; each feeds directly on native eelgrass.

- Adding species that are associated with the habitat, but do not feed directly on it. For example, juvenile Chinook, chum and other salmon, as well as herring, are known to use eelgrass beds for refuge ; and,

- Including predators of the functional groups based on the diet compositions from the key run. For example, great blue heron was added to the food web for eelgrass habitat because it feeds on herring. The productivity of each habitat type was estimated by extracting the biomass by functional group for the cells of each habitat type based on the local food web.

4.0 Results

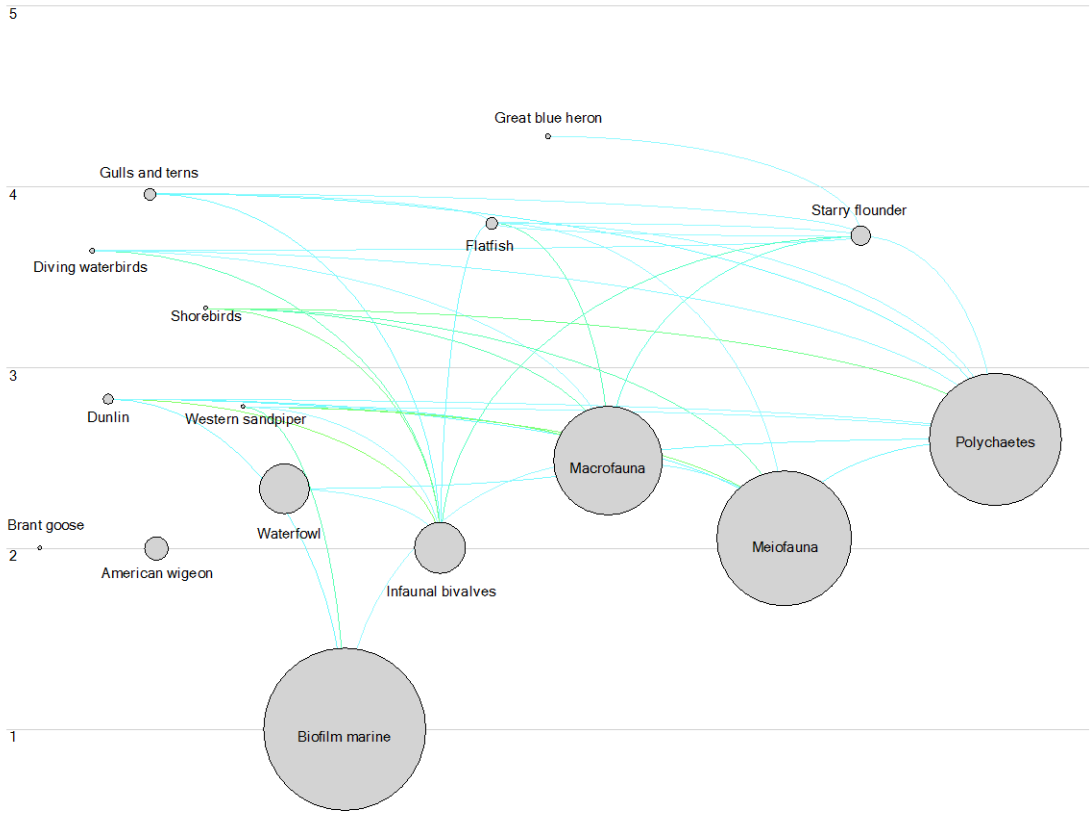
The estimated biomass of each habitat type and their associated functional groups is presented in **Table D-3** to **Table D-8** and summarised in **Table D-9**. The biomass of each habitat type was used as an input parameter to create the food web plots (**Figure D-1** to **Figure D-6**) using the flow chart function of Ecopath with Ecosim with the procedure described above. The biomass for each habitat type for all functional groups is summarized in **Table D-10** in **Appendix D-1**.

Mudflat bench habitat is uniquely productive with biofilm. Areas of the model chosen for the mud bench are likely to support marine type biofilm. They are highly productive for invertebrate groups – which are an important diet item for many bird species. **Table D-3** shows the biomass of directly affected functional groups in mudflat bench habitat.

Table D-3. Absolute biomass of directly affected functional groups in the mudflat bench habitat in the Roberts Bank ecosystem model (unit: t km-2). Only functional groups associated with mudflat bench habitat are included.

American wigeon	0.332
Brant goose	0.009
Diving waterbirds	0.020
Dunlin	0.077
Great blue heron	0.015
Gulls and terns	0.089
Shorebirds	0.008
Waterfowl	2.153
Western sandpiper	0.013
Flatfish	0.091
Starry flounder	0.216
Infaunal bivalves	2.367
Macrofauna	98.639
Meiofauna	545.509
Polychaetes	462.097
Biofilm (marine)	3127.889
Total	**4239.524**

Figure D-1. Food Web Diagram for Mudflat Bench Habitat in the Roberts Bank Ecosystem Model



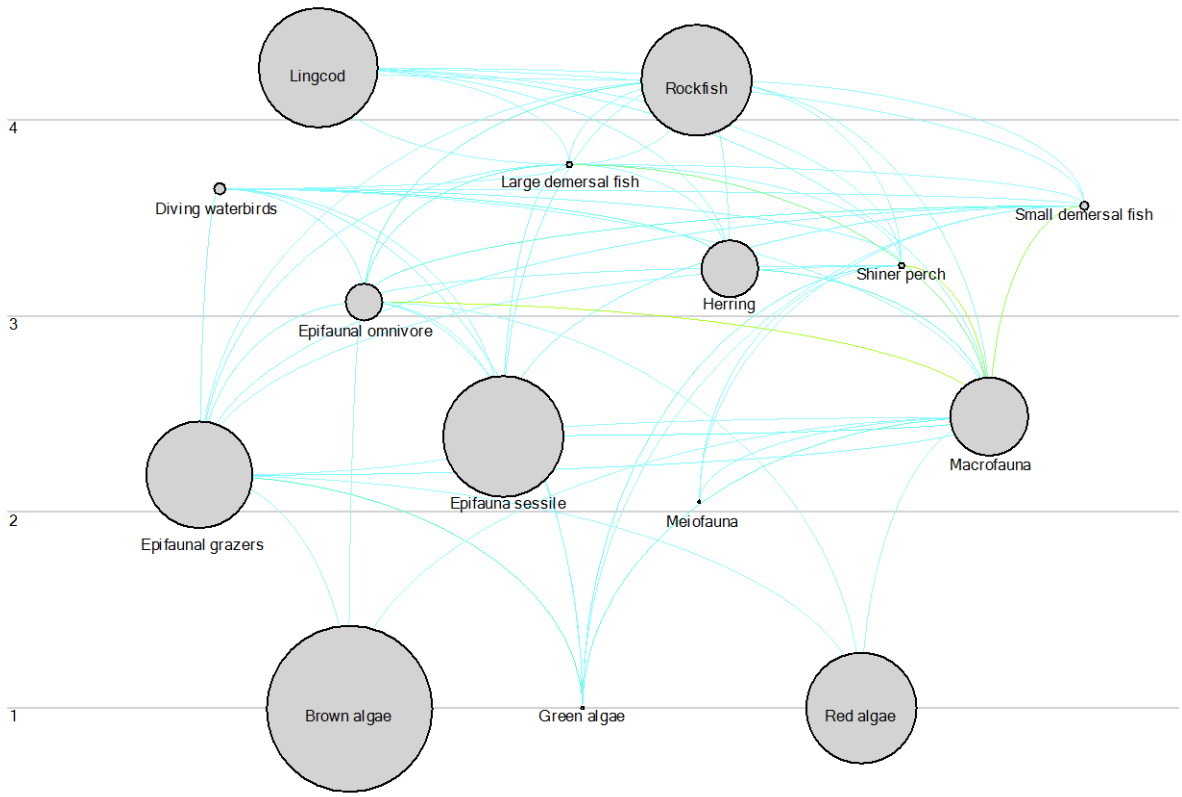
Note: Functional groups are arranged after trophic level (TL, Y-axis) with primary producers and detritus at TL 1, and consumers at increasing TLs depending on their diets. The size of the circles represents each functional group's biomass. The colour of the lines indicates the biomass transferred between groups ranging from low in blue to high in red. For the complete diet composition of each functional group, refer to ESSA (2014a).

The subtidal rock reef habitat provides feeding, refuge and spawning habitat for high abundances of lingcod and rockfish (**Table D-4**). Kelp (brown algae) is also very abundant in this habitat type.

Table D-4. Absolute biomass of key functional groups in the subtidal rock reef habitat areas in the Roberts Bank ecosystem model (unit: t km-2). Only functional groups associated with subtidal rock reef habitat are included.

Diving waterbirds	0.080
Herring	2.590
Large demersal fish	0.022
Small demersal fish	0.073
Lingcod	105.448
Rockfish	63.035
Shiner perch	0.019
Dungeness crab	15.378
Epifaunal grazers	49.317
Epifaunal omnivores	0.709
Epifaunal sessile suspension feeder	116.047
Macrofauna	9.690
Brown algae	1753.383
Green algae	<0.001
Red algae	68.192
Total	**2184.056**

Figure D-2. Food Web Diagram for Subtidal Rock Reef Habitat in the Roberts Bank Ecosystem Model



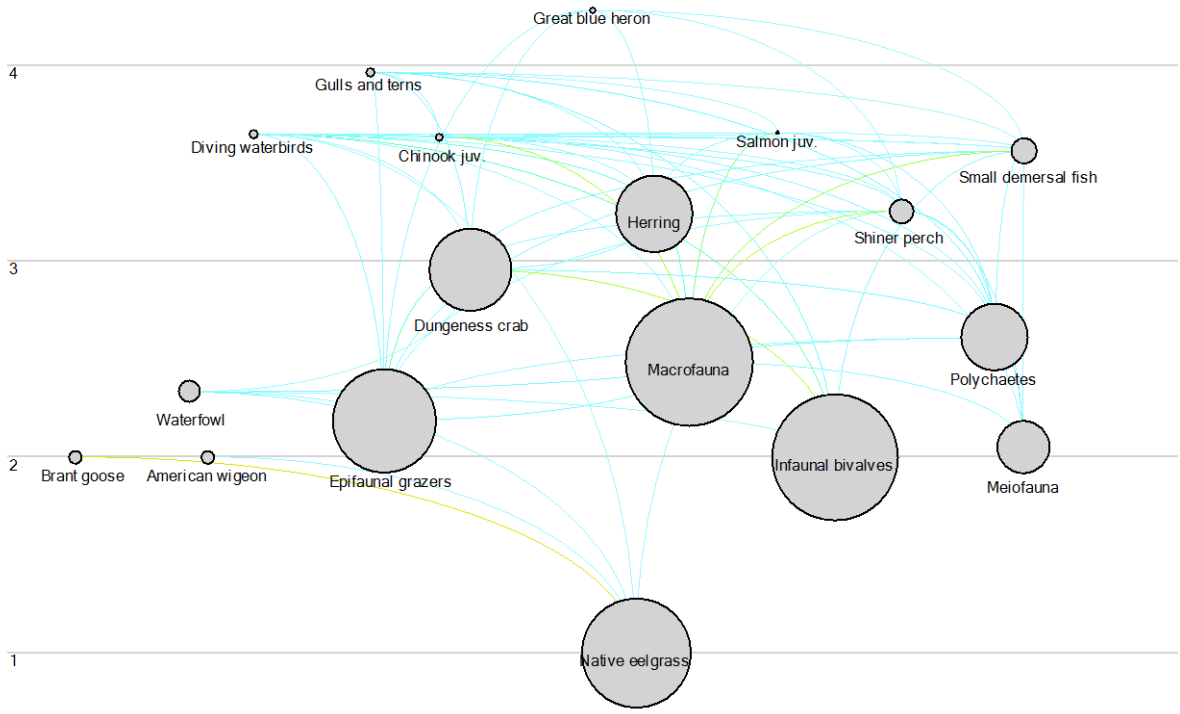
Note: Functional groups are arranged after trophic level (TL, Y-axis) with primary producers and detritus at TL 1, and consumers at increasing TLs depending on their diets. The size of the circles represents each functional group's biomass. The colour of the lines indicates the biomass transferred between groups ranging from low in blue to high in red. For the complete diet composition of each functional group, refer to ESSA (2014a). The subtidal reef area represents depth > 5 m.

Eelgrass is an important habitat type for invertebrates as well as many juvenile fishes (**Table D-5**). As the model does not account for habitat uses as refuge habitat, it likely underestimates the importance of eelgrass habitat areas, particularly for juvenile fishes.

Table D-5. Absolute biomass of key functional groups in the native eelgrass habitat areas in the Roberts Bank ecosystem model (unit: t km-2). Only functional groups associated with native eelgrass habitat are included.

American wigeon	0.085
Brant goose	0.099
Diving waterbirds	0.045
Great blue heron	0.020
Gulls and terns	0.040
Waterfowl	0.236
Chinook juv.	0.028
Chum juv.	0.027
Herring	8.579
Salmon juv.	0.002
Shiner perch	0.281
Small demersal fish	0.261
Dungeness crab	12.492
Epifaunal grazers	42.614
Infaunal bivalves	169.517
Macrofauna	176.664
Meiofauna	2.006
Polychaetes	4.645
Native eelgrass	59.479
Total	**477.120**

Figure D-3. Food Web Diagram for Native Eelgrass Habitat in the Roberts Bank Ecosystem Model



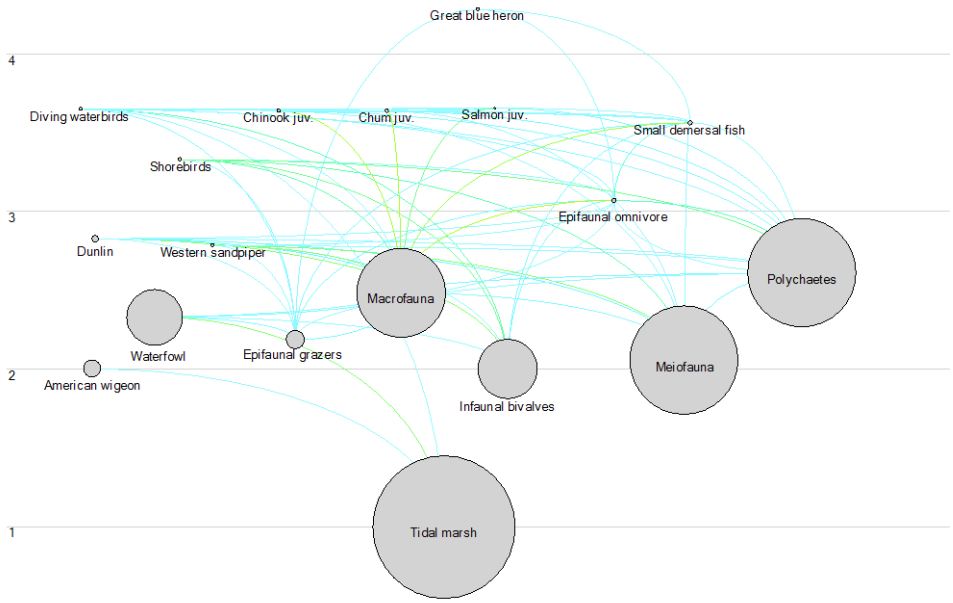
Note: Functional groups are arranged after trophic level (TL, Y-axis) with primary producers and detritus at TL 1, and consumers at increasing TLs depending on their diets. The size of the circles represents each functional group's biomass. The colour of the lines indicates the biomass transferred between groups ranging from low in blue to high in red. For the complete diet composition of each functional group, refer to ESSA (2014a).

Tidal marsh habitat is important for many species (**Table D-6**). This habitat type has the highest estimated bird biomass (see summary in **Table D-9**), is important for juvenile fish, and shows high invertebrate biomasses.

Table D-6. Absolute biomass of key functional groups in the tidal marsh habitat areas in the Roberts Bank ecosystem model (unit: t km-2). Only functional groups associated with tidal marsh habitat are included.

American wigeon	0.218
Diving waterbirds	0.012
Dunlin	0.043
Great blue heron	0.008
Shorebirds	0.004
Waterfowl	5.636
Western sandpiper	0.007
Chum salmon juv.	0.012
Chinook salmon juv.	0.007
Salmon juv.	0.001
Small demersal fish	0.013
Infaunal Bivalve	7.440
Epifaunal grazers	0.254
Epifaunal omnivore	0.025
Macrofauna	66.009
Meiofauna	267.112
Polychaetes	278.389
Tidal marsh vegetation	3225.640
Total	**3850.830**

Figure D-4. Food Web Diagram for Tidal Marsh Habitat in the Roberts Bank Ecosystem Model



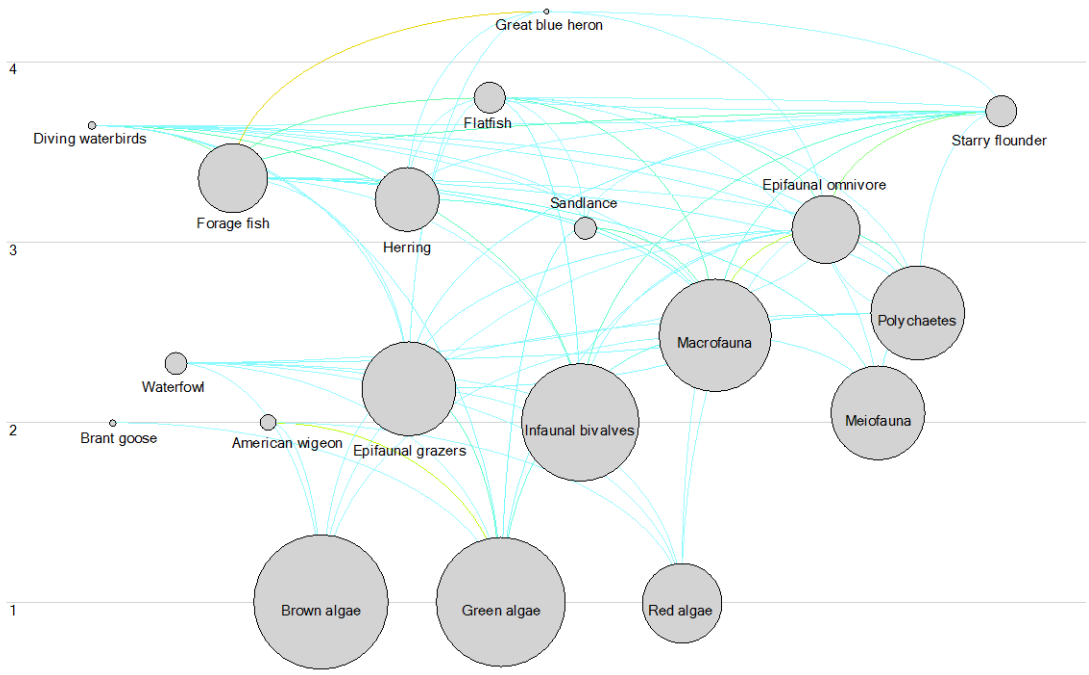
Note: Functional groups are arranged after trophic level (TL, Y-axis) with primary producers and detritus at TL 1, and consumers at increasing TLs depending on their diets. The size of the circles represents each functional group's biomass. The colour of the lines indicates the biomass transferred between groups ranging from low in blue to high in red. For the complete diet composition of each functional group, refer to ESSA (2014a).

Sandy gravel beach habitat shows intermediate biomass levels for fishes and invertebrates relative to other habitat types (**Table D-7**).

Table D-7. Absolute biomass of key functional groups in the sandy gravel beach habitat areas in the Roberts Bank ecosystem model (unit: t km-2). Only functional groups associated with sandy gravel beach habitat are included.

American wigeon	0.142
Brant goose	0.031
Diving waterbirds	0.050
Great blue heron	0.021
Waterfowl	0.300
Flatfish	0.583
Herring	5.584
Sandlance	0.300
Starry flounder	0.595
Forage fish	7.950
Epifaunal grazer	41.250
Epifaunal omnivore	7.416
Infaunal bivalve	178.698
Macrofauna	124.836
Meiofauna	38.462
Polychaetes	39.522
Brown algae	519.260
Green algae	363.312
Red algae	15.841
Total	**1344.153**

Figure D-5. Food Web Diagram for the Sandy Gravel Beach Habitat in the Roberts Bank Ecosystem Model



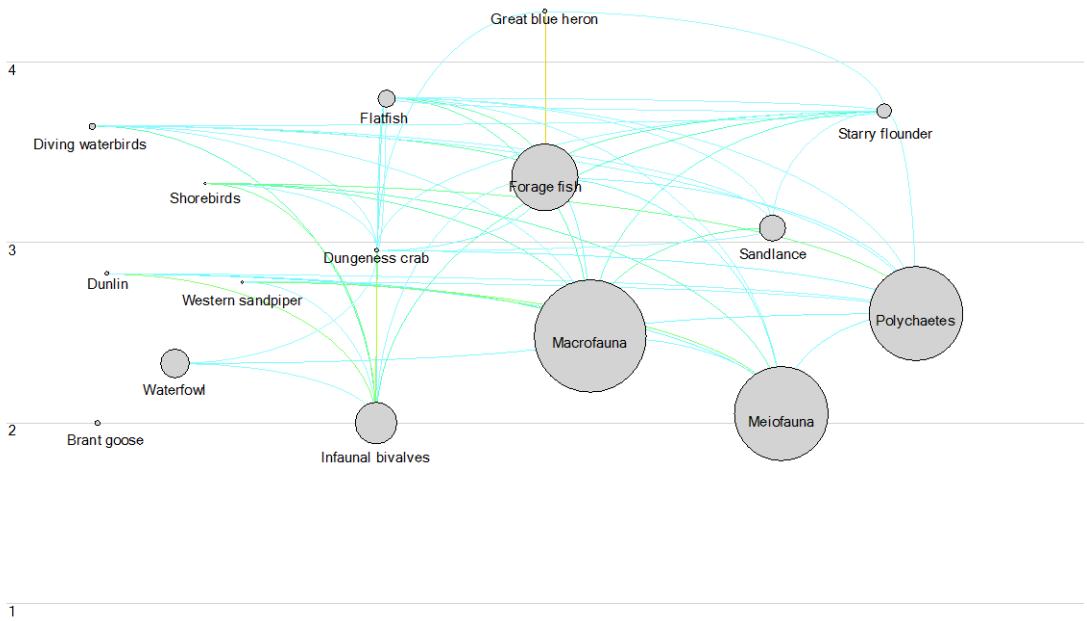
Note: Functional groups are arranged after trophic level (TL, Y-axis) with primary producers and detritus at TL 1, and consumers at increasing TLs depending on their diets. The size of the circles represents each functional group's biomass. The colour of the lines indicates the biomass transferred between groups ranging from low in blue to high in red. For the complete diet composition of each functional group, refer to ESSA (2014a).

Sand flat habitat serves as a reference habitat, and it is the least productive of the habitat areas considered here (**Table D-8**).

Table D-8. Absolute biomass of key functional groups in sandflats habitat in the Roberts Bank ecosystem model (unit: t km-2). Only functional groups associated with sandflats habitat are included.

Brant goose	0.014
Diving waterbirds	0.030
Dunlin	0.007
Great blue heron	0.012
Shorebirds	0.002
Waterfowl	0.505
Western sandpiper	0.002
Flatfish	0.178
Starry flounder	0.120
Forage fish	6.580
Sandlance	0.395
Dungeness crab	0.004
Infaunal bivalves	1.331
Macrofauna	124.836
Meiofauna	38.462
Polychaetes	39.522
Total	**212.000**

Figure D-6. Food Web Diagram for Sandflats Habitat in the Roberts Bank Ecosystem Model



Note: Functional groups are arranged after trophic level (TL, Y-axis) with primary producers and detritus at TL 1, and consumers at increasing TLs depending on their diets. The size of the circles represents each functional group's biomass. The colour of the lines indicates the biomass transferred between groups ranging from low in blue to high in red. For the complete diet composition of each functional group, refer to ESSA (2014a). Sandflats are represented by intertidal soft bottom habitat areas, and include depths of up to 5 m.

5.0 Summary

This memo provides an overview of absolute biomass values for each functional group associated with five onsite offsetting habitat types based on the Roberts Bank ecosystem model. The key species or functional groups associated with each habitat type are aggregated by major taxonomic groupings in **Table D-9**. From this, it is clear that bird and invertebrate functional groups are most abundant on mudflat bench areas, while fish functional groups are most abundant in the subtidal rock reef areas. In terms of biomass, the most productive habitat types are mudflat benches and tidal marsh. Sandflats, which serves as a reference habitat area, are less productive than the other habitat areas – and therefore is the most suitable candidate over which onsite habitat can be created.

Table D-9. Total biomasses of key functional groups aggregated by major taxonomic groupings for the habitat in the Roberts Bank ecosystem model (unit: t km-2)

Group\habitat	Mudflat bench	Subtidal rock reef	Eel-grass	Tidal marsh	Sandy gravel beach	Sand-flats
Birds	3	0	1	6	1	1
Fish	0	171	9	0	15	7
Invertebrates	1,109	176	408	619	430	204
Producers	3,128	1,822	59	3,226	898	0
Total	**4,240**	**2,169**	**477**	**3,851**	**1,344**	**212**

The key species or functional groups that are included in the present analysis are the main groups that rely on these habitats and do not represent all species or groups that occur in the habitat.

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7.0 Statement of limitations

This memo was prepared by ESSA Technologies Ltd. in cooperation with and based on information supplied by Hemmera, for the sole benefit and exclusive use of Port Metro Vancouver. The material in it reflects the best judgment by ESSA Technologies and its sub-contractors in light of information available to it at the time of preparing this memo. Any use that a third party makes of this memo, or any reliance on or decision made based on it, is the responsibility of such third parties. ESSA Technologies and its sub-contractors accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on this memo.

ESSA Technologies and its sub-contractors have performed the work as described above and made the findings and conclusions set out in this memo in a manner consistent with the level of care and skill normally exercised by members of the environmental science profession practicing under similar conditions at the time the work was performed.

This memo represents a reasonable analysis based on the information and methodologies available to ESSA Technologies and its sub-contractors within the established scope, work schedule and budgetary constraints. It is possible that there are effects that have not considered in this memo because of lack of information, and hence currently unrecognised factors. No warranty, expressed or implied, is given concerning the impact of unrecognised factors, expect as specifically noted in this memo.

The conclusions and recommendations contained in the memo were based on applicable legislation existing at the time the memo was drafted. Any changes in the legislation may alter the conclusions and/or recommendations contained in this memo. Regulatory implications discussed in this memo were based on the applicable legislation existing at the time this report was written.

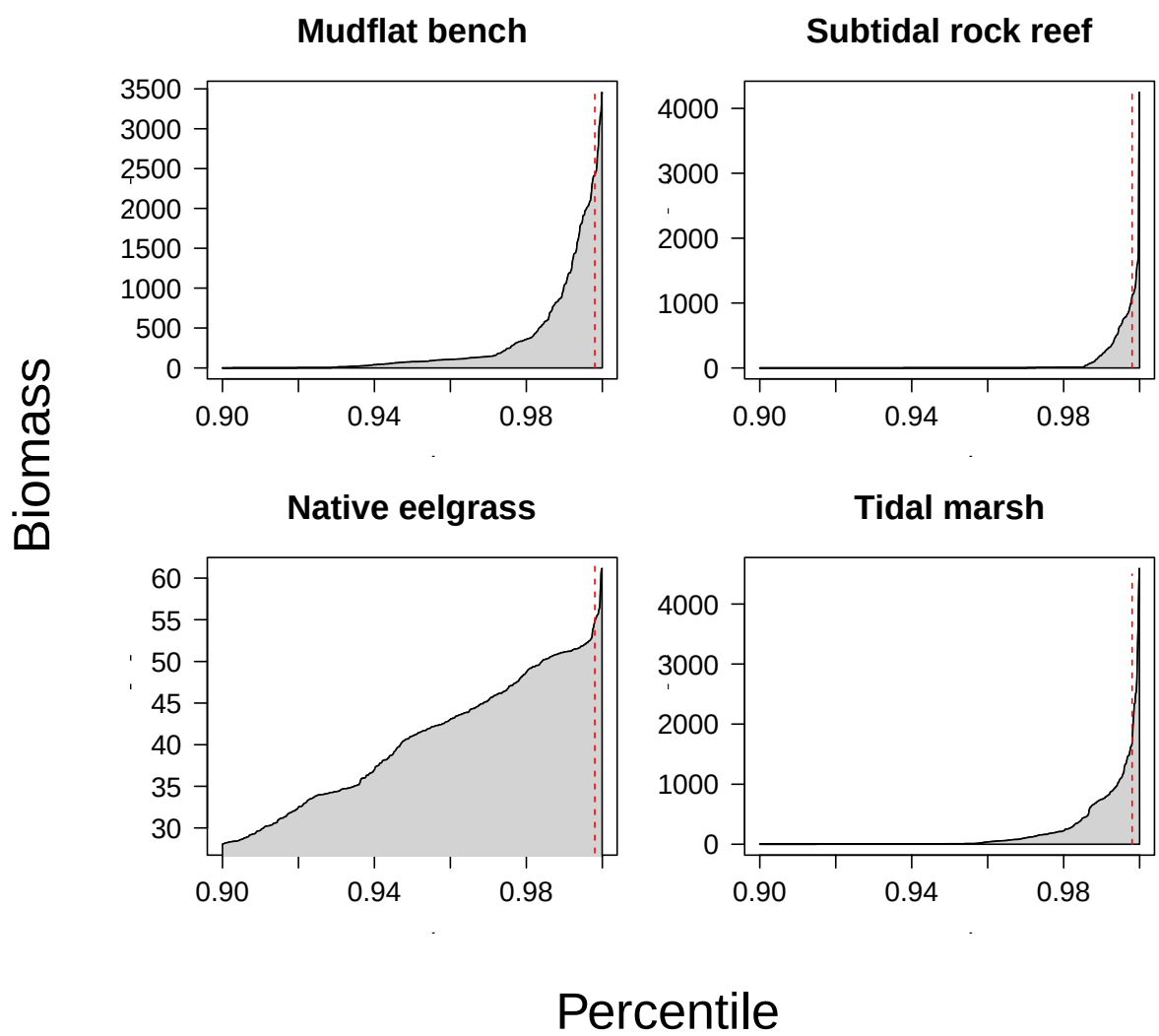
In preparing this memo, ESSA Technologies and its sub-contractors have relied in good faith on information provided by others as noted in this memo, and have assumed that the information provided by those individuals and organizations is both factual and accurate. ESSA Technologies and its sub-contractors accept no responsibility for any deficiency, misstatement or inaccuracy in the memo resulting from the information provided by those individuals or organizations.

The liability of ESSA Technologies to Port Metro Vancouver shall be limited to injury or loss caused by negligent acts of ESSA Technologies. The total aggregate liability of ESSA Technologies related to this agreement shall not exceed the lesser of the actual damages incurred, or the total fee of ESSA Technologies for services rendered on the project.

Appendix D-1 - Determination of habitat productivity

Exceedance plots were constructed for the four habitat areas that were based on abundance of a key target species (as defined in Table 2), and are included here to show the impact of using relationship between percentile threshold and estimated habitat productivity as shown in **Figure D-7.** Exceedance plots illustrate total average biomass of the most productive cells (each with an area of 1 hectare = 100 x 100 m) against the percentile of cells used.

Figure D-7. Exceedance plots by habitat type showing total biomass of a cell (hectare) against the percentile of cells used. The 99.8 percentile is indicated by a vertical, dashed red line



The exceedance plots are constructed by selecting a threshold, e.g., the 99th percentile. Then for each of the four habitat types, the 1% of the 5,468 cells (i.e. 55 cells) in the study area that have the highest abundance of the given habitat type is selected, and the average biomass for these cells is calculated.

For illustration, the 90th percentile (547 cells) for native eelgrass indicates that 10% of all cells in the study area have an average biomass of around 28 t km^{-2}, and the 98th percentile (109 cells) for the groups indicates that 2% of all cells have an average biomass of around 50 t km^{-2}.

It is clear from **Figure D-7** that native eelgrass is quite widely distributed, while the three other habitat types have a much more narrow distribution with only few cells being very productive.

The biomass for each habitat type for all functional groups is summarized in **Table D-10**. Results for marine mammals are not included in the table because their biomass is not expected to change due to the proposed project.

Table D-10. Biomass by habitat type (unit: t km-2)

	Habitat	Mudflat bench	Subtidal rock reef	Native eelgrass	Tidal marsh	Sandy gravel beach	Sandflats
Group	Name \ Area (hectare)	**11**	**8**	**11**	**11**	**14**	**52**
6	American wigeon	0.332	0.001	0.085	0.218	0.142	0.609
7	Bald eagle	0.006	0.008	0.005	0.004	0.005	0.004
8	Brant goose	0.009	0.003	0.099	0.007	0.031	0.014
9	Diving waterbirds	0.020	0.080	0.045	0.012	0.050	0.030
10	Dunlin	0.077	0.000	0.008	0.043	0.011	0.007
11	Great blue heron	0.015	0.000	0.020	0.008	0.021	0.012
12	Gulls and terns	0.089	0.059	0.040	0.054	0.065	0.037
13	Raptors	0.001	0.000	0.000	0.001	0.000	0.000
14	Shorebirds	0.008	0.000	0.001	0.004	0.002	0.002
15	Waterfowl	2.153	0.204	0.236	5.636	0.300	0.505
16	Western sandpiper	0.013	0.000	0.000	0.007	0.001	0.002

	Habitat	Mudflat bench	Subtidal rock reef	Native eelgrass	Tidal marsh	Sandy gravel beach	Sandflats
17	Chinook adult	0.000	7.671	3.056	0.014	0.033	0.000
18	Chinook juvenile	0.034	0.000	0.028	0.012	0.021	0.009
19	Chum adult	0.000	4.450	1.563	0.006	0.015	0.000
20	Chum juvenile	0.020	0.001	0.027	0.007	0.013	0.006
21	Dogfish	0.000	1.278	0.406	0.002	0.002	0.000
22	Flatfish	0.091	0.917	0.790	0.026	0.583	0.178
23	Forage fish	8.984	6.552	11.481	4.846	7.950	6.580
24	Herring	0.872	2.590	8.579	0.345	5.584	0.534
25	Large demersal fish	0.090	0.022	0.473	0.033	0.596	0.165
26	Lingcod	0.000	105.448	0.176	0.000	0.112	0.000
27	Rockfish	0.000	63.035	0.129	0.000	0.063	0.000
28	Salmon adult	0.000	2.267	0.809	0.004	0.008	0.000
29	Salmon juvenile	0.001	0.002	0.002	0.001	0.001	0.001
30	Sandlance	0.705	0.077	0.289	0.441	0.300	0.395
31	Shiner perch	0.599	0.019	0.281	0.251	0.362	0.180
32	Skate	0.000	0.116	0.255	0.000	0.000	0.000
33	Small demersal fish	0.036	0.073	0.261	0.013	0.470	0.097
34	Starry flounder	0.216	0.086	0.460	0.064	0.595	0.120
35	Carnivorous zooplankton	15.630	37.958	23.755	2.554	10.741	3.086
36	Dungeness crab	0.003	15.378	12.492	0.000	2.087	0.004
37	Epifaunal grazers	11.467	49.317	42.614	0.254	41.250	12.395
38	Epifaunal omnivore	1.110	0.709	7.274	0.025	7.416	1.370
39	Epifauna sessile	0.041	116.047	0.266	0.001	74.679	0.098
40	Infaunal bivalves	2.367	107.409	169.517	7.440	178.698	1.331
41	Jellyfish	0.172	13.700	6.228	0.039	3.428	0.337
42	Macrofauna	98.639	9.690	176.664	66.009	124.836	49.585
43	Meiofauna	545.509	0.001	2.006	267.112	38.462	52.153
44	Omnivorous and herbivorous zooplankton	1.693	108.693	111.956	0.000	63.753	2.370
45	Polychaetes	462.097	0.001	4.645	278.389	39.522	115.848
46	Orange sea pen	0.000	0.184	0.000	0.000	0.003	0.000
47	Shrimp	0.108	0.083	0.667	0.047	0.741	0.464
48	Biofilm fresh	0.000	0.000	0.000	0.824	0.000	0.000
49	Biofilm marine	3127.889	0.000	0.000	516.761	0.000	84.324

	Habitat	Mudflat bench	Subtidal rock reef	Native eelgrass	Tidal marsh	Sandy gravel beach	Sandflats
50	Brown algae	0.000	1753.383	0.505	0.000	519.260	0.000
51	Native eelgrass	0.000	1.708	59.479	0.000	0.145	0.000
52	Green algae	566.984	0.000	118.634	583.067	363.312	1,028.908
53	Japanese eelgrass	0.533	0.000	0.081	0.732	0.234	0.479
54	Red algae	0.000	68.192	0.005	0.000	15.841	0.000
55	Phytoplankton	34.299	23.013	36.054	28.924	33.091	15.465
56	Tidal marsh	235.721	0.000	0.000	3225.640	25.038	89.316
57	Biomat	954.404	0.000	0.000	5.603	0.000	0.000
	Total	**6,073**	**2,500**	**802**	**4,995**	**1,560**	**1,467**