Appendix IR2020-1.2-A

Roberts Bank Terminal 2 Draft Report- Roberts Bank Ecosystem Model Update

Roberts Bank Terminal 2 - Roberts Bank Ecosystem Model Update

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym / Abbreviation	Definition
B	Biomass
B.C.	British Columbia
CD	Chart Datum
DFO	Fisheries and Oceans Canada
EE	Ecotrophic Efficiency
EIS	Environmental Impact Statement
EwE	Ecopath with Ecosim and Ecospace
IR	Information Request
MC	Monte Carlo
P/B	Production / Biomass Ratio
Q/B	Consumption / Biomass Ratio
RB	Roberts Bank
UBC	University of British Columbia
VBGF	von Bertalanffy Growth Function
VFPA	Vancouver Fraser Port Authority

LIST OF SYMBOLS AND UNITS OF MEASURE

Symbol / Unit of Measure	Definition
ha	hectare
km	kilometre
m	metre
m^2	square metre
t	tonnes
t/ha	tonnes per hectare
t/km^2	tonnes per square kilometre

1.0 INTRODUCTION

The Vancouver Fraser Port Authority (port authority) is proposing a marine container terminal at Roberts Bank in Delta, British Columbia (B.C.) that will handle 2.4 million twenty-foot equivalent unit containers annually based on the proposed design. The Roberts Bank Terminal 2 project (RBT2 or project) consists of three main components: 1) a new multi-berth marine container terminal; 2) a widened causeway and 3) an expanded tug basin.

In support of responding to an information request (IR) from the minister of Environment and Climate Change Canada dated August 24, 2020[1], Hemmera Envirochem Inc. (Hemmera) was tasked with analyzing how the offsetting plan proposed for the project: (i) would fully offset project impacts to juvenile Chinook salmon habitat and migration, and (ii) would counterbalance residual effects of the project on fish and fish habitat. To respond to this request, an updated version was used of the Roberts Bank ecosystem model (RB model) that was originally developed in 2014 using Ecopath with Ecosim and Ecospace (EwE) to support the marine biophysical effects assessment presented in the project's Environmental Impact Statement (EIS; Hemmera 2014a,b, ESSA 2014). The updated RB model was used to quantify changes with the project in the productivity of Roberts Bank ecosystem components as well as productivity losses associated with project construction. Aspects of the EwE software were also used to assist in the quantification of offsetting productivity gains associated with offsetting habitats proposed for the project. Results of the analysis presented in this report informed **IR2020-1.2**.

This report summarizes new, since the submission of the EIS and subsequent response to completeness and sufficiency IRs by the review panel, technical information regarding the transfer of the RB model to the most-up-to-date professional version of the EwE software and updates to the RB model. New technical information is also provided regarding the updated RB model key run and sensitivity analysis. The new quantitative approach to estimating productivity losses from underwater noise during in-water project construction activities is also described and analysis results are provided. Lastly, technical information is included regarding how Ecopath was used to inform the new alternative approach, recommended by DFO (2019a), to calculating productivity gains associated with the creation of offsetting habitats.

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[1] CIAR Document #2067 From the Minister of Environment and Climate Change to the Vancouver Fraser Port Authority re: Information Request. Available at https://www.ceaa-acee.gc.ca/050/documents/p80054/135827E.pdf.

2.0 METHODOLOGY

The RB model presented in the EIS (Hemmera 2014a,b, ESSA 2014) was used as a base model and was updated for the analysis described in this report. The same team of experts from the University of British Columbia that worked on the RB model for the EIS was retained by the port authority to run the updated RB model. This section describes the methodology used to update the RB model and to undertake additional analyses using the latest professional version of the EwE software. The study area for the updated RB model is the same as described in the EIS (Hemmera 2014a); it is presented in **Section 2.1** for ease of reference. Specifically, the following sections describe:

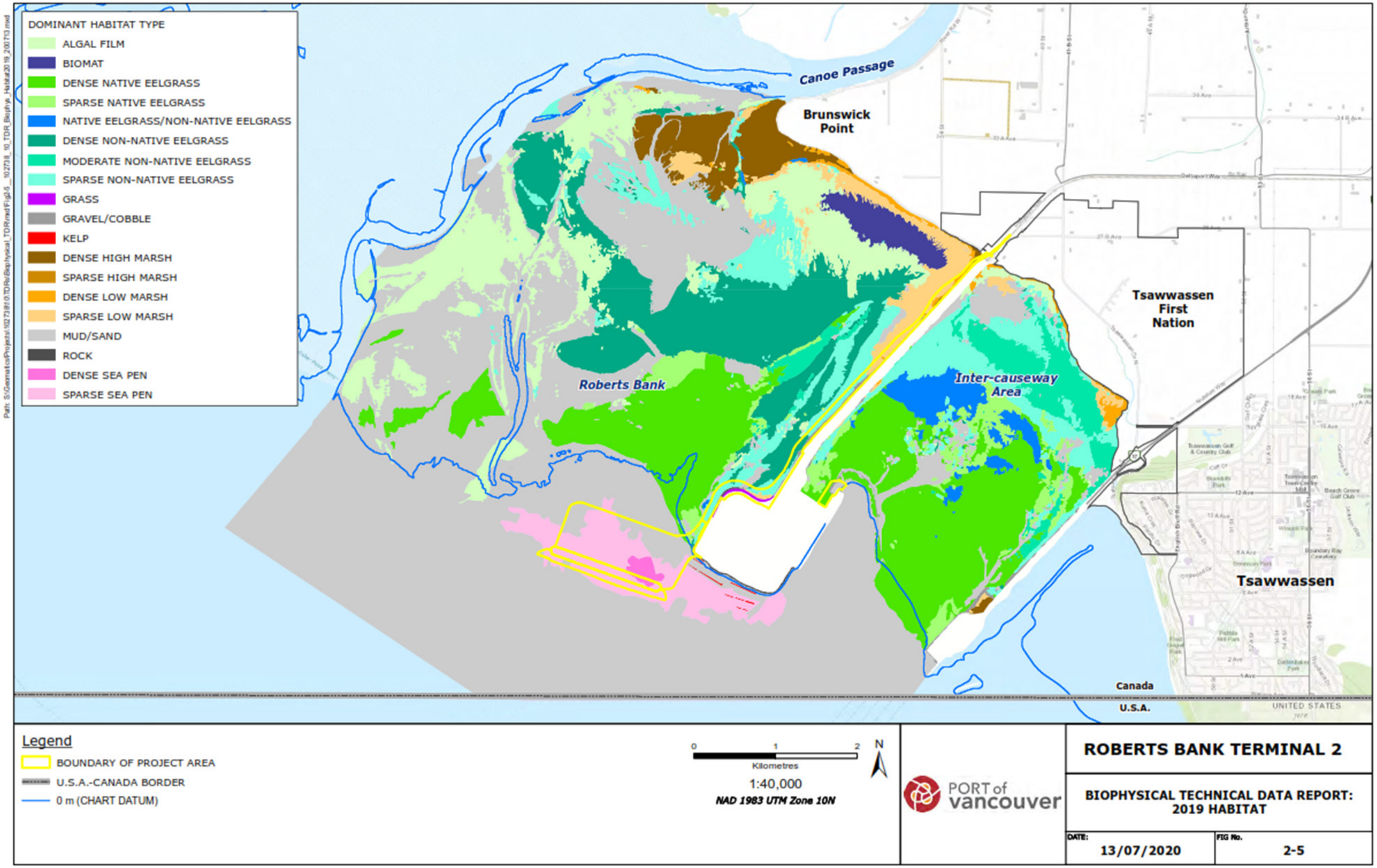
- The transfer to the latest professional version of the EwE software (**Section 2.2**)
- Updates to the RB model including adding life history stages in the food web of the RB model, updating input biomass data, and balancing of the updated RB model (**Section 2.3**)
- Sensitivity analysis to evaluate how robust the outputs of the updated RB model are to uncertainty in input parameters (**Section 2.4**)
- Quantifying underwater noise-related losses in productivity during project construction with and without the implementation of mitigation (**Section 2.5**)
- Calculating productivity values of offsetting habitat types proposed for the project and of underlying habitats (**Section 2.6**)

2.1 Study area

The RB model is focused on Roberts Bank, in Delta, B.C., and the study area is identical to what was used for the EIS. The study area of the RB model is 54.68 km^2 and extends from the high tide level northeast to the –100 metres chart datum (m CD) depth contour in the west to Canoe Passage in the northwest and the BC Ferries Tsawwassen terminal in the southeast (**Figure 2-1**). The area is characterized by extensive productive tidal flats with various habitat types 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.

The proposed project has a total footprint of 182.5 hectares (ha) (1.83 km^2). The portion of the footprint that was modelled in Ecospace includes the footprint associated with the widening of the Roberts Bank causeway and the construction of the marine terminal totalling 165.5 ha (1.66 km^2), corresponding to 3.0 percent (%) of the total study area (54.68 km^2). The proposed project footprint modelled in Ecospace does not include the temporary disturbance of 3.1 ha (0.031 km^2) associated with the proposed expansion of the tug basin. Also, it does not account for potential additional footprint reductions by up to 14.4 ha described in IR2020-2.1. Potential reduction in footprint-related effects to fish and fish habitat productivity should this potential additional footprint reduction be implemented are described in IR2020-2.1. Hence, forecasts of the updated RB model key run and MC sensitivity analysis presented in this report are considered conservative.

Figure 2-1 **Study area for the updated RB model with underlying habitats mapped in 2019**



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

2.2 EwE software transfer

The RB model for the EIS was constructed using EwE Version 6.5.10929.0 (V6.5; released on November 27, 2014). For reproducibility, V6.5 was used throughout the sufficiency and panel review phases of the project's environmental assessment, following submission of the EIS in 2015. The development of EwE has been continuous, including the addition of new features and capabilities along with system improvements, resulting in regular new release versions of the software. To benefit from continued software development, the RB model was updated using the latest professional EwE version 6.7.0.16956 (V6.7; released on July 11, 2020). By transferring to the latest professional software version, the updated RB model incorporated the improved capabilities of a newer EwE version, including the following:

- Applying diagnostics prior to balancing the Ecopath model
- Improved management of the spatial database
- Improved productivity scaling
- Correction of a data processing programming error in the temporal-spatial framework of Ecospace

These software improvements facilitated more accurate modelling of the Roberts Bank ecosystem and generated more comprehensive estimates of model uncertainty. The increased spatial capabilities of the updated software also enabled the quantification of construction-related effects that were not feasible for the EIS.

2.3 Roberts Bank ecosystem model update

For clarity, biomass and production are used throughout the report as measurable proxies of productivity. The updated RB model was updated to reflect: (i) biomass data collected during field surveys conducted for the project in 2019, and (ii) recommendations made by DFO during their technical review of the project's environmental assessment of ecosystem productivity (DFO 2016). Specifically, DFO commented that consideration of different life stages of species in the RB model would allow the exploration of how the project may affect them (DFO 2016). In response to DFO comments, updates to the RB model included incorporating different life history stages in the functional groups of Chinook and chum salmon, Dungeness crab and biofilm (**Section 2.3.1**). Furthermore, other modifications of the RB model included biomass updates for groups of marine vegetation, marine infauna, and Pacific herring (**Section 2.3.2**); and the subsequent balancing of the updated RB model due to the aforementioned modifications (**Section 2.3.3**).

2.3.1 Functional group modifications

Table 2-1 provides a list of the 64 functional groups comprising the food web of the updated RB model, six groups more than the RB model developed for the EIS given the addition of multistanza groups for Chinook and chum salmon and for Dungeness crab, and the consolidation of biofilm (as explained below). The list of functional groups includes 24 representative species or groups (shown in **Table 2-1** in bold font) that were selected to structure the marine biophysical effects assessment presented in the EIS.

Chinook, chum, and Dungeness crab were converted to multistanza groups to represent different life history stages or stanzas (Walters et. al. 2008) that are present at Roberts Bank. For Chinook, chum, and Dungeness crab, each stanza was described in the updated RB model using the following stanza-specific information (Heymans et al. 2016): age (in months), total mortality (equivalent to production over biomass

(P/B)), the growth constant K from the von Bertalanffy growth function (VBGF)[2], the estimate of weight at maturity as a fraction of weight at infinity (W_{mat}/W_{inf})[3], and estimates of diet and predation (expressed within the diet composition matrix of Ecopath). Values for input parameters of the multistanza groups are presented in **Section 2.3.1.1** for Chinook and chum salmon, in **Section 2.3.1.2** for Dungeness crab, and for the consolidated biofilm group in **Section 2.3.1.3**.

Table 2-1 Overview of functional groups that comprise the food web of the updated RB model

Functional groups					
Marine mammals		22	**Chum* adult**	45	Epifaunal omnivore
1	Baleen whales	23	Chum* feeders	46	Epifaunal sessile
2	Dolphins and porpoises	24	**Chum* smolt**	47	**Infaunal bivalves***
3	Pinnipeds	25	Chum* freshwater	48	Jellyfish
4	Southern resident killer whales*	26	Chum* non RB returning	49	**Macrofauna***
5	Transient killer whales*	27	Dogfish	50	**Meiofauna**
Birds		28	**Flatfish**	51	Omnivorous and herbivorous zooplankton
6	American wigeon*	29	**Forage fish**	52	Polychaetes*
7	Bald eagle*	30	**Herring**	53	**Orange sea pen**
8	Brant goose*	31	**Large demersal fish**	54	Shrimp
9	Diving waterbirds	32	**Lingcod***	**Vegetation**	
10	Dunlin*	33	**Rockfish***	55	Biofilm*
11	Great blue heron*	34	Salmon adult	56	**Brown algae***
12	Gulls and terns	35	Salmon juvenile	57	**Native eelgrass***
13	Raptors	36	**Sandlance***	58	Green algae*
14	Shorebirds	37	**Shiner perch***	59	**Non-native eelgrass***
15	Waterfowl	38	Skate	60	Red algae
16	Western sandpiper*	39	**Small demersal fish**	61	Phytoplankton
Fish		40	**Starry flounder***	62	**Intertidal marsh***
17	**Chinook* adult**	**Invertebrates**		63	Biomat
18	Chinook* feeders	41	Carnivorous zooplankton	**Detritus**	
19	**Chinook* smolt**	42	**Dungeness crab* adult**	64	Detritus
20	Chinook* freshwater	43	**Dungeness crab* juvenile**		
21	Chinook* non RB returning	44	Epifaunal grazers		

Notes:

- Functional groups in bold font are representative species or groups that were selected to structure the marine biophysical effects assessment presented in the project's EIS.
- * marks focal species identified by the Productive Capacity Technical Advisory Group to be ecologically linked to many components of the Roberts Bank ecosystem and included in the RB model (Hemmera 2014a).

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[2] The von Bertalanffy growth function is a model to determine in animals growth of the body size (length or weight) as a function of age (von Bertalanffy 1934, reviewed for fish populations e.g., by Pauly 1984, Beverton and Holt 1993)

[3] Weight at maturity as a fraction of weight at infinity (asymptotic weight) is also known as relative weight at maturity used to determine a relationship between body size and fecundity.

2.3.1.1 Chinook and chum salmon

Four multistanza groups were created for each Chinook and chum salmon: freshwater, smolt, feeder, and adult (**Table 2-1**). Recruitment for Chinook and chum salmon smolts was kept constant in the updated RB model to ensure that model outputs reflect the influence of local environmental conditions on Chinook and chum salmon smolts during their residence time in the study area.

The influence of local environmental conditions on freshwater and feeder stanzas was minimized by setting their diets to 99.9% import (i.e., 99.9% of their prey originates from outside the boundaries of the study area). This setup ensures that the size of the returning adult year class for each Chinook and chum salmon depends on the local environmental conditions at Roberts Bank for smolts only.

The starting month of age was set at 0, 2, 4, and 40 months for freshwater, smolt, feeder, and adult stanzas, respectively. Empirical information from Roberts Bank collected during the project's field surveys in 2012 and 2013 was used to calculate smolt biomass (Archipelago 2014a, Hemmera 2014a), which was in turn used to calculate the biomass for the other stanzas.

The consumption over biomass (Q/B) value was modified based on an assumed P/Q rate of 0.267 (Carl Walters. Pers. Com. 2020). Q/B was estimated to be 37.9, 15.0, 4.2, and 1.5 per year for freshwater, smolt, feeder, and adult stanzas, respectively. The VBGF K constant was set at 0.45 per year assuming juveniles reside at Roberts Bank for two months (Carl Walters. Pers. Comm. 2020). Total mortality was estimated to be 4.0, 4.0, 3.0, and 0.2 per year for freshwater, smolt, feeder, and adult stanzas, respectively (Carl Walters. Pers. Com. 2020).

In addition to the multistanza groups described above, two additional functional groups of 'non Roberts Bank returning' adults were created for Chinook and chum salmon. The adult stanzas of Chinook and chum salmon function as recipients of mass and energy of smolt stanzas that recruit to the adult salmon population. The 'non-Roberts Bank returning' functional groups represent the large annual flow of biomass through the study area during the return migration of Chinook and chum salmon to spawning grounds in the Fraser River watershed. During their return migration, adult Chinook and chum salmon have generally ceased feeding prior to ascending the river. The large amount of returning salmon biomass that flows through the study area provides energy inputs (food) to predators that occur there, but only draws minimal resources. In the updated RB model, 'non Roberts Bank returning' adult salmon account for about 99% of the original adult salmon biomass in the RB model developed for the EIS. Biomass of 'non Roberts Bank returning' adult salmon was estimated to be 3.39 tonnes per square kilometre (t/km^2) for Chinook and 2.02 t/km^2 for chum salmon. Biomass of the adult stanzas was estimated to be 0.03 t/km^2 for Chinook and 0.02 t/km^2 for chum salmon, calculated by subtracting from the original adult salmon biomass in the RB model for the EIS the biomass of 'non Roberts Bank returning' adults in the updated RB model. P/B and Q/B of 'non Roberts Bank returning' adult groups of both salmon species were set at 0.4 and 1.6, respectively.

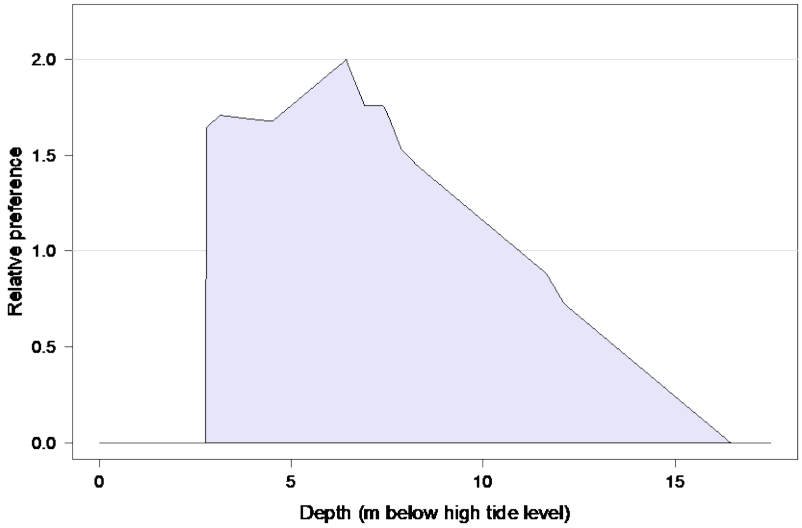
Environmental preferences for depth, salinity, current speed, wave height, and substrate type applied to Chinook and chum salmon multistanza and 'non-Roberts Bank returning' groups were the same as those presented in Hemmera (2014a).

2.3.1.2 Dungeness crab

For Dungeness crab, two multistanza groups (juvenile and adult) were created with starting month ages set at 0 and 8 months, respectively. Biomass for juvenile and adult crab was estimated to be 0.57 t/km^2 and 4.45 t/km^2, respectively. Juvenile crab biomass was estimated based on empirical surveys undertaken for the project at Roberts Bank in 2012 and 2013 (Hemmera 2014c). Adult crab biomass was estimated using the VBGF K constant and total mortality (equivalent to P/B). The VBGF K constant was set at 0.55 per year, based on Wolff and Cerda (1992) for a proxy species, *Cancer polyodon*. Q/B and total mortality were set respectively at 20 and 3 per year for juvenile crab, and at 7.69 and 2 per year for adult crab (Carl Walters. Pers. Com. 2020).

Environmental preferences for depth, salinity, current speed, wave height, and substrate type applied to adult crab were the same as those presented in Hemmera (2014a). Environmental preferences applied for juvenile crab were also the same as those presented in Hemmera (2014a) except for depth. Environmental preference for depth by juvenile crab was set to reflect preference for low intertidal to shallow subtidal zones, based on literature (Hemmera 2014d and references therein; **Figure 2-2**).

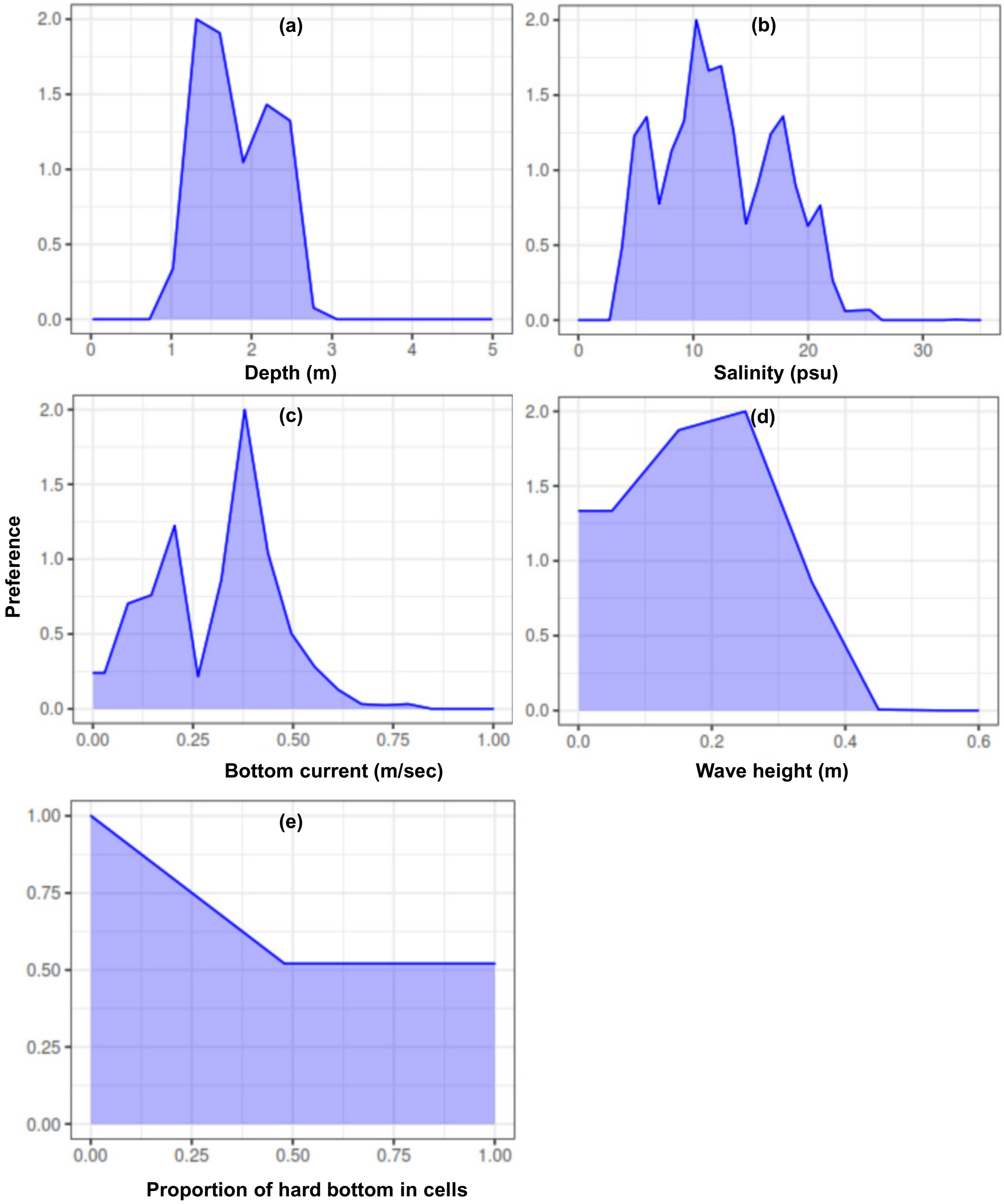
Figure 2-2 Depth preference by juvenile Dungeness crab



2.3.1.3 Biofilm

In the updated RB model, biofilm was consolidated into a single functional group by combining the marine and freshwater biofilm groups of the RB model developed for the EIS. This change reflects current understanding that biofilm is adapted to a range of salinity conditions and is best classified as estuarine. This reflects results from the empirical surveys undertaken for the project between 2016 and 2018, which concluded that there are no statistical differences in biofilm community composition across the large salinity gradient observed in the study area (Hemmera and Advisian 2017, Hemmera 2018, Hemmera et al. 2019, VFPA 2019a). Biomass of biofilm was estimated to be 64.01 t/km^2, calculated using the methodology described in Hemmera (2014b). Environmental preference functions for biofilm were also consolidated and those used in the updated RB model are shown in **Figure 2-3** for depth, salinity, bottom current, wave height, and substrate type.

Figure 2-3 **Environmental preference functions used in the updated RB model for biofilm and (a) depth (metres; m), (b) salinity (practical salinity units; psu); (c) bottom current (metres per second; m/sec); (d) wave height (m); and preference for soft substrate**



2.3.2 Biomass input updates

Biomass inputs were updated for some functional groups of marine vegetation (i.e., native eelgrass, non-native eelgrass, intertidal marsh), and of marine invertebrates (i.e., macrofauna, meiofauna, bivalves, orange sea pens), to reflect current (2019) conditions based on additional empirical surveys undertaken for the project at Roberts Bank in 2019. Biomass input of Pacific herring was also updated to reflect recent DFO research findings (Boldt et al. 2019) for the Strait of Georgia.

2.3.2.1 Marine vegetation

The areal extent of marine vegetation in the study area (**Figure 2-1**) was mapped in 2019 to provide current (2019) estimates of biomass. To reflect findings of these additional empirical surveys, biomass of native eelgrass, non-native eelgrass, and intertidal marsh was updated in the RB model (**Table 2-2**). The mapped areal extent was converted to biomass using the methods described in Hemmera (2014b).

Table 2-2 Biomass inputs of marine vegetation functional groups included in the updated RB model based on empirical data collected for the project in 2019

Functional group	t/km^2
Native eelgrass	17.27
Non-native eelgrass	0.86
Biofilm	64.01
Biomat	50.17
Intertidal marsh	23.54

2.3.2.2 Marine invertebrates

Macrofauna, meiofauna (intertidal only), infaunal bivalves, and orange sea pens were sampled during empirical surveys undertaken for the project in 2019, and characterized in terms of density, abundance, and biomass. Data from 2019 were used to update biomass estimates for these functional groups in the updated RB model.

Mean biomass of macrofauna was estimated to be 75.26 t/km^2 for the intertidal zone and 31.26 t/km^2 for the subtidal zone. Mean biomass by tidal zone was weighted by the proportion each tidal zone is represented in the updated RB model (i.e., 67% intertidal and 33% subtidal) and then summed for an estimated total biomass of 60.77 t/km^2 (**Table 2-3**). Mean biomass of meiofauna (intertidal only) was estimated to be 38.97 t/km^2 (**Table 2-3**).

Mean biomass of infaunal bivalves was estimated to be 207.8 t/km^2 and 67.95 t/km^2 for the intertidal and subtidal zone, respectively. These estimates were weighted by the proportion of each tidal zone in the updated RB model (i.e., 67% intertidal and 33% subtidal) and then summed for an estimated total biomass of 91.9 t/km^2 (**Table 2-3**).

The distribution and density (abundance per m^2) of orange sea pens in the study area (**Figure 2-1**) were updated during surveys in 2019. Densities were calculated for both the sparse and dense orange sea pen aggregations and were converted to total abundance by multiplying with the mapped areal extent of sparse and dense sea pen distribution. Total abundance was converted to biomass by multiplying with an estimated mean individual wet weight (Batie 1971). Mean wet weight was derived by converting mean dry weight with a factor of 19.3 for sea cucumbers (Ricciardi and Bourget 1999). Mean biomass for orange sea pens was estimated to be 0.09 t/km^2 (**Table 2-3**).

Table 2-3 Biomass inputs of marine infaunal functional groups included in the updated RB model based on empirical data collected for the project in 2019

Functional group	t/km^2
Macrofauna	60.77
Meiofauna	38.97
Infaunal bivalves	91.90
Orange sea pens	0.09

2.3.2.3 Pacific herring

Biomass of Pacific herring was updated to reflect recent DFO research findings by Boldt et al. (2019) regarding the influence of biological (e.g., spawning biomass of adult herring, timing of spawning, prey availability, predator abundance) and environmental (e.g., sea surface temperature, sea level, river discharge) factors on the inter-annual variability of abundance and condition of Pacific herring in the Strait of Georgia. Herring biomass in the updated RB model was set to 2 t/km^2.

2.3.3 Updated Roberts Bank model balancing and key run

In an Ecopath model, production of prey groups must meet the consumption demand of predators (also referred to as mass balance). Ecopath checks mass balance by evaluating the ecotrophic efficiency (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 within the system. An Ecopath model is rarely balanced when it is first constructed (Heymans et al. 2016). Balancing is an iterative process that requires careful evaluation of parameter inputs of those functional groups whose mass does not balance. To ensure an Ecopath model is balanced, diets are adjusted first, followed by P/B and Q/B values; biomass estimates are changed only if necessary (Heymans et al. 2016).

Updates described in **Sections 2.3.1** and **2.3.2** led to the updated RB model being unbalanced for one functional group – forage fish. The EE of forage fish was 1.06 due to increased predation by adult Dungeness crab. The updated RB model was balanced by reducing from 6% to 3% the contribution of forage fish to the diet of adult Dungeness crab, and allocating the remaining 3% of the diet of adult Dungeness crab to detritus.

Following balancing, the updated RB model was run to yield the key run. The key run is a well-defined model reference run that serves as a basis for further evaluations of uncertainty and of alternative model scenarios. Outputs of the updated RB model key run provide one representation of the Roberts Bank ecosystem once it has approached equilibrium.

2.4 Sensitivity analysis

Sensitivity analysis was undertaken to evaluate how uncertainty in input parameters may influence performance of the updated RB model and robustness of model outputs. The methods of the sensitivity analysis mirror those used in the EIS, described in ESSA (2014), and subsequently in responses to the review panel's IRs for completeness (i.e., IR2.7; VFPA 2016) and sufficiency (i.e., IR3-09; VFPA 2017). Uncertainty in input parameters to the updated RB model was evaluated using Monte Carlo (MC) simulations. For the updated RB 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 (Steenbeek et. al. 2016). The plug-in that was developed for the updated RB model used the existing MC capabilities (and interface) from Ecosim but was designed to run in Ecospace. The outputs of both the updated RB model key run and the MC sensitivity analysis were used to inform the calculations of project-related net gains in the productivity of fish and fish habitat at Roberts Bank after avoidance, reduction, and offsetting measures, presented in **IR2020-1.2**, including discounting to address uncertainty in the updated RB model outputs and temporal lag associated with the time that may be required for indirect changes in fish and fish habitat productivity to be realized (described in **Appendix IR2020-1.2-D**).

For the updated RB model, the outputs of the ‘with project’ and ‘without project’ scenarios were evaluated by randomly varying the values of B, P/B, and Q/B within the confidence intervals (CIs; defined in the response to preliminary technical question 2.7 (VFPA 2016)) specified in the model’s pedigree[4].

For each MC run, each set of sampled parameters was checked to ensure they yielded a balanced Ecopath model. Each balanced Ecopath model had a 10 year spin up until the ecosystem stabilized, and then was run for an additional 10 years projected into the future. This process was conducted under two different scenarios, one with the project and one without the project. In the ‘with project’ run, the project was added after one year, and the environmental conditions were changed instantaneously. Results for both the ‘with project’ and ‘without project’ runs were extracted for the tenth year of the simulation. The MC approach generated 2,000 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 associated uncertainty (i.e., the 95% CI obtained as the range between the 2.5 and 97.5 percentile biomass result).

2.5 Underwater noise-related productivity losses during project construction

Proposed in-water construction activities have the potential to generate underwater noise at levels that may result in physical injury or mortality of fish or behavioural disturbance (e.g., startle or alarm, habitat avoidance, changes to natural movements; Popper and Hastings 2009a,b). Project-related changes in the acoustic environment are not anticipated to affect marine invertebrates given their lack of sensitivity to sound pressure (Popper and Hawkins 2019). Accordingly, changes in the acoustic environment were not included as an effect mechanism in the marine invertebrates effects assessment presented in the EIS.

In-water construction activities that may result in impulsive[5] underwater noise at levels that may injure or kill fish include the use of an impact hammer to drive piles during the installation of temporary (e.g., temporary barge ramps) and permanent (e.g., mooring dolphins) infrastructure, and to install a short sheet pile wall section to close the terminal containment dykes. In-water construction activities that may generate continuous[6] (non-impulsive) underwater noise that may disturb fish include, but are not limited to, vibratory pile driving, dredging and pumping of sediment for infilling, vibro-densification, as well as vessel movements of tugs and support vessels during in-water construction. Changes in fish productivity associated with underwater noise-related construction effects before and after implementation of mitigation

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[4] The pedigree of EwE assigns a CI to the input parameter values based on their origin. For example, a 10 to 40% CI is used for input parameters that are quantified using empirical data, a 50% CI is assigned to input parameters estimated using empirical relationships, and a 80% and 90% CI are used for data inputs based on other models and professional judgement, respectively.

[5] Impulsive sound is high in intensity, and of short duration (i.e., less than several seconds), generated from activities such as impact pile driving.

[6] Continuous sound is less intense but longer lasting than impulsive sound, and is generated from activities such as vessel movement, vibratory piling, and dredging.

measures were quantified by incorporating into the updated RB model outputs of the acoustic propagation modelling undertaken by JASCO (**Appendix IR2020-2.3-C**). The approach to and outputs of the acoustic propagation modelling, as well as steps to incorporate these outputs into the updated RB model are described below.

2.5.1 Acoustic propagation modelling

In support of IR2020-2.3, underwater noise was modelled by JASCO for eight unique construction scenarios, each representing anticipated combinations of marine works that will occur concurrently during project construction. Two of eight scenarios considered impact piling activities with and without the implementation of mitigation measures. The remaining six scenarios considered combination of in-water construction activities that may generate continuous underwater noise. Acoustic propagation modelling was carried out using JASCO's Marine Operations Noise Model (**Appendix IR2020-2.3-C**).

Potential injury to fish was assessed using criteria (shown in **Table 2-4**) developed by Popper et al. (2014). The Popper et al. (2014) criteria reflect the best-available science and supersede the interim criteria developed in 2008 by a panel of hydroacoustic and fisheries experts (FHWG 2008) that were applied in the EIS.

Based on results of acoustic propagation modelling, without mitigation, the cumulative sound exposure level (SEL) thresholds of 203 and 207 decibels (dB) re 1μPa^2 s for 100 minutes of pile driving were exceeded, respectively, at a maximum distance of 120 m and 70 m from the sound source. For this scenario, the peak sound level (PK) threshold of >207 dB re 1μPa was exceeded at 30 m from the sound source.

With a confined bubble curtain as mitigation, the cumulative SEL thresholds of 203 and 207 dB re 1μPa^2 s for 100 minutes of pile driving activity were exceeded respectively at a maximum distance of 30 m and 10 m from the sound source. For this scenario with mitigation, the PK threshold of >207 dB re 1μPa was exceeded at 10 m from the sound source.

Table 2-4 Criteria for auditory recoverable injury and mortality to fish with swim bladder involved in hearing adapted from Popper et al. (2014)

Criteria	PK (dB re 1μPa)	Cumulative SEL (dB re 1μPa^2 s)
Recoverable injury	>207	203
Mortality	>207	207

Notes:

- Criteria use unweighted sound levels
- Criteria used in modelling have been developed for fish with swim bladder involved in hearing, such as for Pacific herring, that are sensitive to underwater noise
- PK – peak sound level, SEL – sound exposure level

Behavioural disturbance to fish from continuous noise during construction was assessed used audiogram-weighted sound level thresholds of 90 dB$_{ht}$[7] for flatfish, herring, and salmon. Based on results of acoustic modelling, the 90 dB$_{ht}$ behavioural threshold was exceeded for herring during all six scenarios of continuous

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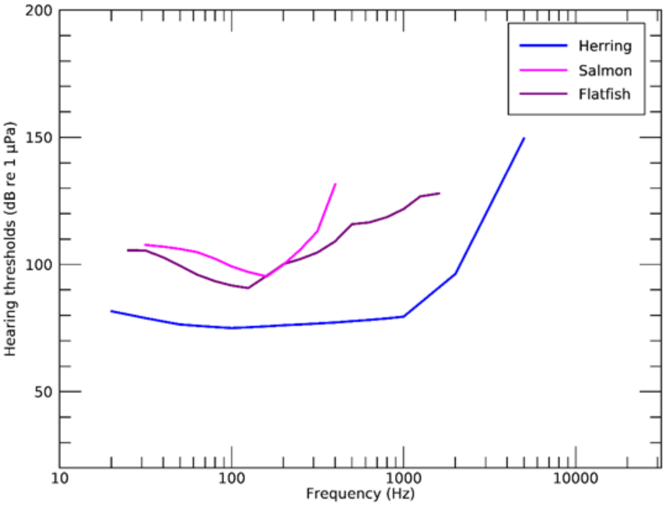
[7] dB$_{ht}$ – decibel level above the animal's hearing threshold (Nedwell et al. 2007; see also VFPA 2015, and the port authority's response to IR5-26 and IR5-27 in VFPA 2018b).

noise within a radius of 820 m from the sound source. For salmon and flatfish, behavioural disturbance was predicted to be localized within up to 10 m from the sound source. Salmon and flatfish are considered hearing generalists[8] and are less likely to experience acoustic disturbance from underwater noise (**Figure 2-4**). In contrast, herring are considered hearing specialists[10] as they are more sensitive to underwater noise (Popper and Hawkins 2019).

Figure 2-4 Audiograms for herring, salmon, and flatfish



Notes: Audiograms for herring by Enger (1967), for salmon by Hawkins and Johnstone (1978), and for flatfish by Chapman and Sand (1974) and Zhang et al. (1998).

Based on results of acoustic propagation modelling, the following three of eight scenarios of construction activities modelled by JASCO were incorporated into the updated RB model to quantify losses in productivity associated with the following:

Physical injury or mortality of fish:

1. Impact piling a 914 mm steel cylindrical pile at the mooring dolphin without noise attenuation
2. Impact piling a 914 mm steel cylindrical pile at the mooring dolphin with a confined bubble curtain as a noise attenuation mitigation measure

Behavioural disturbance to herring, considered a hearing specialist[9]:

3. Summer dredging, pumping ashore, and vibro-densification with six tugs maneuvering and one tug towing a barge

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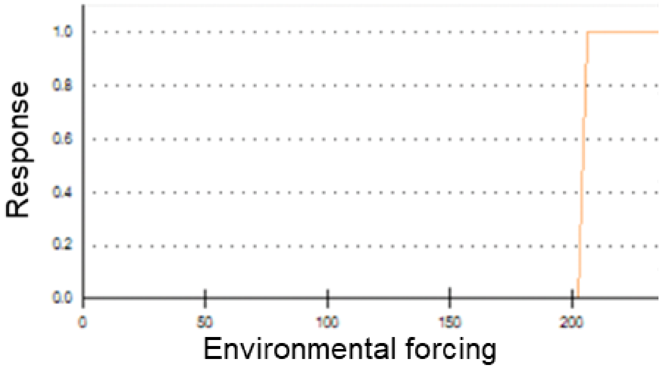
[8] Hearing generalists include fish without or with reduced swim bladders or with swim bladders not connected or coupled to the inner ear and have a narrower bandwidth or frequency range of hearing and are less sensitive to sound pressure (Popper and Hastings 2009a,b, Popper et al. 2014). In contrast, hearing specialists have a functional connection between the swim bladder and the inner ear, leading to a broader bandwidth of hearing and high auditory sensitivity (Popper and Hastings 2009a,b, Popper et al. 2014).

[9] All other representative fish species and groups are considered to be hearing generalists and behavioural disturbance is expected to be localized, within 10 m from the sound source, based on results for salmon and flatfish.

2.5.2 Ecosystem modelling of underwater noise effects

Underwater noise construction effects on the productivity of representative species or groups in the study area were modelled using a professional version (6.7.0.17220) of EwE that incorporated a response function for modelling lethal environmental effects (Chagaris et al 2000). This response function (**Figure 2-5**) expresses the proportion of the fish population that is subject to mortality based on underwater noise levels that exceed criteria set in **Table 2-4**. Values of input parameters to the updated RB model were the same as described in Hemmera (2014b) and modified as described in **Section 2.3**.

Figure 2-5 **Response function for impulsive noise. Underwater noise levels below 203 decibels result in no impact and greater than 207 decibels lead to 100% fish mortality**



Based on the project's proposed construction activities, the sequence and associated timeline of project construction activities implemented in the updated RB model are shown in **Table 2-5**. The Areas of underwater noise propagation (ensonified area), in the form of shapefiles produced by JASCO for each of the three scenarios of acoustic propagation modelling (listed in **Section 2.5.1**), were converted from ArcGIS to georeferenced ASCII files and were incorporated in the Ecospace temporal-spatial framework.

Table 2-5 In-water construction activities assessed, underwater noise type, modelling scenario, fish response, and anticipated schedule implemented in the updated RB model

Construction activity modelled	Underwater noise type	Modelling scenario[i]	Fish response	Year	Month	Activity duration (months)
Start of construction				Year 1	Aug	
Install temporary barge ramps	Impulsive	1, 2	Mortality	Year 1, 2	Aug – Sep	1
Dredge at dredge basin	Continuous	3	Behavioural disturbance	Year 2	Apr – Oct[ii]	6
Install mooring dolphin at tug basin	Impulsive	1, 2	Mortality	Year 2	Aug – Oct[ii]	2
Dredge at dredge basin	Continuous	3	Behavioural disturbance	Year 3	Apr – Oct[ii]	6
Other marine construction	Continuous	3	Behavioural disturbance	Year 3	Apr – Oct[ii]	6
Other marine construction	Continuous	3	Behavioural disturbance	Year 4	Apr – Oct[ii]	6
Other marine construction	Continuous	3	Behavioural disturbance	Year 5	Apr – Oct[ii]	6
Other marine construction	Continuous	3	Behavioural disturbance	Year 6	Apr – Oct[ii]	6
Other marine construction	Continuous	3	Behavioural disturbance	Year 7	Apr – Oct[ii]	6

Notes:

i. Acoustic propagation modelling scenarios are described in Section 2.5.1.
ii. Behavioural disturbance was considered to occur for seven months of the year (between April and October) as herring was caught in the study area predominantly in spring and summer during empirical surveys undertaken for the project in 2012 and 2013 (Archipelago 2014a,b). April coincides with the end of the fisheries sensitive window for gravid Dungeness crab (October 15 to March 31 for waters deeper than -5 m CD).

Loss in productivity of representative species or groups was calculated by running the updated RB model over a 10-year time frame. Losses in productivity due to impulsive noise generated during impact piling were quantified by forcing 100% mortality upon all fish representative species or groups in the updated RB model within areas where mortality criteria were predicted to be exceeded, based on acoustic propagation modelling. Fish mortality was assumed within ensonified areas with underwater noise levels greater than 207 dB (**Table 2-4**, **Figure 2-5)**, without and with the use of a confined bubble curtain as a noise attenuation measure (scenarios 1 and 2; **Section 2.5.1**).

Losses in productivity as a result of continuous noise generated during project construction activities were quantified for herring by incorporating in the updated RB model acoustic modelling scenario 3 (**Section 2.5.1**). This was quantified by applying the environmental response function shown in **Figure 2-6**. This response function denotes that an increase in underwater noise by 50 dB and 75 dB above the species' hearing threshold (expressed in dB_{ht}) leads respectively to a 50% and 85% reduction in foraging by herring. At 90 dB above the species' hearing threshold, herring will temporarily leave the area of disturbance. This response function was designed based on findings by Nedwell et al. (2007) summarized in **Table 2-6.**

Figure 2-6 **Environmental response function denoting behavioural disturbance to Pacific herring associated with increasing levels of continuous underwater noise**

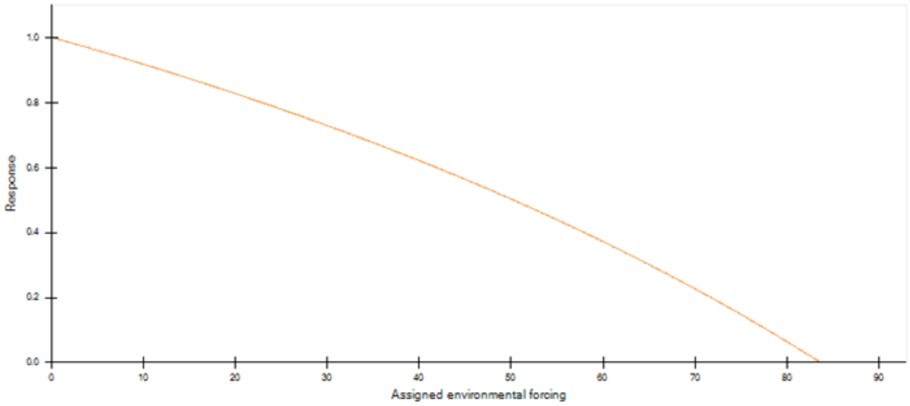


Table 2-6 **Reaction of individual fish to varied sound levels above a species' hearing threshold (expressed in dB$_{ht}$)**

dB$_{ht}$	*Effect*
<0	None
0-50	Mild reaction in minority of individuals, probably not sustained
50-90	Stronger reaction by majority of individuals, but habituation may limit duration of effect. At 75 dB$_{ht}$, approximately 85% of individuals will react to the noise
>90	Strong avoidance reaction by virtually all individuals

Source: Nedwell et al. 2007

2.6 Productivity values for offsetting habitats

Consistent with the recommendation by DFO (2019b), food web models specific to each offsetting habitat type were constructed using the Ecopath module of EwE. Ecopath was also used to create food web models of the habitat types, specifically intertidal and subtidal sand, underlying offsetting habitats proposed to be constructed. Productivity values of habitat types were calculated using local, habitat specific empirical estimates of biomass per functional group comprising the food web of each habitat type and were independent of the outputs of the updated RB model. Developing food web models for each habitat type allowed for the enforcement of mass balance limits within each food web model to ensure biomass estimates were ecologically realistic.

2.6.1 Selection of species or groups by habitat type

The functional groups comprising the food web of each habitat type were selected consistent with the habitat specific food webs presented in the port authority's response to IR7-26 (VFPA 2018c). Where applicable, the food web of each habitat type included multistanzas for Chinook and chum salmon, as well as for Dungeness crab, as described in **Section 0**. Higher trophic level species or groups (e.g., birds) were included in the habitat specific food webs for completeness but were not considered in the calculation of offsetting productivity values. This is because their proportion of diet within these habitats is low overall and the predation pressure they exert is overestimated when included.

2.6.2 Food web model inputs

For each functional group comprising the food web of each habitat type, inputs to the food web models included estimates of B, P/B, Q/B, and diet composition. Where available, habitat specific local field data collected during the project's 2012, 2013, and 2019 surveys (Archipelago 2014a,b,c, Hemmera 2020) were used to generate habitat specific biomass estimates. This approach is conservative as it may underestimate productivity of created habitats by reflecting existing conditions of fish populations that may be depressed and not necessarily reflect the capacity of the created habitat. For example, Chinook salmon stocks of the Fraser Late stock aggregate (such as ocean-type Chinook salmon from the Harrison River) have been exhibiting over the last three decades a decreasing trend in abundance and marine survival rates (e.g., Riddel et al. 2013, Dorner et al. 2018, Brown et al. 2019). Decreasing number of Chinook salmon adults returning to the Fraser River watershed to spawn would in turn lead to decreasing numbers of Chinook salmon juveniles outmigrating to the estuary to rear. As such, decreasing numbers of juvenile Chinook salmon using constructed marshes at Roberts Bank would reflect depressed adult populations and not a reduced capacity of constructed marshes to support larger numbers of juvenile Chinook salmon. For those functional groups for which empirical information was not available, biomass inputs of the updated RB model were used or were informed from the literature. P/B and Q/B input values for the habitat food web models were the same as in the updated RB model.

For each habitat specific food web model, the diet matrix was adjusted by removing from the diet matrix of the updated RB model those functional groups that were not associated with the specific habitat type. The diet matrix was adjusted as follows: For consumers with a diet deficit greater than 1%, due to the removal of a potential prey from the food web of a habitat type, the proportion of deficit was considered imported. This meant that a portion of the diet for a species that was accounted for in the updated RB model was unavailable in the habitat specific food web model. Therefore, it was assumed that the predator would most likely obtain that part of the diet outside of the habitat system. For consumers left with a diet deficit of 1% or less, the remaining diet was proportionally re-distributed to all remaining prey groups.

2.6.3 Food web model balancing

Habitat specific food web models were balanced to meet mass balance requirements and following the methods described in **Section 2.3.3**. Following balancing, each food web model yielded productivity estimates for each species or group per hectare of associated habitat, including underlying habitat types.

3.0 RESULTS

This section presents changes in the productivity of representative species or groups as a result of the project, forecasted by the updated RB model key run (**Section 3.1**), and the MC sensitivity analysis (**Section 0**). Changes in productivity of representative fish species or groups from underwater noise-related construction effects are described in **Section 3.3**. Lastly, productivity values of offsetting intertidal marsh, native eelgrass, and subtidal rock reef habitat proposed for the project, as well as of intertidal and subtidal sand underlying offsetting habitats proposed to be constructed are presented in **Section 3.4**.

3.1 Updated RB model key run

Outputs of the updated RB model key run for representative species or groups are shown in **Table 3-1**. As noted earlier, the proposed project footprint incorporated in the updated RB model does not account for potential additional footprint reductions by up to 14.4 ha and potential associated reduction in footprint-related effects to fish and fish habitat productivity (described in IR2020-2.1). Hence, forecasts of the updated RB model key run and MC sensitivity analysis presented in this report are considered conservative.

Overall, with the project, productivity is forecasted to increase by 1,614.18 t, of which 1,240.47 t were forecasted for primary producers, followed by invertebrates (379.15 t). Productivity of fish is forecasted to decrease overall by 5.43 t. Productivity for 15 of 24 representative species or groups (62.5%) was forecasted to increase with the project, while for nine representative species or groups (37.5%) productivity with the project was forecasted to decrease. Productivity for six representative species or groups (25%) were forecasted to increase with the project by less than 5%[10] and for eight representative species or groups (33%) productivity increases were forecasted to be greater than 5%. Productivity decreases by less than 5% were forecasted for five representative species or groups (21%) and by greater than 5% for four representative species or groups (17%).

With respect to primary producers, intertidal marsh was forecasted to increase by 83% (1,070.77 t; **Table 3-1**) with the project, followed by native eelgrass (23%, 218.25 t) and non-native eelgrass (11%, 5.17 t). For marine invertebrates, greatest productivity increases were forecasted for macrofauna (20%, 651.89 t) followed by meiofauna (7%, 149.23 t). For marine fish, greatest increases in productivity were forecasted for shiner perch (14%, 1.22 t), lingcod (9%, 2.89 t) and juvenile chum salmon (8%, 0.04 t).

Of those representative species or groups forecasted to decrease, brown algae were forecasted to decrease by 12% (52.7 t; **Table 3-1**). For marine invertebrates, greatest losses in productivity were forecasted for orange sea pens (54%, 2.67 t) followed by infaunal bivalves (8%, 420.73 t). Productivity losses for marine fish representative species or groups are generally forecasted to be smaller than 5% (**Table 3-1**), except for small demersal fish which are forecasted to decrease by 6% (0.23 t).

Gains in productivity with the project are generally showed by bottom-up supporting (i.e., lower trophic level) groups, such as marine vegetation and primary consumers (e.g., macrofauna and meiofauna). Losses in productivity of marine invertebrate species or groups are predominantly attributed to the marine terminal footprint (e.g., for infaunal bivalves and orange sea pens). For higher trophic level groups, such as fish, changes in productivity are generally small, with increases likely attributed to increases in prey availability (such as for juvenile chum) and decreases largely driven by the marine terminal footprint (such as for

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[10] In the EIS, a 5% change in the productivity of a representative species or group was considered to be negligible, within the error margins of the RB model.

flatfish). For more mobile, schooling pelagic species, such as forage fish, the marine terminal footprint over-emphasizes loss of productive habitat. Pelagic species such as forage fish primarily use the water column more widely at Roberts Bank and are not restricted to the water column within the terminal footprint. They also rely for food on resources such as zooplankton that are widely distributed and available within the water column at Roberts Bank and surrounding areas of the Strait of Georgia and are thus not limiting.

Table 3-1 Biomass (tonnes; t) for representative species or groups without and with the project, change ratio (with/without), and biomass difference (with – without project) for the updated RB model key run

Representative species or group	Biomass without project (t)	Biomass with project (t)	Change ratio (with/without)	Biomass difference (with – without; t)
Chinook adult	1.65	1.68	1.02	0.03
Chinook smolt	0.66	0.66	1.01	0.00
Chum adult	1.24	1.23	0.99	-0.01
Chum smolt	0.49	0.53	1.08	0.04
Flatfish	20.40	20.10	0.98	-0.34
Forage fish	573.00	563.00	0.98	-9.95
Herring	243.00	244.00	1.00	1.10
Large demersal fish	8.39	8.17	0.98	-0.21
Lingcod	32.00	34.90	1.09	2.89
Rockfish	18.50	18.00	0.97	-0.52
Sandlance	11.30	11.60	1.02	0.26
Shiner perch	8.92	10.10	1.14	1.22
Small demersal fish	3.95	3.70	0.94	-0.25
Starry flounder	11.50	11.80	1.03	0.30
Dungeness crab adult	243.00	244.00	1.00	0.76
Dungeness crab juvenile	31.10	32.20	1.03	1.06
Infaunal bivalves	5,020.00	4,600.00	0.92	-420.73
Macrofauna	3,240.00	3,890.00	1.20	651.89
Meiofauna	2,130.00	2,280.00	1.07	149.23
Orange sea pen	4.91	2.25	0.46	-2.67
Brown algae	448.00	395.00	0.88	-52.70
Native eelgrass	943.00	1,160.00	1.23	218.25
Non-native eelgrass	46.90	52.10	1.11	5.17
Intertidal marsh	1,280.00	2,360.00	1.83	1,070.77
Total	**14,321.91**	**15,945.02**	**1.11**	**1,614.18**

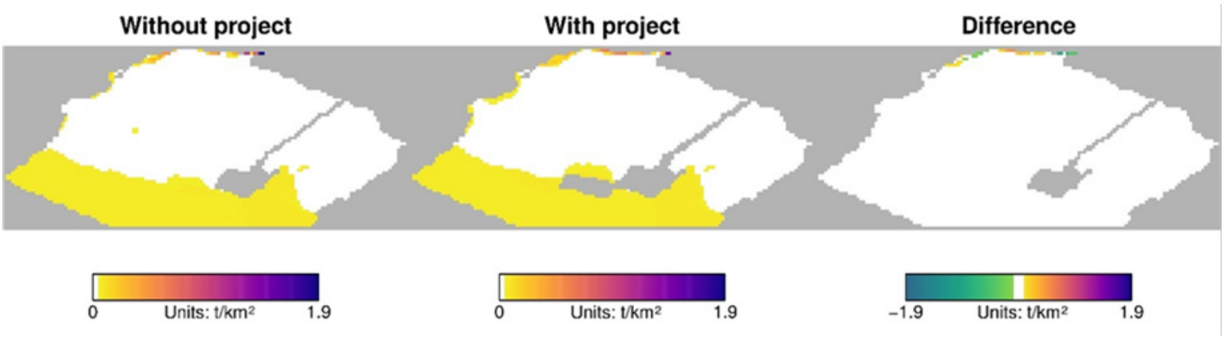
Ecospace plots provide a visualization of the updated RB model outputs and are shown in **Figure 3-1** for the 24 representative species or group. Ecospace plots provide a graphical representation of productivity (in t/km^2) without and with the project and the difference (with – without the project; t). They also indicate those applicable environmental preference functions that were considered to influence the spatial distribution of productivity changes with the project for each representative species or group. To remind the reader, environmental preference functions were used in Ecospace to reflect the response preference of functional groups for environmental variables such as depth, salinity, bottom current, wave height, and substrate type (i.e., hard or soft). Environmental preference functions of functional groups in the RB model are described in Hemmera (2014a), while **Section 2.3.1** describes updates to environmental preference function that pertain to multistanzas and modified functional groups in the updated RB model.

The colour scales of the Ecospace plots in **Figure 3-1** are relative and not fixed. In other words, all the without project scales range from yellow to purple but the units they represent will change relative to the metrics of the functional groups. For example, the maximum production for Chinook salmon adult and Chinook salmon smolt is 1.9 t/km^2 and 0.02 t/km^2, respectively, but they are both represented by deep purple (see first two Ecospace plots in **Figure 3-1** below).

Figure 3-1 **Ecospace plots of forecasted biomass change (tonnes; t) of representative species or groups without and with the project and the difference (with – without project) for the updated RB model key run**

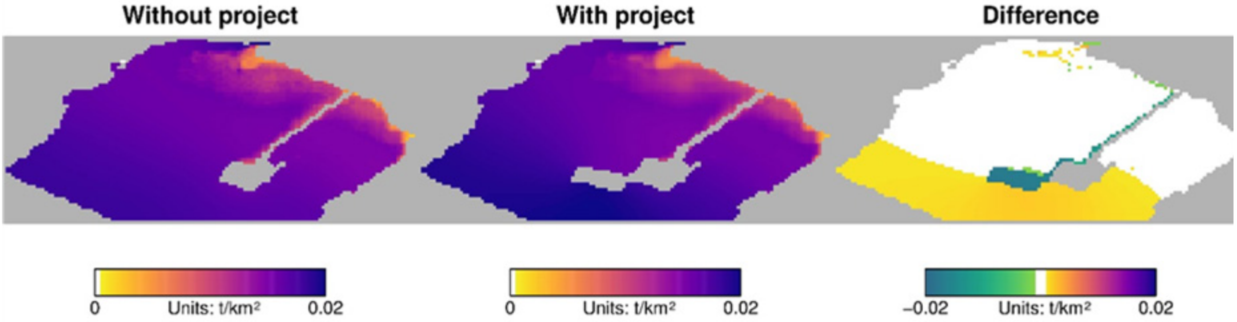
Chinook adult

Biomass (with/without) = 1.02
Biomass (with – without) = 0.027 t
Production (with – without) = 0.005 t/year
Environmental preference functions: Depth



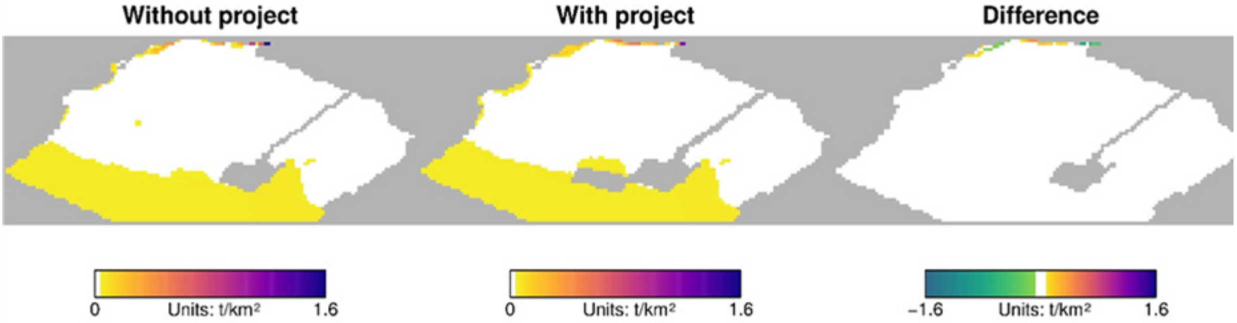
Chinook smolt

Biomass (with/without) = 1.01
Biomass (with – without) = 0.005 t
Production (with – without) = 0.019 t/year
Environmental preference functions: Depth



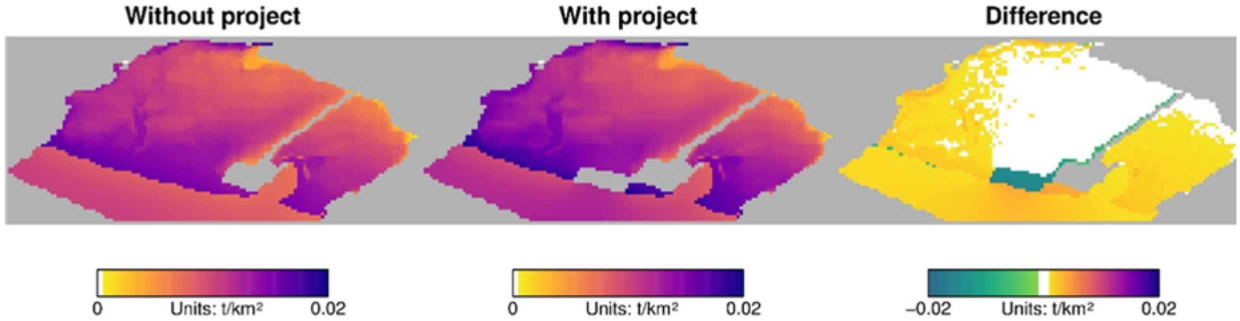
Chum adult

Biomass (with/without) = 0.99
Biomass (with – without) = -0.010 t
Production (with – without) = -0.002 t/year
Environmental preference functions: Depth



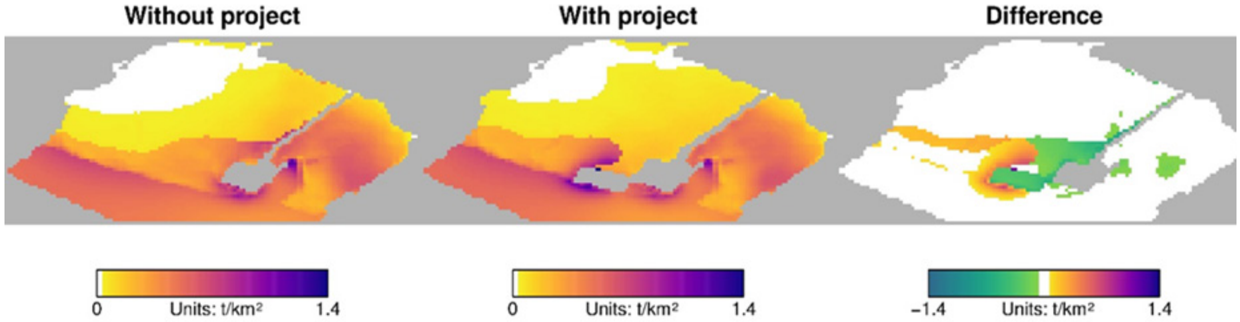
Chum smolt

Biomass (with/without) = 1.08
Biomass (with – without) = 0.039 t
Production (with – without) = 0.157 t/year
Environmental preference functions: Depth



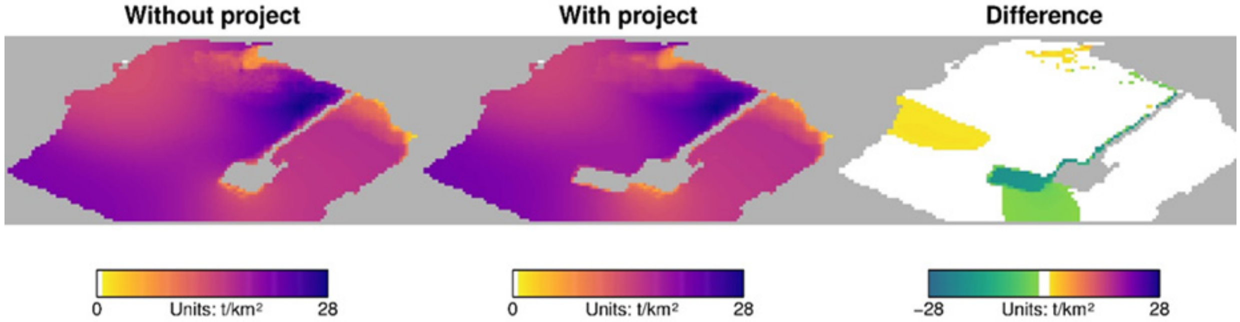
Flatfish

Biomass (with/without) = 0.98
Biomass (with – without) = -0.341 t
Production (with – without) = -0.126 t/year
Environmental preference functions: Depth, salinity, hard/soft



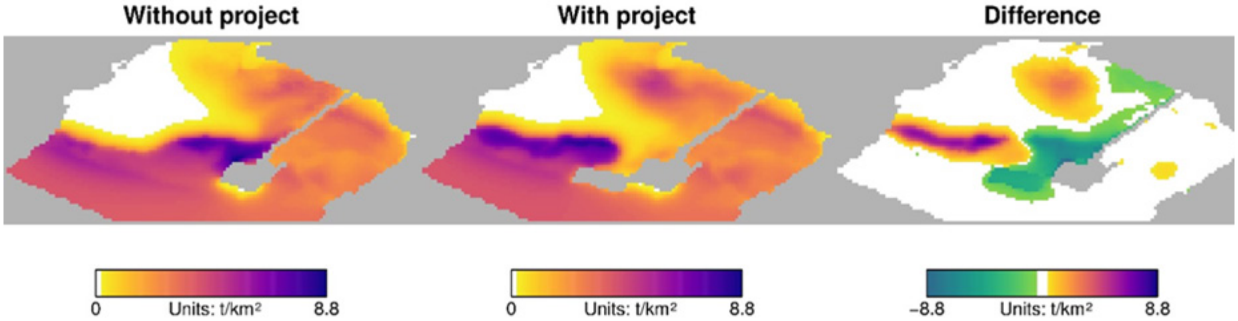
Forage fish

Biomass (with/without) = 0.98
Biomass (with – without) = -9.952 t
Production (with – without) = -9.454 t/year
Environmental preference functions: Depth, hard/soft



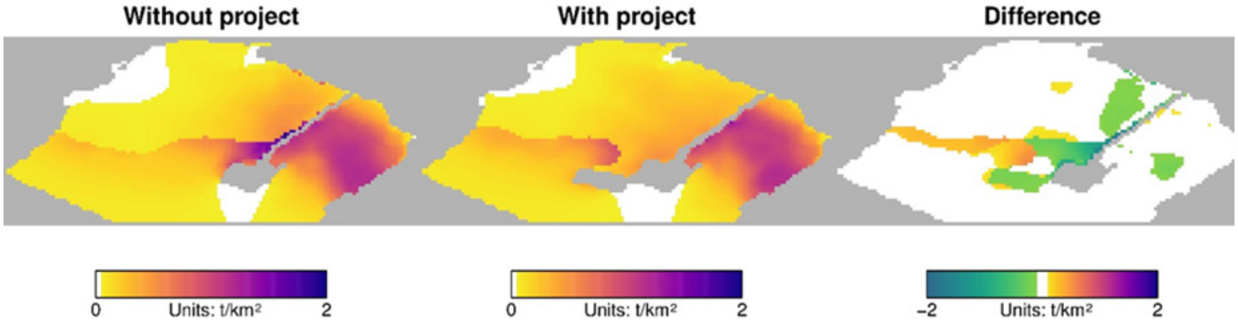
Herring

Biomass (with/without) = 1.00
Biomass (with – without) = 1.098 t
Production (with – without) = 0.878 t/year
Environmental preference functions: Depth, salinity



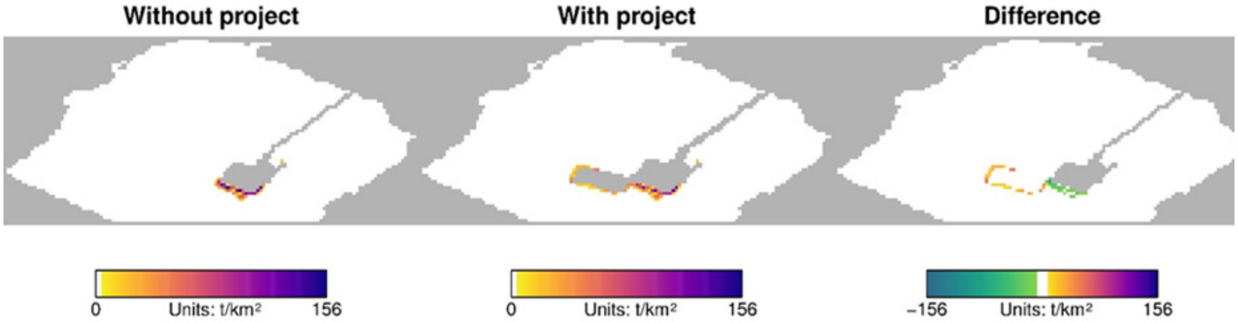
Large demersal fish

Biomass (with/without) = 0.98
Biomass (with – without) = -0.213 t
Production (with – without) = -0.109 t/year
Environmental preference functions: Depth, salinity



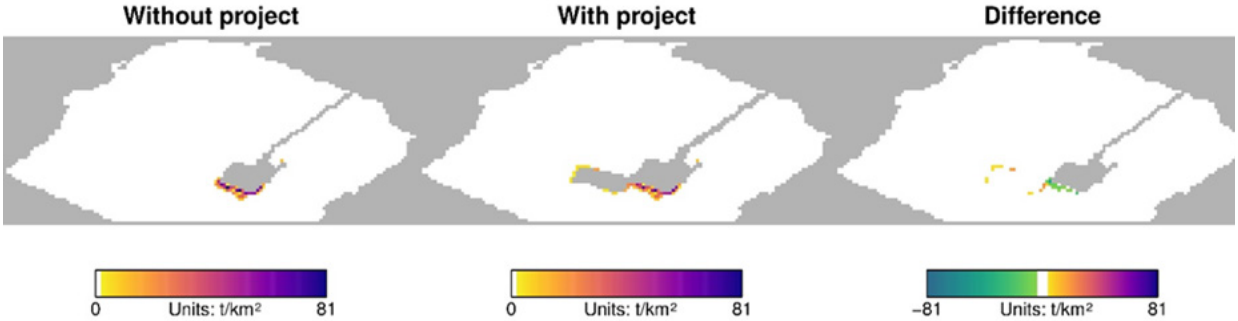
Lingcod

Biomass (with/without) = 1.09
Biomass (with – without) = 2.885 t
Production (with – without) = 0.894 t/year
Environmental preference functions: Depth, salinity, hard/soft



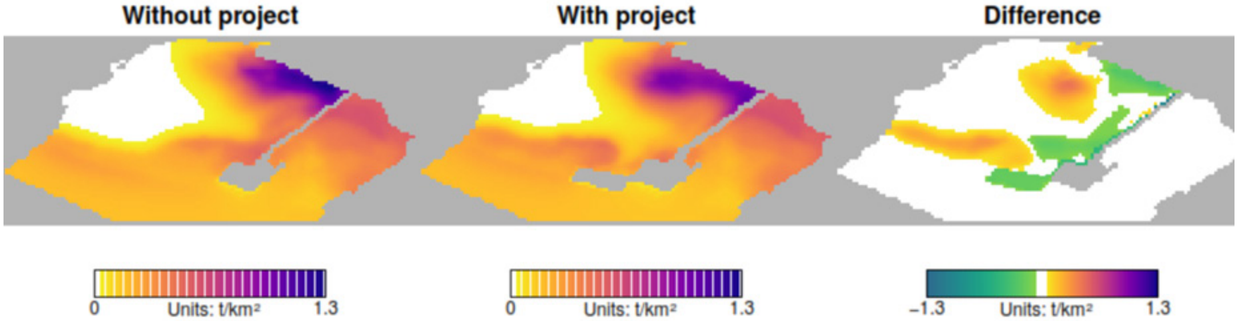
Rockfish

Biomass (with/without) = 0.97
Biomass (with – without) = -0.517 t
Production (with – without) = -0.114 t/year
Environmental preference functions: Depth, salinity, hard/soft



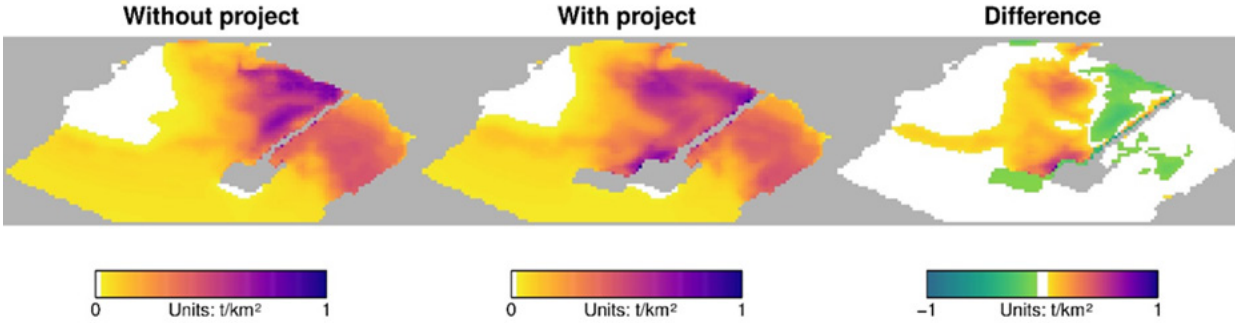
Sandlance

Biomass (with/without) = 1.02
Biomass (with – without) = 0.259 t
Production (with – without) = 0.122 t/year
Environmental preference functions: Depth, salinity, hard/soft



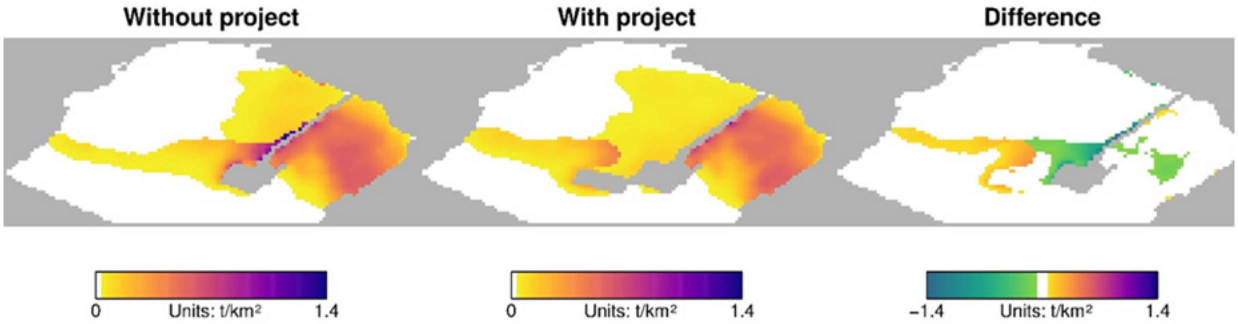
Shiner perch

Biomass (with/without) = 1.14
Biomass (with – without) = 1.218 t
Production (with – without) = 1.546 t/year
Environmental preference functions: Depth, hard/soft



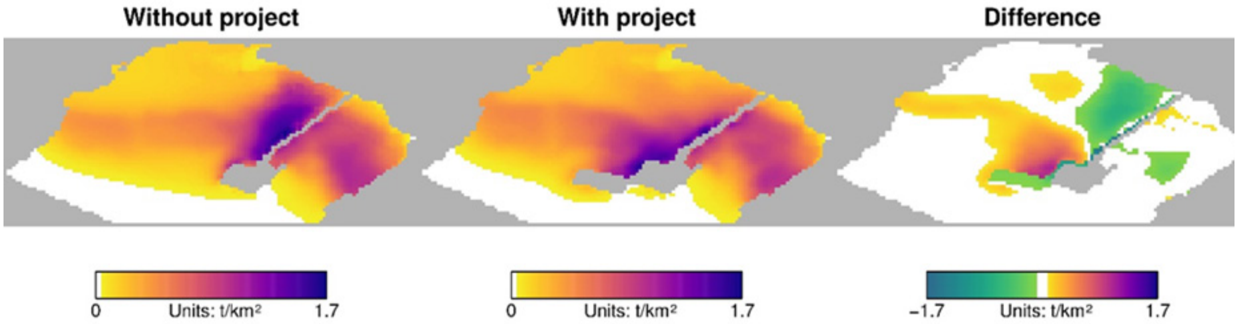
Small demersal fish

Biomass (with/without) = 0.94
Biomass (with – without) = -0.247 t
Production (with – without) = -0.247 t/year
Environmental preference functions: Depth, salinity



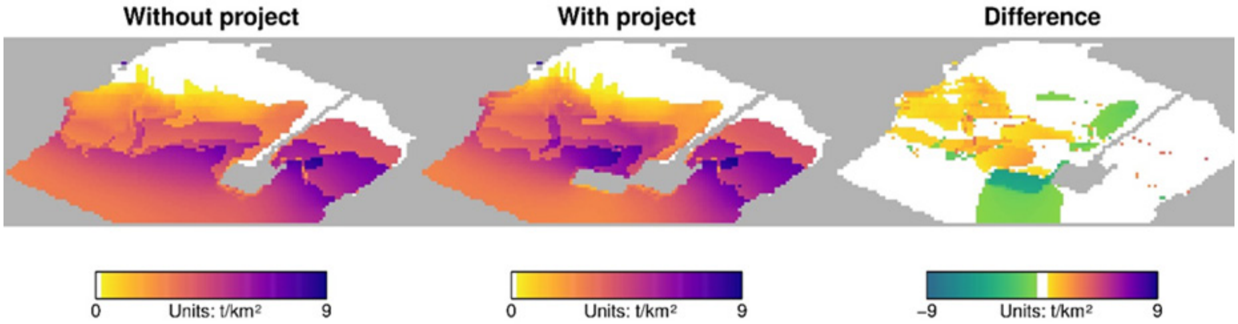
Starry flounder

Biomass (with/without) = 1.03
Biomass (with – without) = 0.303 t
Production (with – without) = 0.121 t/year
Environmental preference functions: Depth, hard/soft



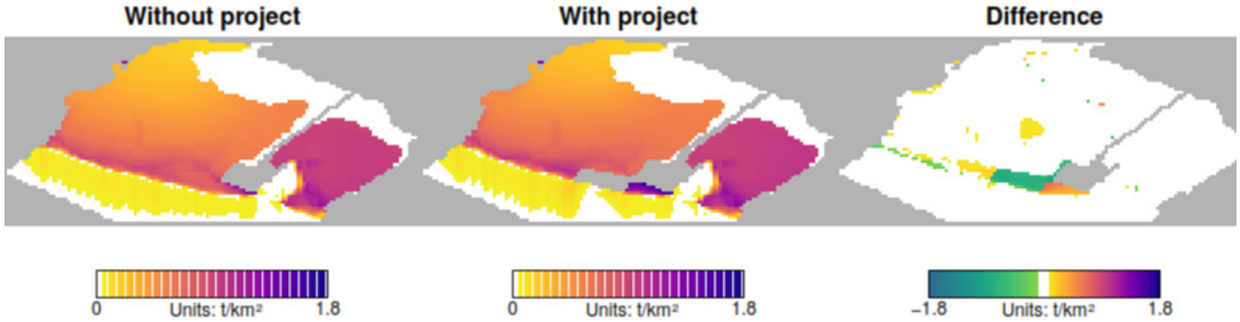
Dungeness crab adult

Biomass (with/without) = 1.00
Biomass (with – without) = 0.757 t
Production (with – without) = 1.513 t/year
Environmental preference functions: Depth, salinity



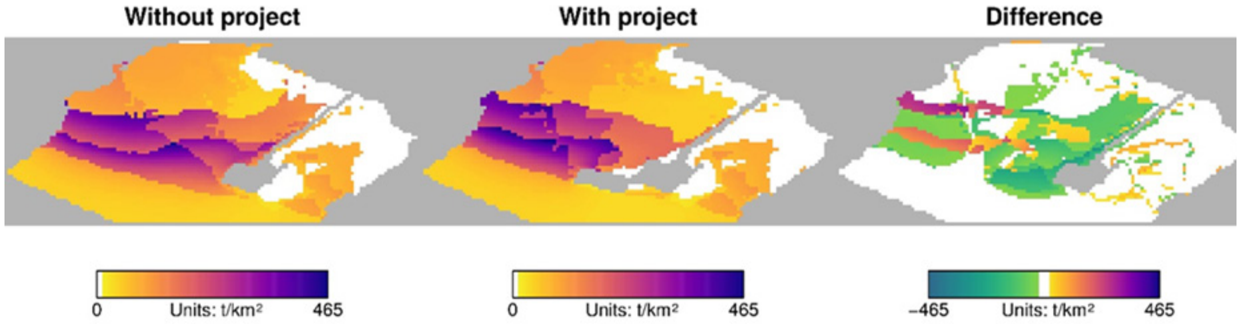
Dungeness crab juvenile

Biomass (with/without) = 1.03
Biomass (with – without) = 1.057 t
Production (with – without) = 3.172 t/year
Environmental preference functions: Depth


Without project
With project
Difference

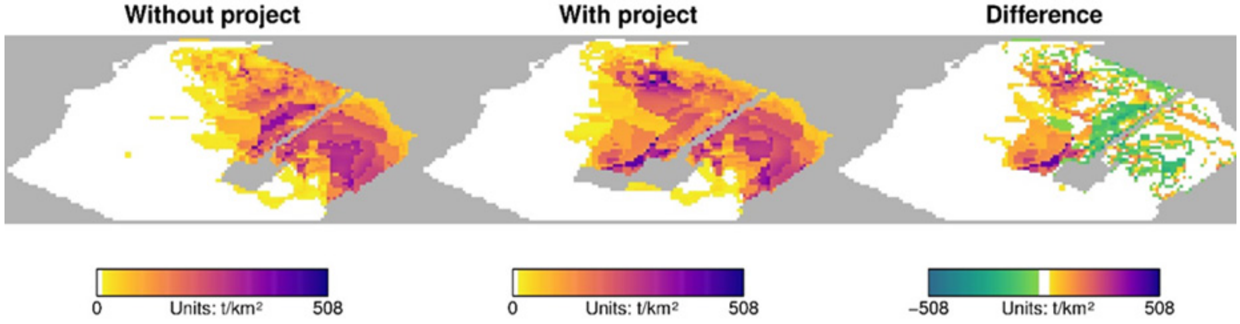
Infaunal bivalves

Biomass (with/without) = 0.92
Biomass (with – without) = -420.735 t
Production (with – without) = -866.293 t/year
Environmental preference functions: Depth, salinity, current, wave, hard/soft


Without project
With project
Difference

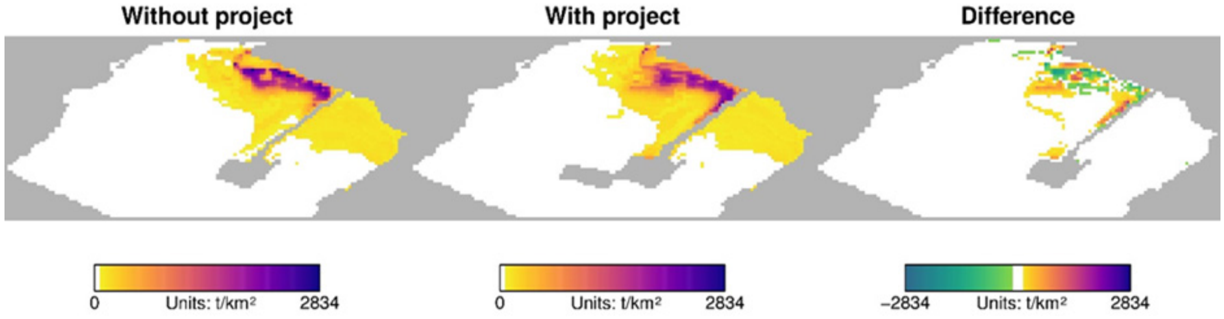
Macrofauna

Biomass (with/without) = 1.20
Biomass (with – without) = 651.893 t
Production (with – without) = 2,607.573 t/year
Environmental preference functions: Depth, salinity, current, wave, hard/soft


Without project
With project
Difference

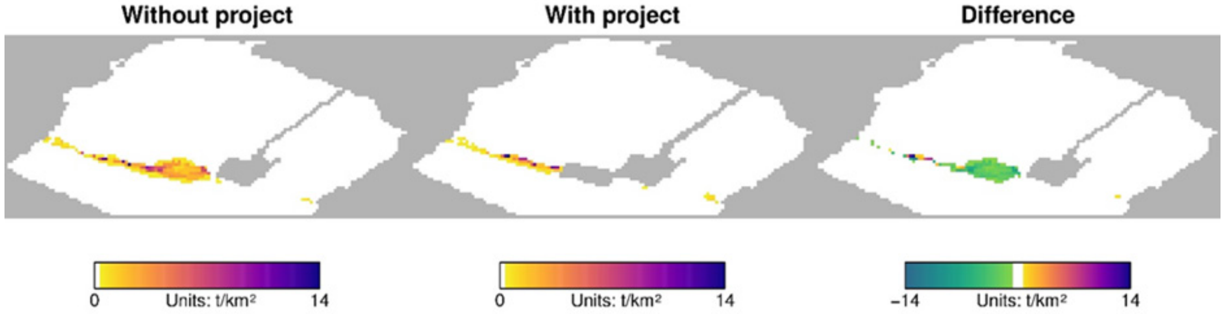
Meiofauna

Biomass (with/without) = 1.07
Biomass (with – without) = 149.227 t
Production (with – without) = 1,193.817 t/year
Environmental preference functions: Depth, salinity, current, wave, hard/soft



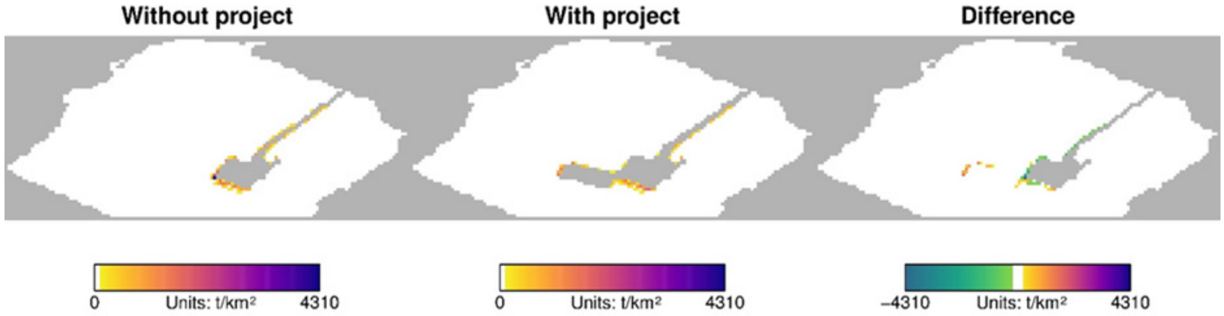
Orange sea pen

Biomass (with/without) = 0.46
Biomass (with – without) = -2.667 t
Production (with – without) = -3.200 t/year
Environmental preference functions: Depth, salinity, current, wave, hard/soft



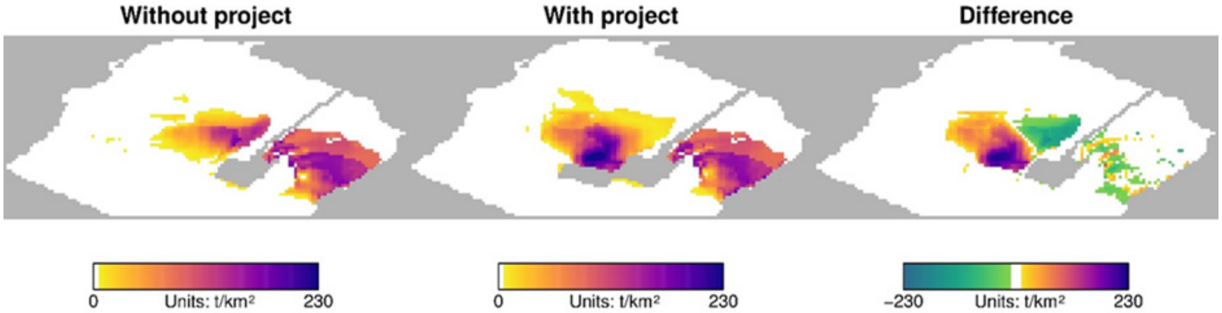
Brown algae

Biomass (with/without) = 0.88
Biomass (with – without) = -52.704 t
Production (with – without) = -474.338 t/year
Environmental preference functions: Depth, salinity, current, wave, hard/soft



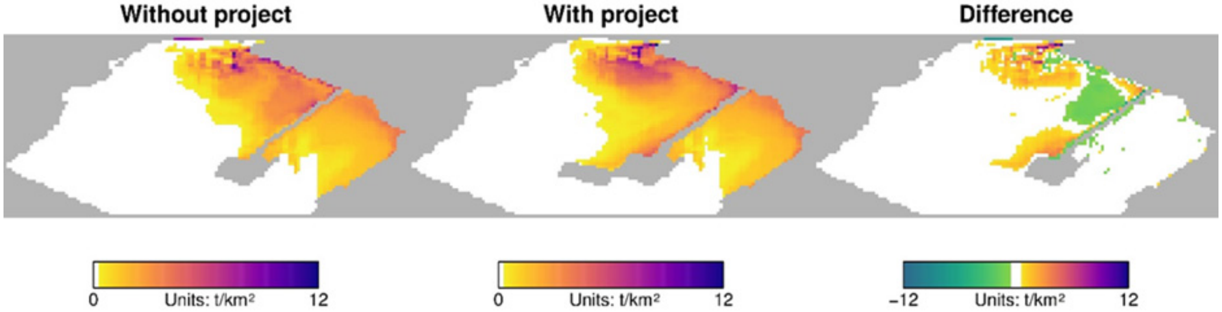
Native eelgrass

Biomass (with/without) = 1.23
Biomass (with – without) = 218.255 t
Production (with – without) = 3,928.584 t/year
Environmental preference functions: Depth, salinity, current, wave, hard/soft



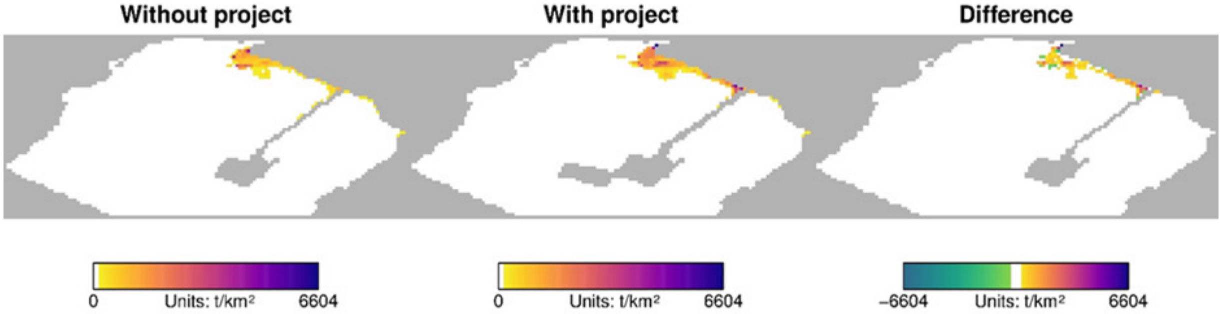
Non-native eelgrass

Biomass (with/without) = 1.11
Biomass (with – without) = 5.168 t
Production (with – without) = 51.677 t/year
Environmental preference functions: Depth, salinity, current, wave, hard/soft



Intertidal marsh

Biomass (with/without) = 1.83
Biomass (with – without) = 1,070.767 t
Production (with – without) = 16,061.511 t/year
Environmental preference functions: Depth, salinity, current, wave, hard/soft



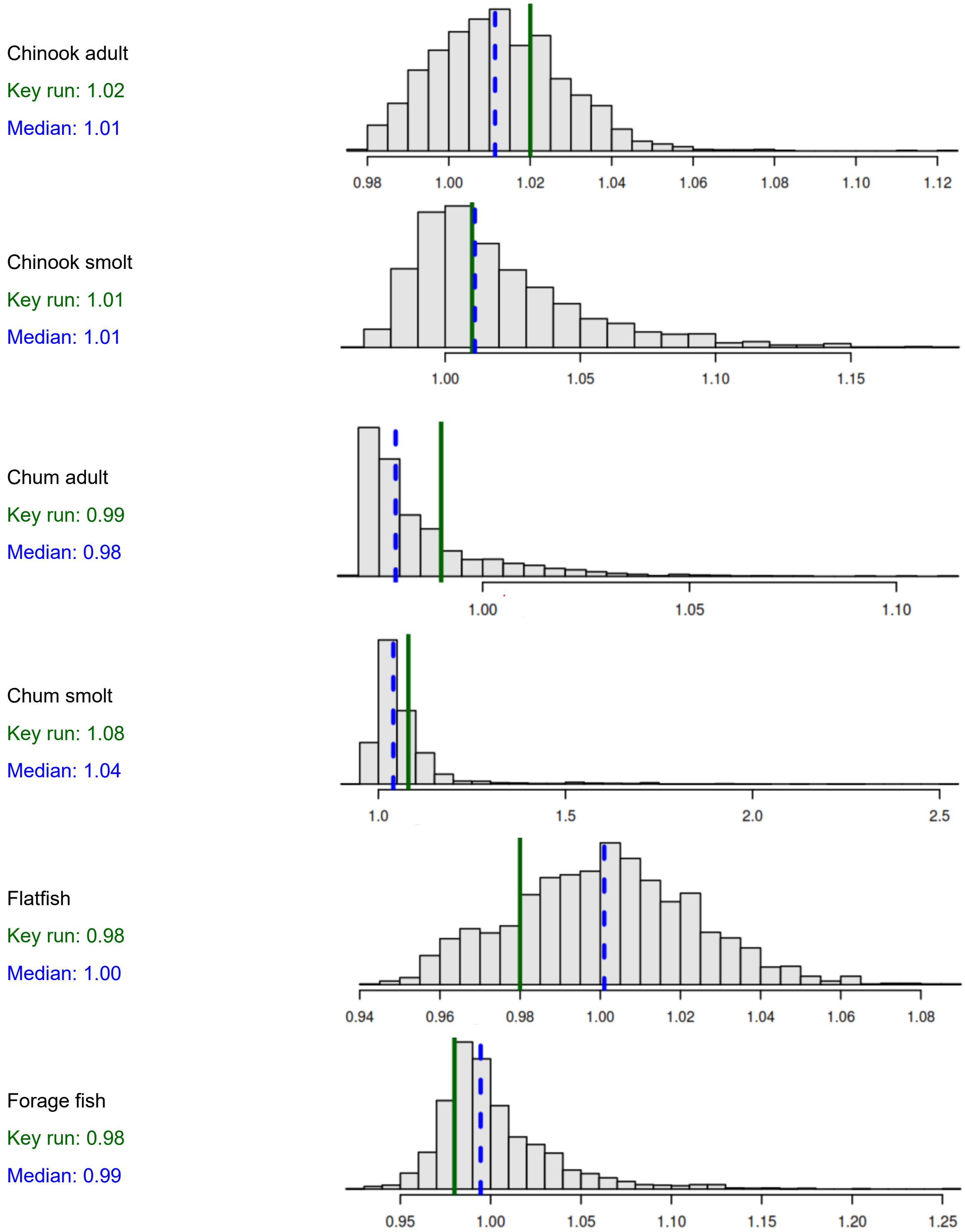
3.2 Sensitivity analysis

Two thousand MC simulation runs were performed generating 2,000 sets of output values. The MC sensitivity results comprise the most likely representation of the Roberts Bank ecosystem with the project once it has approached equilibrium. As indicated in **Section 2.4**, the outputs of both the updated RB model key run and the MC sensitivity analysis were used to inform the calculations of project-related net gains in the productivity of fish and fish habitat at Roberts Bank after avoidance, reduction, and offsetting measures, presented in **IR2020-1.2**, including discounting to address uncertainty in the updated RB model outputs and temporal lag associated with the time that may be required for indirect changes in fish and fish habitat productivity to be realized (described in **Appendix IR2020-1.2-D**).

Histograms of the MC simulation outputs for the 24 representative species or groups are presented in **Figure 3-2**. For each representative species or group, the outputs of the updated RB model key run (in green font) and the median (most likely) value of the MC simulation runs (in blue font) are shown on the left of each plot in **Figure 3-2**. The green solid vertical lines on each plot indicate the updated RB model key run, and the blue dashed lines show the median (most likely) MC 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. For interpretation, a ratio value below 1 represents biomass loss; for example, a ratio of 0.98 represents a 2% biomass loss. In contrast, a ratio value above 1 represents biomass gain; for example, a ratio of 1.02 represents a 2% biomass gain. Note that the x-axes are relative and not fixed.

Outputs of the MC simulation runs for the 24 representative species or groups expressed in biomass ratio (with/without project) and biomass difference (with – without project; in t) are shown by percentile in **Table 3-2** and **Table 3-3**, respectively. Overall, sensitivity analysis showed high certainty in the outputs of the MC simulation runs, with less than 5% difference in the biomass change ratio between the 75th and 50th percentile range for most representative species or groups (20 out of 24; 83%;**Table 3-2**). Between the 90th and 50th percentile range, the difference in the biomass change ratio is less than 5% for 12 out of 24 (50%) representative species or groups (**Table 3-2**). For primary producers, there is no difference in the outputs of the MC simulation runs between the 90th and 50th percentile range. For marine invertebrates, the greatest difference in the change ratio between the 90th and 50th percentile range was 11% for adult Dungeness crab and macrofauna, followed by 9% for meiofauna and 7% for juvenile Dungeness crab (**Table 3-2**), and for marine fish, 14% and 12% for lingcod and rockfish, respectively, followed by 9% for shiner perch and chum smolts, and 7% for sandlance and starry flounder (**Table 3-2**).

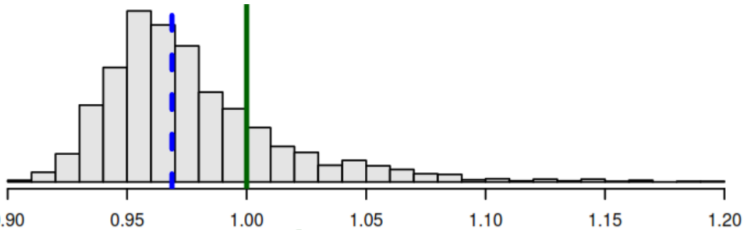
Figure 3-2 Biomass ratio (with/without project) of representative species or groups based on 2,000 MC simulation runs to evaluate uncertainty in input parameters. The green solid line indicates the output of the updated RB model key run, and the blue dashed line shows the median (most likely) output of the MC simulation runs



Herring

Key run: 1.00

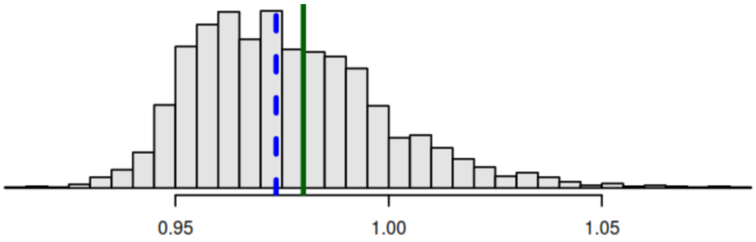
Median: 0.97



Large demersal fish

Key run: 0.97

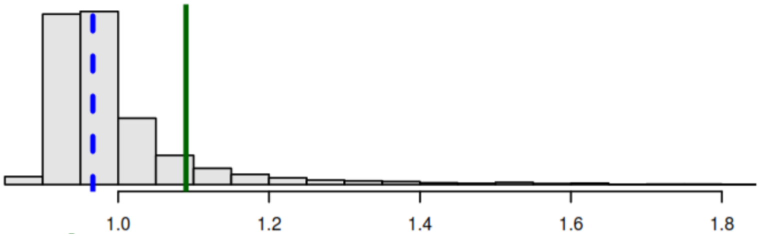
Median: 0.97



Lingcod

Key run: 1.09

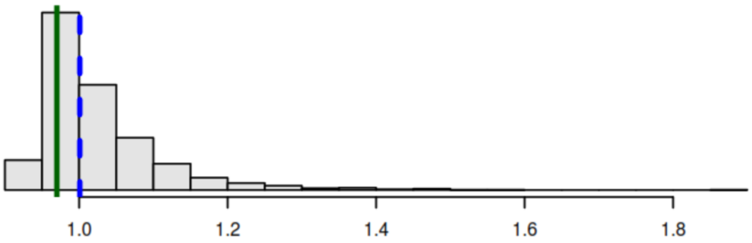
Median: 0.97



Rockfish

Key run: 0.97

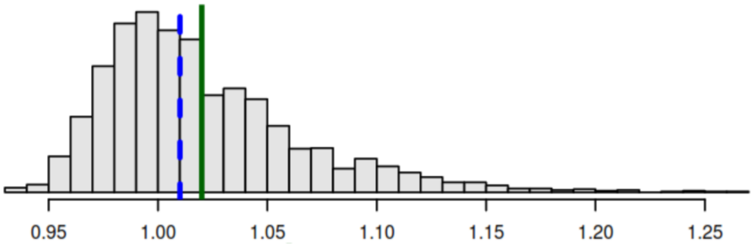
Median: 1.00



Sandlance

Key run: 1.02

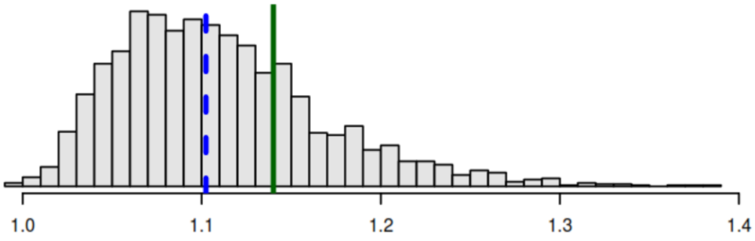
Median: 1.01



Shiner perch

Key run: 1.14

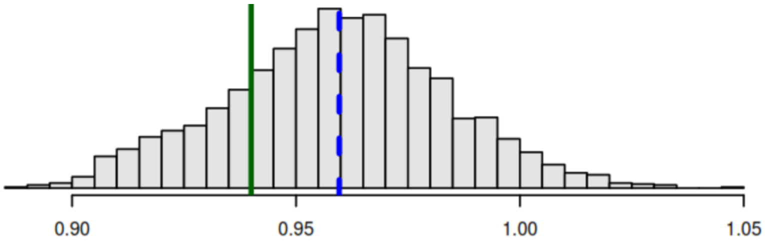
Median: 1.10



Small demersal fish

Key run: 0.94

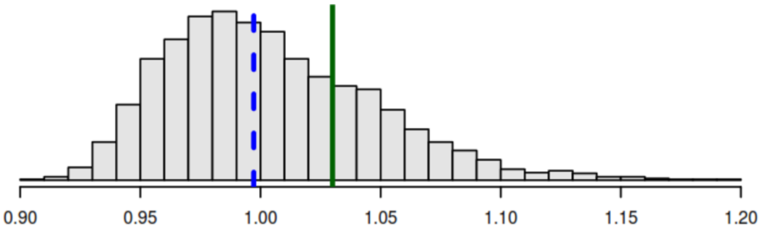
Median: 0.96



Starry flounder

Key run: 1.03

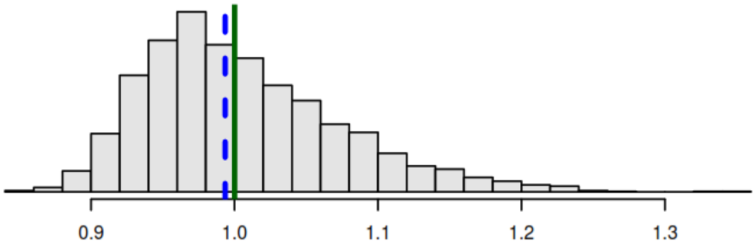
Median: 1.00



Dungeness crab adult

Key run: 1.00

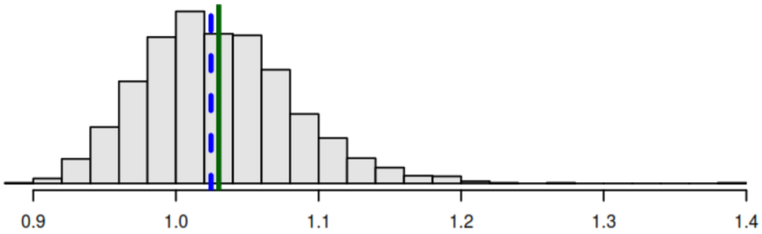
Median: 0.99



Dungeness crab juvenile

Key run: 1.03

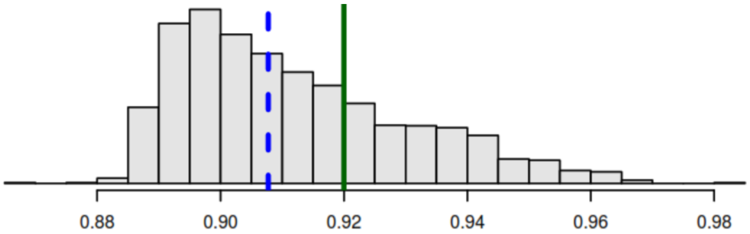
Median: 1.02



Infaunal bivalves

Key run: 0.92

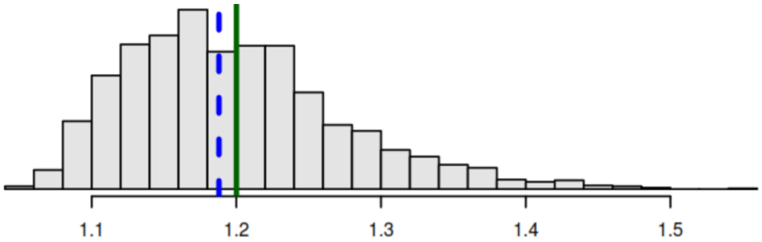
Median: 0.91



Macrofauna

Key run: 1.20

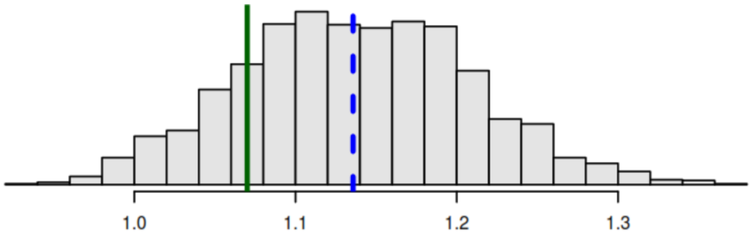
Median: 1.19



Meiofauna

Key run: 1.07

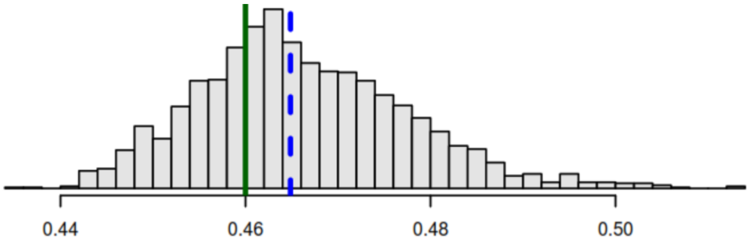
Median: 1.14



Orange sea pen

Key run: 0.46

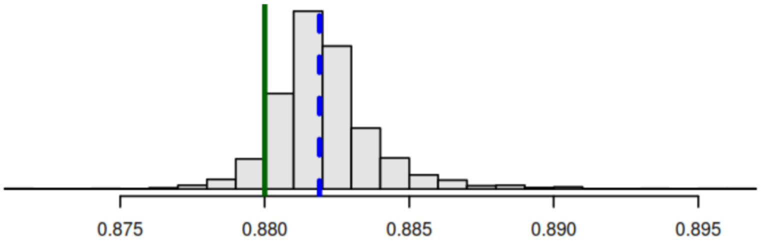
Median: 0.46



Brown algae

Key run: 0.88

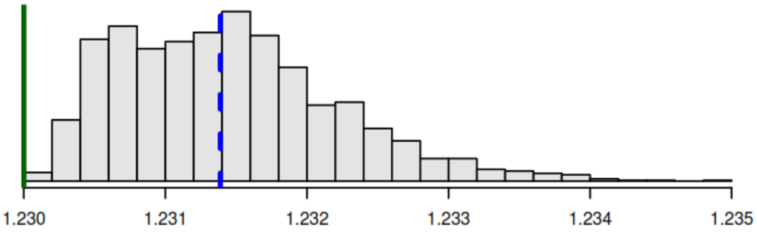
Median: 0.88



Native eelgrass

Key run: 1.23

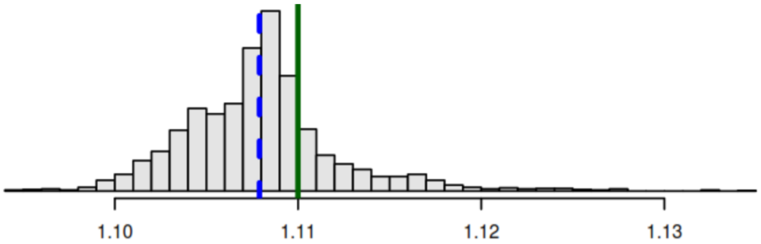
Median: 1.23



Non-native eelgrass

Key run: 1.11

Median: 1.11



Intertidal marsh

Key run: 1.83

Median: 1.83

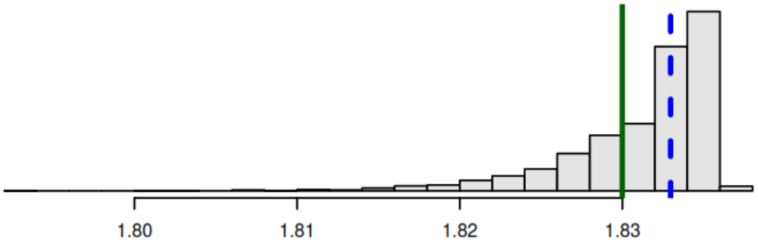


Table 3-2 **Biomass ratio (by pct, percentile; with/without project) by representative species and functional groups based on 2,000 MC simulation runs to evaluate uncertainty in input parameters**

Representative species or group	Biomass ratio (with/without project)										
	0.010 pct	0.025 pct	0.050 pct	0.100 pct	0.250 pct	0.500 pct	0.750 pct	0.900 pct	0.950 pct	0.975 pct	0.990 pct
Chinook adult	0.98	0.99	0.99	0.99	1.00	1.01	1.02	1.03	1.04	1.05	1.06
Chinook smolt	0.98	0.98	0.98	0.99	1.00	1.01	1.03	1.06	1.09	1.10	1.13
Chum adult	0.97	0.97	0.97	0.97	0.97	0.98	0.99	1.01	1.02	1.03	1.05
Chum smolt	0.98	0.98	0.99	1.00	1.01	1.04	1.08	1.13	1.20	1.39	1.67
Flatfish	0.96	0.96	0.96	0.97	0.99	1.00	1.02	1.03	1.04	1.05	1.06
Forage fish	0.95	0.96	0.96	0.97	0.98	0.99	1.02	1.04	1.07	1.09	1.12
Herring	0.92	0.93	0.93	0.94	0.95	0.97	0.99	1.03	1.05	1.08	1.11
Large demersal fish	0.90	0.90	0.91	0.92	0.94	0.97	1.02	1.11	1.21	1.35	1.52
Lingcod	0.93	0.94	0.95	0.95	0.97	1.00	1.05	1.12	1.18	1.25	1.36
Rockfish	0.95	0.96	0.97	0.97	0.99	1.01	1.04	1.08	1.11	1.14	1.17
Sandlance	1.01	1.03	1.03	1.04	1.07	1.10	1.14	1.19	1.22	1.25	1.29
Shiner perch	0.91	0.91	0.92	0.93	0.94	0.96	0.98	0.99	1.00	1.01	1.02
Small demersal fish	0.93	0.94	0.94	0.95	0.97	1.00	1.03	1.06	1.08	1.10	1.13
Starry flounder	0.89	0.90	0.91	0.93	0.95	0.99	1.05	1.10	1.14	1.17	1.21
Dungeness crab adult	0.93	0.94	0.95	0.96	0.99	1.02	1.06	1.10	1.12	1.15	1.18
Dungeness crab juvenile	0.89	0.90	0.91	0.93	0.95	0.99	1.05	1.10	1.14	1.17	1.21
Infaunal bivalves	0.89	0.89	0.89	0.89	0.90	0.91	0.92	0.94	0.95	0.95	0.96
Macrofauna	1.08	1.09	1.10	1.11	1.14	1.19	1.24	1.30	1.35	1.38	1.42
Meiofauna	0.99	1.00	1.02	1.05	1.09	1.14	1.19	1.23	1.25	1.28	1.30
Orange sea pen	0.44	0.45	0.45	0.45	0.46	0.46	0.47	0.48	0.49	0.49	0.50
Brown algae	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.89	0.89	0.89
Native eelgrass	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23
Non-native eelgrass	1.10	1.10	1.10	1.10	1.11	1.11	1.11	1.11	1.12	1.12	1.12
Intertidal marsh	1.82	1.82	1.82	1.83	1.83	1.83	1.83	1.83	1.84	1.84	1.84

Notes: For interpretation, ratio value below 1 represents biomass loss, for example ratio of 0.98 represents a 2% biomass loss; ratio value above 1 represents biomass gain, for example ratio of 1.02 represents a 2% gain.

Table 3-3 **Biomass difference (with – without project; in tonnes, t) by percentile (pct) for representative species or groups based on 2,000 MC simulation runs to evaluate uncertainty in input parameters**

Representative species or group	Biomass difference (with – without project; t)										
	0.010 pct	0.025 pct	0.050 pct	0.100 pct	0.250 pct	0.500 pct	0.750 pct	0.900 pct	0.950 pct	0.975 pct	0.990 pct
Chinook adult	-0.03	-0.02	-0.02	-0.01	0.00	0.02	0.04	0.06	0.06	0.07	0.09
Chinook smolt	-0.02	-0.01	-0.01	-0.01	0.00	0.01	0.02	0.04	0.06	0.07	0.09
Chum adult	-0.04	-0.04	-0.03	-0.03	-0.03	-0.03	-0.01	0.01	0.02	0.04	0.06
Chum smolt	-0.01	-0.01	-0.01	0.00	0.01	0.02	0.04	0.07	0.10	0.19	0.33
Flatfish	-0.89	-0.83	-0.74	-0.61	-0.30	0.02	0.32	0.62	0.79	0.96	1.15
Forage fish	-28.40	-23.85	-20.40	-15.86	-10.19	-3.16	8.88	24.60	38.63	53.45	71.16
Herring	-19.45	-17.71	-16.39	-14.80	-11.50	-7.59	-1.81	6.45	12.93	18.40	26.45
Large demersal fish	-0.53	-0.49	-0.45	-0.41	-0.34	-0.22	-0.08	0.05	0.15	0.26	0.37
Lingcod	-3.30	-3.07	-2.85	-2.57	-1.98	-1.07	0.51	3.49	6.78	11.05	16.67
Rockfish	-1.34	-1.18	-1.00	-0.84	-0.51	0.02	0.95	2.26	3.32	4.64	6.60
Sandlance	-0.56	-0.47	-0.39	-0.31	-0.14	0.11	0.49	0.96	1.27	1.57	1.93
Shiner perch	0.12	0.22	0.30	0.40	0.61	0.91	1.27	1.69	1.98	2.26	2.55
Small demersal fish	-0.37	-0.36	-0.33	-0.29	-0.22	-0.16	-0.10	-0.03	0.00	0.03	0.07
Starry flounder	-0.80	-0.71	-0.64	-0.53	-0.32	-0.03	0.36	0.73	0.97	1.18	1.50
Dungeness crab adult	-27.57	-23.28	-20.74	-17.62	-10.99	-1.60	11.13	24.55	34.14	41.23	49.84
Dungeness crab juvenile	-2.24	-1.89	-1.49	-1.12	-0.24	0.76	1.94	3.07	3.82	4.58	5.58
Infaunal bivalves	-571.03	-563.81	-556.69	-544.61	-515.40	-463.20	-385.24	-303.48	-261.08	-234.64	-193.01
Macrofauna	245.67	279.38	314.41	358.71	464.26	608.94	778.63	977.63	1,119.14	1,216.37	1,373.59
Meiofauna	-27.06	4.75	39.91	98.66	184.17	288.97	398.70	486.29	541.62	601.56	646.99
Orange sea pen	-2.73	-2.72	-2.71	-2.69	-2.66	-2.63	-2.58	-2.55	-2.52	-2.49	-2.46
Brown algae	-54.71	-54.27	-53.92	-53.68	-53.29	-52.91	-52.50	-51.88	-51.37	-50.80	-49.72
Native eelgrass	217.14	217.20	217.28	217.37	217.68	218.20	218.68	219.24	219.58	219.95	220.38
Non-native eelgrass	4.65	4.71	4.76	4.83	4.94	5.06	5.14	5.30	5.44	5.54	5.77
Intertidal marsh	1,043.31	1,048.01	1,052.09	1,056.24	1,061.56	1,066.20	1,067.92	1,068.66	1,069.00	1,069.32	1,069.92

Table 3-4 presents the difference (in t) between the MC median (i.e., the 50th percentile; with project) minus the biomass output of the 'without project' scenario. **Table 3-4** also presents the change ratio that corresponds to the MC median biomass over the 'without project' biomass (column 'Median change ratio (median with project/without project)'; **Table 3-4**). Lastly, the median change ratio is compared to the change ratio of the updated RB model key run (**Table 3-1**) and the difference is also shown in **Table 3-4**.

In general, when uncertainty in input parameters was considered, the median change ratio was generally similar to the change ratio of the updated RB model key run. For seven of 24 representative species or groups (29%), the median change ratio was the same as the change ratio for the updated RB model key run (**Table 3-4**). These seven groups included primary producers (brown algae, native and non-native eelgrass, intertidal marsh) and species such as large demersal fish and orange sea pens that are rooted to local empirical data. For 12 of 24 representative species or groups (50%) the median change ratio decreased indicating a slightly more conservative outcome when taking into account uncertainty in input parameters (**Table 3-4**). Of these, lingcod decreased by 12% and eleven of the 12 groups by up to 4% (Chinook and chum adult, sandlance, Dungeness crab adult and juvenile, infaunal bivalves, macrofauna by 1%; herring, starry flounder by 3%; chum smolt, shiner perch by 4%; **Table 3-4**). For the remaining five of 24 groups (21%), the median change ratio increased, indicating larger increases in biomass with the project when taking into account uncertainty in input parameters (**Table 3-4**). Four of the groups increased slightly by up to 3% (i.e., forage fish by 1%, flatfish and small demersal fish by 2%, rockfish by 3%) and by 7% for meiofauna (**Table 3-4**).

Table 3-4 **Biomass difference (in tonnes, t) for representative species or groups (MC median with project – without project), and the difference in change ratio between the MC median and the updated RB model key run**

Representative species or group	Biomass (without project, t)	Median biomass (with project, t)	Biomass difference (median with project – without project, t)	Median change ratio (median with project/without project)	Updated key run change ratio (from Table 3-1) (with/without project)	Change ratio difference (median – updated key run)
Chinook adult	1.65	1.67	0.02	1.01	1.02	-0.01
Chinook smolt	0.66	0.67	0.01	1.01	1.01	0.00
Chum adult	1.24	1.21	-0.03	0.98	0.99	-0.01
Chum smolt	0.49	0.51	0.02	1.04	1.08	-0.04
Flatfish	20.40	20.42	0.02	1.00	0.98	0.02
Forage fish	573.00	569.84	-3.16	0.99	0.98	0.01
Herring	243.00	235.41	-7.59	0.97	1.00	-0.03
Large demersal fish	8.39	8.17	-0.22	0.97	0.97	0.00
Lingcod	32.00	30.93	-1.07	0.97	1.09	-0.12
Rockfish	18.50	18.52	0.02	1.00	0.97	0.03
Sandlance	11.30	11.41	0.11	1.01	1.02	-0.01
Shiner perch	8.92	9.83	0.91	1.10	1.14	-0.04
Small demersal fish	3.95	3.79	-0.16	0.96	0.94	0.02
Starry flounder	11.50	11.47	-0.03	1.00	1.03	-0.03
Dungeness crab adult	243.00	241.40	-1.60	0.99	1.00	-0.01

Representative species or group	Biomass (without project, t)	Median biomass (with project, t)	Biomass difference (median with project – without project, t)	Median change ratio (median with project/without project)	Updated key run change ratio (from Table 3-1) (with/without project)	Change ratio difference (median – updated key run)
Dungeness crab juvenile	31.10	31.86	0.76	1.02	1.03	-0.01
Infaunal bivalves	5,020.00	4,556.80	-463.20	0.91	0.92	-0.01
Macrofauna	3,240.00	3,848.94	608.94	1.19	1.20	-0.01
Meiofauna	2,130.00	2,418.97	288.97	1.14	1.07	0.07
Orange sea pen	4.91	2.28	-2.63	0.46	0.46	0.00
Brown algae	448.00	395.09	-52.91	0.88	0.88	0.00
Native eelgrass	943.00	1,161.20	218.20	1.23	1.23	0.00
Non-native eelgrass	46.90	51.96	5.06	1.11	1.11	0.00
Intertidal marsh	1,280.00	2,346.20	1,066.20	1.83	1.83	0.00

3.3 Underwater noise-related productivity losses during project construction

Table 3-5 presents productivity losses of marine fish representative species or groups from physical injury or mortality that may result from impulsive noise generated during impact piling proposed for the project with and without the implementation of mitigation. **Table 3-5** also includes productivity losses from behavioural disturbance to herring that may result from continuous noise generated during project construction activities such as summer dredging, pumping ashore, and vibro-densification, with support vessels and tugs (i.e., a summer scenario representative of acoustic conditions during combination of project construction activities when herring are present in the study area).

Changes in the acoustic environment during loud project construction activities have the potential to adversely affect the productivity of seven fish representative species or groups. Without mitigation, loss in fish productivity is forecasted to be 2.27 t (injury: 0.59 t; behavioural disturbance: 1.68 t; **Table 3-5**). With mitigation, such as the deployment of a confined bubble curtain or similar sound dampening device during impact piling, productivity losses are reduced to 2.0 t, forecasted for five marine fish representative species or groups (**Table 3-5**). This result is largely overestimated and thus considered conservative (for reasons described in the bullets below). Reduction measures (including measures described in CIAR Document #2001 and new measures identified in **IR2020-2.3**) that will be implemented by the port authority will fully mitigate injury or mortality of marine fish from impulsive underwater noise. Specifically:

- The analysis assumed the deployment of an impact hammer exclusively. In fact, pile installation as part of project construction will be conducted predominantly using a vibratory hammer, which generates less noise.
- Since the public hearing, additional reduction measures have been identified (described in **IR2020-2.3**) which were not considered in modelling of productivity effects from underwater noise. Requirements for impact piling have been reduced, and impact piling will be required for only four piles (one for each of the three temporary barge ramps and one for the mooring dolphin) to test the capacity of these piles. The duration of impact piling per pile is anticipated to be 15 minutes for a total of approximately one hour for the entire project construction phase (see **IR2020-2.3** and **Appendix IR2020-2.3-D**).

- Impact piling was modelled to be undertaken continuously for two months within Year 1 and Year 2 of project construction (see **Appendix IR2020-1.2-A**, Table 2-6). In fact, impact piling will only be undertaken for a total of approximately one hour for the entire project construction phase (see above).
- The analysis does not consider all reduction measures to be implemented as part of the project's Underwater Noise Management Plan, including the following:
    - Application of gradual startup or ramping of construction activities, such as pile driving, to allow marine species to habituate or temporarily leave the area.
    - Deployment of hydrophones and procedures in cases of threshold exceedances, and additional mitigation measures that will prevent injury to marine fish during impact pile driving, including but not limited to additional sound reduction or dampening methods or technologies.

Predicted losses in herring productivity from project-related behavioural disturbance are conservative, i.e., overstated, based on additional construction phase mitigation measures that have been identified for southern resident killer whales (SRKW) as part of **IR2020-2.3**, which are also expected to reduce effects from behavioural disturbance to herring. Specifically:

- The port authority will avoid all vibratory and impact pile driving, vibro-densification of the caisson foundation mattress rock, and removal of the piles for the temporary barge ramps from June 1, or later, on the date when SRKW are confirmed to be present in the Salish Sea, to September 30 (**Appendix IR2020-2.3-D**). The time period between June 1 and September 30 of SRKW presence in the Salish Sea coincides with recruitment of juvenile herring to shallow nearshore habitats including of the Fraser River estuary (see EIS Section 13, Table 13-5).
- Sequencing, where feasible, of in-water construction activities will limit underwater noise aggregation and will reduce potential behavioural disturbance to herring.

Given these additional reduction measures, behavioural disturbance to herring would be temporary and reversible once the disturbance has ceased. Given this conservatism and that behavioural disturbance of herring will be temporary and reversible, after offsetting (see below), the residual effect from behavioural disturbance to herring is considered not significant.

Table 3-5 Estimated losses in productivity of fish representative species or groups associated with changes in the acoustic environment form project construction activities without and with mitigation

Representative species or group	Injury during piling (without mitigation, t)	Injury during piling (with mitigation, t)	Behavioural disturbance (t)	Total productivity loss (with mitigation, t)
Chinook adult	0.00	0.00	0.00	0.00
Chinook smolt	0.00	0.00	0.00	0.00
Chum adult	0.00	0.00	0.00	0.00
Chum smolt	0.00	0.00	0.00	0.00
Flatfish	-0.02	-0.02	0.00	-0.02
Forage fish	-0.33	-0.13	0.00	-0.13
Herring	-0.19	-0.13	-1.68	-1.81
Large demersal fish	-0.01	0.00	0.00	0.00
Lingcod	-0.01	-0.01	0.00	-0.01
Rockfish	-0.01	0.00	0.00	0.00
Sandlance	-0.01	-0.01	0.00	-0.01
Shiner perch	0.00	0.00	0.00	0.00
Small demersal fish	0.00	0.00	0.00	0.00
Starry flounder	0.00	0.00	0.00	0.00
Total	**-0.59**	**-0.30**	**-1.68**	**-2.00**

3.4 Productivity values for offsetting habitats

This section describes productivity values (in t/ha) associated with offsetting habitats (i.e., intertidal marsh, native eelgrass, subtidal rock reef), as well as intertidal and subtidal sand underlying offsetting habitats proposed to be constructed. To remind the reader, higher trophic level species or groups (e.g., birds) were not considered in the calculation of offsetting productivity gains (as explained in **Section 2.6.1**).

Intertidal marsh habitat: Biomass (in t/ha) of the representative species or groups comprising the intertidal marsh food web are presented in **Table 3-6**. Infaunal bivalves and macrofauna contribute the most to the productivity of the intertidal marsh food web with 0.919 t/ha and 0.753 t/ha, respectively. Other contributors are shiner perch (0.481 t/ha), meiofauna (0.391 t/ha) and intertidal marsh (0.235 t/ha).

Native eelgrass habitat: Biomass (in t/ha) of the representative species or groups comprising the native eelgrass food web are presented in **Table 3-6**. Infaunal bivalves, macrofauna and meiofauna contribute the most to productivity of the native eelgrass food web with 0.919, 0.753 and 0.391 t/ha respectively. Other contributors are adult Dungeness crab (0.205 t/ha), native eelgrass (0.173 t/ha) and shiner perch (0.129 t/ha).

Subtidal rock reef habitat: Biomass (in t/ha) of the representative species or groups comprising the food web of the subtidal rock reef habitat are presented in **Table 3-6**. Brown algae are by far the largest contributor to the productivity of the subtidal rock reef food web with 129.180 t/ha. Other contributors are lingcod (0.345 t/ha), rockfish (0.303 t/ha), large demersal fish (0.157 t/ha) and forage fish (0.105 t/ha).

Intertidal sand habitat: Biomass (in t/ha) of the representative species or groups comprising the intertidal sand food web are presented in **Table 3-6**. Infaunal bivalves and macrofauna contribute the most to the productivity of the intertidal sand food web with 0.919 and 0.731 t/ha respectively, followed by meiofauna (0.391 t/ha).

Subtidal sand habitat: Biomass (in t/ha) of the representative species or groups comprising the subtidal sand food web are presented in **Table 3-6**. Infaunal bivalves are the largest contributor to productivity with 0.680 t/ha. Other contributors are large and small demersal fish (0.002 t/ha each) and starry flounder (0.001 t/ha).

Table 3-6 Biomass of representative species or groups forming the food web of offsetting habitats (i.e., intertidal marsh, native eelgrass, subtidal rock reef), and intertidal and subtidal sand underlying offsetting habitats proposed to be constructed

Representative species or group	Biomass (t/ha)				
	Intertidal marsh	Native eelgrass	Subtidal rock reef	Intertidal sand	Subtidal sand
Chinook adult	0.002	0.001		<0.001	
Chinook smolt	0.003	0.001		0.001	
Chum adult	0.001	0.003		<0.001	
Chum smolt	0.002	0.005		<0.001	
Flatfish		<0.001		0.004	
Forage fish	<0.001	0.012	0.105	0.008	<0.001
Herring		0.044	0.020	0.000	<0.001
Large demersal fish		0.011	0.157	0.002	0.002
Lingcod			0.345		
Rockfish			0.303		
Sandlance		0.003		0.002	
Shiner perch	0.481	0.129	0.002	0.003	<0.001
Small demersal fish	0.001	0.041	0.004	0.002	0.002
Starry flounder	0.001	0.002	0.008	0.001	0.001
Dungeness crab adult		0.205		<0.001	
Dungeness crab juvenile		0.026		<0.001	
Infaunal bivalves	0.919	0.919	<0.001	0.919	0.680
Macrofauna	0.753	0.753		0.731	
Meiofauna	0.391	0.391		0.391	
Orange sea pen					
Brown algae			129.180		
Native eelgrass		0.173			
Non-native eelgrass					
Intertidal marsh	0.235				

Notes:

- t/ha – tonnes per hectare.
- Grey cells indicate that the representative species or group is not part of the food web of that habitat and, therefore, does not contribute any biomass gains to the offsetting or underlying habitat type.

4.0 SUMMARY OF KEY FINDINGS

The updated RB model comprised 64 functional groups (six groups more than the RB model developed for the EIS given the addition of multistanza groups for Chinook and chum salmon and for Dungeness crab, and the consolidation of biofilm). In the updated RB model, environmental preference functions to variables including depth, salinity, bottom current, wave height, and substrate type (i.e., hard or soft) by functional groups were consistent with those used in the RB model developed for the EIS (Hemmera 2014b), except for environmental preference by juvenile crab for depth. The depth preference function for juvenile Dungeness crab was modified to reflect preference for low intertidal to shallow subtidal zones. In the updated RB model, data on diet composition, B, P/B, Q/B, and EE were consistent with those in the RB model developed for the EIS (Hemmera 2014b). Biomass input values were updated for Pacific herring to reflect recent (2019) DFO research findings (Boldt et al. 2019) for the Strait of Georgia, as well as for marine vegetation (i.e., native eelgrass, non-native eelgrass, intertidal marsh), and marine invertebrates (i.e., macrofauna, meiofauna, infaunal bivalves, orange sea pens) to reflect current (2019) empirical estimates for Roberts Bank.

The updated RB model was run using V6.7 – the latest professional version of the EwE software – and yielded the updated RB model key run. As noted earlier, the proposed project footprint incorporated in the updated RB model does not account for potential additional footprint reductions by up to 14.4 ha and potential associated reduction in footprint-related effects to fish and fish habitat productivity (described in IR2020-2.1). Hence, forecasts of the updated RB model key run and MC sensitivity analysis presented in this report are considered conservative. Overall, productivity is forecasted to increase with the project by 1,614.18 t, of which 1,240.47 t are attributed to primary producers (primarily intertidal marsh (1,070.77 t), followed by native eelgrass (218.25 t), and non-native eelgrass (5.17 t). For invertebrates, productivity is forecasted to increase with the project by 379.15 t (primarily macrofauna (651.89 t) and meiofauna (149.23 t)). Lastly, productivity of fish is forecasted to decrease overall by 5.43 t.

Uncertainty in input parameters, specifically B, P/B. and Q/B, was evaluated using a MC sensitivity analysis. Two thousand MC simulation runs were performed generating 2,000 sets of output values. In general, when uncertainty in input parameters was considered, the median change ratio was generally the same or decreased slightly compared to the change ratio of the updated RB model key run, indicating a slightly more conservative outcome. For seven of the 24 representative species or groups, the median change ratio did not change, while for 12 of the 24 representative species or groups the median change ratio decreased by up to 4%, except for lingcod which decreased by 12%. For the remaining five of 24 representative species or groups, the median chance ratio increased by up to 3%, except for meiofauna which increased by 7%.

The updated RB model was used to quantify productivity changes associated with in-water project construction activities that have the potential to generate underwater noise at levels that may result in physical injury or mortality to fish or lead to behavioural disturbance. Without mitigation, project-related changes in the acoustic environment are forecasted to result in productivity loss by 2.27 t of seven marine fish representative species or groups. With mitigation, such as the deployment of a confined bubble curtain or similar sound dampening device during impact piling, productivity losses are reduced to 2.0 t, forecasted for five marine fish representative species or groups. Productivity losses from changes in the acoustic environment during project construction are considered conservative as they have assumed the exclusive deployment of an impact hammer. In fact, pile installation as part of project construction will be conducted predominantly using a vibratory hammer. In addition, losses in herring productivity associated with behavioural disturbance are considered temporary and reversible once the disturbance has ceased.

Productivity values of offsetting habitat types proposed to be constructed for the project were calculated using food web models that were specific to each offsetting habitat type. Food web models were constructed using the Ecopath module of EwE. Food web models were also created for intertidal and subtidal sand underlying the proposed offsetting habitats. Productivity gains by habitat type were calculated using local, habitat specific empirical estimates of biomass per species or group comprising the food web of each habitat type and were independent of the outputs of the updated RB model. Developing food web models for each habitat type allowed for the enforcement of mass balance limits within each food web model to ensure biomass estimates were ecologically realistic.

Updates to the RB model enabled incorporation of current (2019) empirical information collected for the project as well as for life history resolution to be represented for functional groups such as Chinook and chum salmon, and Dungeness crab, in response to DFO comments. Overall, the conclusions from the ecosystem modelling study using the updated RB model are that the project is forecasted to result in a net increase in the productivity of the Roberts Bank ecosystem as a result of project-related changes in coastal geomorphic conditions and food-web dynamics. Net increase in productivity is driven primarily by productivity increases in marine vegetation and marine invertebrates. The transfer of the RB model developed for the EIS to the latest professional version of the EwE software facilitated more accurate modelling of the Roberts Bank ecosystem using new spatio-temporal functions in Ecospace, including additional analyses to quantify potential project-related changes in productivity of representative species or group from loud construction activities. Lastly, the ecosystem modelling study using the updated RB model generated comprehensive estimates of uncertainty and demonstrated that outputs are robust to uncertainty in input parameters.

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6.0 CLOSURE

We sincerely appreciate the opportunity to have assisted you with this project and if there are any questions, please do not hesitate to contact the undersigned by phone at 604.669.0424.

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Appendix IR2020-1.2-B

Tug Basin Expansion Effects to Fish and Fish Habitat

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April 14, 2021

File No. 102738-10

Attention: Charlene Menezes, Environmental Project Management Specialist, Infrastructure Sustainability

Re: RBT2 – Tug Basin Expansion Construction Effects to Fish and Fish Habitat

1.0 INTRODUCTION

The Roberts Bank Terminal 2 project (RBT2 or project) is a proposed new container terminal located in Delta, B.C. The project consists of three main components: (1) a new multi-berth marine container terminal, (2) a widened causeway, and (3) an expanded tug basin.

Located on the east side of the Deltaport Terminal, the existing tug basin is proposed to be deepened (up to a depth of –6.5 metres Chart Datum (m CD)) and expanded to accommodate additional tug moorage to support the terminal operations at RBT2 (**Figure 1**). In addition to dredging, construction activities are expected to include removal and possible salvage of portions of the existing slope and crest protection materials, installation of new slope and crest protection, and installation of mooring infrastructure.

The proposed tug basin expansion area is currently intertidal mudflat, characterized by dense native eelgrass cover (*Zostera marina*) in the shallow areas and adjacent to the crest protection structure of the existing tug basin. Areas with riprap and slope fill material support bladed kelp, foliose red and green algae (*Ulva* sp.), plumose anemone (*Metridium senile*), and mottled sea star (*Evasterias troschelii*). The proposed tug basin expansion will result in a permanent habitat alteration of intertidal mudflat to both subtidal soft substrate and hard substrate habitat (e.g., crest protection riprap and mooring infrastructure). Dredging to deepen and expand the tug basin is expected to remove patches of dense native eelgrass, resulting in depths that are not conducive to native eelgrass re-colonization and potential associated effects in the productivity of fish and fish habitat.

The effects of the proposed tug basin expansion on fish and fish habitat were assessed in the RBT2 Environmental Impact Statement (EIS)[1] qualitatively, using multiple lines of evidence (also refer to the response to IR7-24 (Appendix IR7-24A, Table IR7-24-A1)[2]). To inform the quantitative analysis of net

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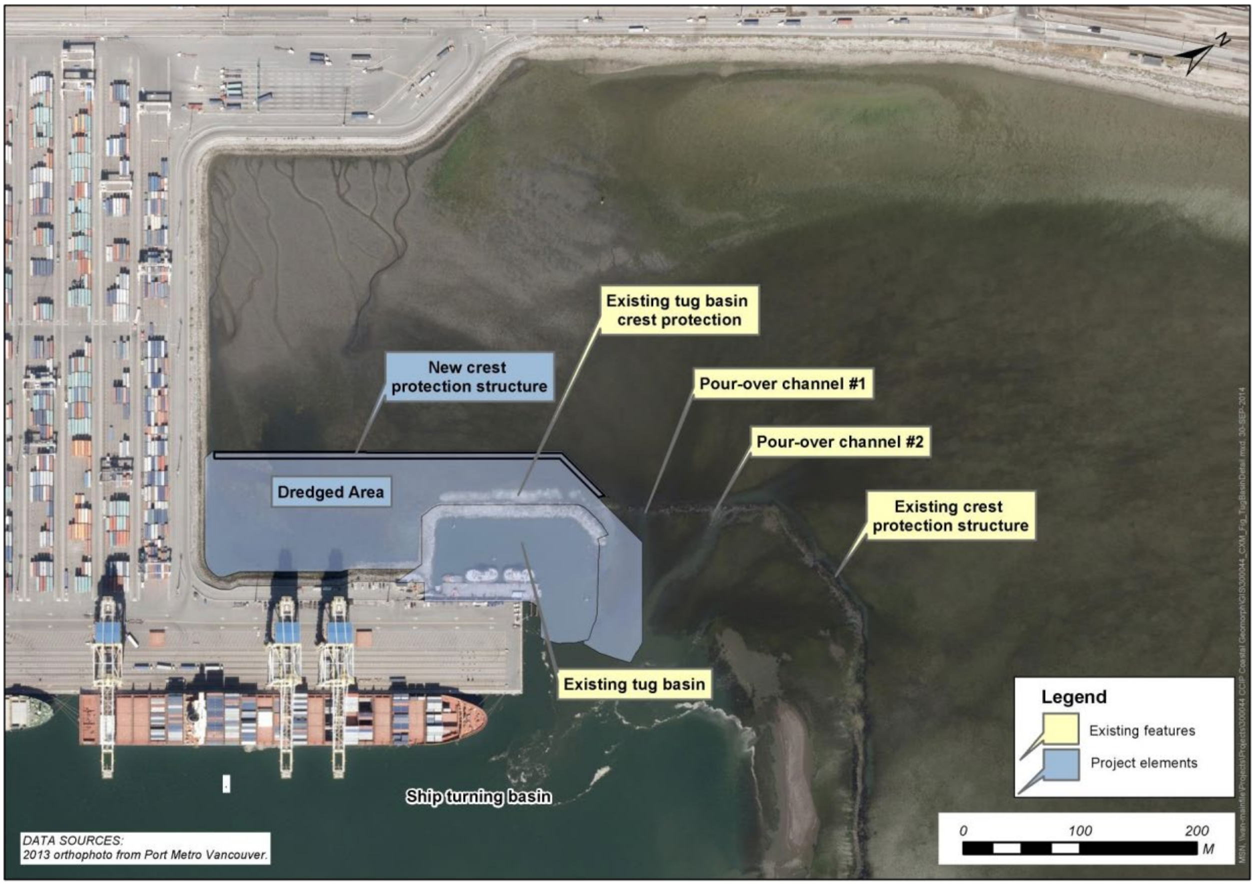
[1] CIAR Document #181 Roberts Bank Terminal 2 Project - Environmental Impact Statement, Volume 3: Biophysical Effects Assessments. https://www.ceaa-acee.gc.ca/050/documents/p80054/101365E.pdf.

[2] CIAR Document #1360 From the Vancouver Fraser Port Authority to the Review Panel re: Responses to Information Requests: IR7-24, IR7-25, IR7-26, IR7-27, IR7-30, IR9-05, IR10-10, IR11-13, IR11-14, IR11-15, IR11-16, IR11-17, IR11-18, IR11-19,

change in the productivity of fish and fish habitat presented in **IR2020-1.2**, Hemmera Envirochem Inc. (Hemmera) was tasked with quantifying these potential effects to fish and fish habitat productivity associated with the permanent habitat alteration from the tug basin expansion. This report describes the methods used and presents quantitative results.



DATA SOURCES:
2013 orthophoto from Port Metro Vancouver.

Figure 1 Schematic layout of the expanded tug basin proposed for RBT2 as well as features of the existing tug basin

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IR11-21, 12-10, and IR13-17 (See Reference Documents #1000, 1122, 1130, 1179, 1206 and 1228). https://www.ceaa-acee.gc.ca/050/documents/p80054/126250E.pdf.

2.0 METHODS

Changes in the productivity of fish and fish habitat from the proposed tug basin expansion were assessed in the EIS qualitatively using mutliple lines of evidence that did not include use of the RB model. Both the RB model constructed for the EIS and the updated RB model incorporated direct and indirect effects relating to the footprints of the marine terminal and the widened causeway. Given that the expansion of the tug basin will result in permanent alteration of habitat, as opposed to a direct (footprint-related) loss, it was not methodologically appropriate to use the original and updated RB model to quantify potential loss in fish and fish habitat productivity associated with the proposed tug basin expansion. The method that was used instead is described in detail below. Elements of the updated RB model that were relied upon to undertake the analysis presented in this report include 'without project' outputs of the updated RB model key run to describe existing conditions of fish and fish habitat productivity in the tug basin expansion area. Additional information on methodological steps followed are provided below.

Two steps were used to quantify potential effects to fish and fish habitat productivity associated with the permanent habitat alteration from the tug basin expansion: i) determine existing fish and fish habitat productivity associated with the proposed tug basin expansion area, and ii) calculate the productivity loss associated with the proposed expansion. For clarity, biomass (expressed in tonnes; t) is used throughout this report as a measurable metric of productivity.

To start, the existing fish and fish habitat productivity within the proposed tug basin expansion area (**Figure 1**) was determined by extracting outputs of the updated Roberts Bank ecosystem model (updated RB model) key run (see **Appendix IR2020-1.2-A**). This was done by overlaying the ArcGIS® shapefile of the proposed expanded tug basin on the 'without project' outputs of the updated RB model key run. The extracted productivity values were summed by representative species or group (used in the project's EIS to structure the marine biophysical effects assessment) and a total estimate was generated of existing productivity within the proposed tug basin expansion area.

The second step calculated the productivity that is expected to be impacted as a result of the permanent alteration of habitat from the proposed expansion. The life history and habitat requirements of each representative species or group were assessed against the habitat that will result from the proposed expansion and a percent reduction was applied to the existing productivity values, as follows:

- 0% loss - For representative species or groups that are not considered to be impacted by the proposed expansion and will continue to contribute to the productivity of the expanded tug basin after construction.
- 50% loss - For representative species or groups that are likely to be subject to a shift in community composition and associated reduction in productivity associated with habitat alteration.
- 100% loss - For representative species or groups that will no longer contribute to the productivity of the expanded tug basin following habitat alteration.

Habitat alteration will result in the conversion of intertidal mudflat to both subtidal soft substrate and hard substrate or structures (e.g., new crest protection structure). Marine invertebrate infaunal species (e.g., infaunal bivalves, macrofauna, meiofauna) are expected to re-establish in the resulting subtidal soft substrate, however, they are expected to contribute a reduced productivity after construction due to: (i) a reduction in the area of soft substrate available for re-colonization and (ii) generally lower productivity characterizing infaunal communities in subtidal soft substrates compared to the productivity of intertidal mudflats at Roberts Bank. To be conservative, a 50% loss was applied to the productivity of marine invertebrate infaunal species contributing to existing productivity in the tug basin expansion area based on professional judgement and informed by biomass estimates of infaunal bivalves and macrofauna estimated for the intertidal and subtidal areas at Roberts Bank during empirical surveys undertaken for the project in 2019[3]. The 50% loss in productivity was also applied to flatfish species or groups (i.e., flatfish, starry flounder (*Platichthys stellatus*)) and large demersal fish to account for a 50% reduction in benthic infaunal prey.

The bottom elevation of the expanded tug basin is expected to be dredged to a depth of –6.5 m CD and the subtidal habitat will not be suitable for eelgrass re-establishment following the expansion of the tug basin. As such, a 100% loss was applied to the productivity of eelgrass, and of representative species or groups (i.e., forage fish, herring (*Clupea pallassii*), Pacific sand lance (*Ammodytes hexapterus*), shiner perch (*Cymatogaster aggregata*), small demersal fish) that are associated with eelgrass habitat in the tug basin expansion area. Although the depths that will characterize the expanded tug basin are within the depth distribution of juvenile Dungeness crab[4], the alteration of highly suitable intertidal habitat to subtidal habitat is expected to be a lower habitat preference, thus, a 100% reduction was also conservatively applied in the productivity of juvenile Dungeness crab (*Metacarcinus magister*).

After a percent reduction (i.e., 0, 50 or 100%) was applied to the existing productivity values, the total productivity loss was summed for all fish and fish habitat representative species or groups associated with the proposed tug basin expansion.

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[3] During empirical surveys undertaken for the project in 2019, mean biomass of macrofauna in the subtidal zone was estimated to be 31.3 t/km^2, or 42% lower, than in the intertidal zone, which was estimated to be 75.3 t/km^2. For infaunal bivalves, mean biomass in the subtidal zone was estimated to be 67.9 t/km^2, or 33% lower, than in the intertidal zone, which was estimated to be 207.8 t/km^2 (see also **Appendix IR2020-1.2-A**).

[4] CIAR Document #181 RBT2 EIS, Volume 3: Biophysical Effects Assessments, Appendix 12-A. https://www.ceaa-acee.gc.ca/050/documents/p80054/101361E.pdf.

3.0 RESULTS AND DISCUSSION

Overall, construction for the proposed tug basin expansion will result in the permanent alteration of intertidal mudflat to both soft and hard (e.g., crest protection riprap or mooring infrastructure) subtidal substrate . Associated loss in productivity is quantitatively estimated to be 5.18 t of fish and 5.60 t of fish habitat for a total of 10.78 t (**Table 1**) and supports the qualitative consulsions reported in the EIS.

The proposed tug basin expansion area represents 27.77 t (0.19%) of existing total productivity at Roberts Bank (14,321.91 t based on the 'without project' outputs of the updated RB model key run), across 24 representative species or groups included in the EIS (**Table 1**). Marine vegetation comprises the majority of this biomass at 17.30 t (62%), with brown algae and native eelgrass contributing 11.70 t and 5.53 t respectively. The next largest contribution to existing productivity is associated with marine invertebrates for a total of 9.51 t (34%) of biomass, the majority of which is attributed to macrofauna 7.52 t, followed by infaunal bivalves with 1.22 t (**Table 1**). Juvenile Dungess crab contribute very little to the existing productivity within the proposed tug basin expansion area (0.03 t). Marine fish contribute a total of 0.96 t (4%) of biomass, largely driven by forage fish (0.35 t), lingcod (*Ophiodon elongatus*, 0.25 t), and rockfish (0.18 t). The existing productivity of both adult and juvenile Chinook (*Oncorhynchus tshawytscha)* and chum salmon (*O. keta*) associated with the proposed tug basin expansion area is estimated to be <0.01 t, as this area represents a small proportion of the overall productive area for salmon at Roberts Bank (**Table 1**).

Of the 24 representative species or groups that contribute to the existing productivity within the proposed tug basin expansion area, eight are not expected to undergo a loss in productivity as a result of the habitat alteration associated with the proposed tug basin expansion. For example, adult Dungeness crab have been documented using the existing tug basin and are expected to also use the subtidal habitat that would result from the proposed tug basin expansion. Also, no loss in productivity is anticipated for brown algae (e.g., rockweed, kelp) since the addition of crest protection riprap and mooring infrastructure will provide hard attachment substrate for macroalgal communities to establish. Additionally, juvenile Chinook and chum salmon are expected to continue to use the water column to reach intertidal rearing habitats adjacent to the expanded tug basin. Marine fish mitigation measures applicable to the proposed tug basin expansion are presented in IR7-24[5] and addressed in the main body of this IR response.

Six representative species or groups that contribute to the existing biomass within the proposed tug basin expansion area were assumed to experience a 50% reduction in existing productivity associated with habitat alteration from the tug basin expansion (**Table 1**). Marine infaunal bivalves, macrofauna and meiofauna, presently occupying intertidal soft substrates in the tug basin expansion area are anticipated to re-colonize available subtidal soft substrates following construction at a 50% reduction in existing productivity. Changes to the species assemblage is probable, as newly established subtidal infaunal communities may host different species than existing intertidal ones and subtidal habitat is expected to be less productive compared to intertidal mudflats at Roberts Bank[3]. Infaunal bivalve loss (e.g., cockles, littleneck clams) is expected to be limited, as sediments within the expanded footprint area are muddy and thus unsuitable for larger clam species that prefer coarser sediment textures. Productivity of the subtidal soft substrates within the expanded tug basin area is anticipated to be similar or equal to productivity of subtidal soft substrates within of the adjacent existing tug basin.Overall, the tug basin expansion is expected

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[5] CIAR Document #1360 From the Vancouver Fraser Port Authority to the Review Panel re: Responses to Information Requests: IR7-24, IR7-25, IR7-26, IR7-27, IR7-30, IR9-05, IR10-10, IR11-13, IR11-14, IR11-15, IR11-16, IR11-17, IR11-18, IR11-19, IR11-21, 12-10, and IR13-17 (See Reference Documents #1000, 1122, 1130, 1179, 1206 and 1228). https://www.ceaa-acee.gc.ca/050/documents/p80054/126250E.pdf.

to result in a 50% loss in marine benthic invertebrate productivity (e.g. infaunal bivalves, macrofauna, meiofauna) from 9.29 t to 4.65 t after the proposed tug basin expansion (**Table 1**). Three representative species or groups of marine fish that are associated with soft substrates are also anticipated to have a 50% reduction (or 0.03 t; **Table 1**) in productivity: flatfish, large demersal fish, and starry flounder.

Dredging the expanded tug basin will convert the intertidal mudflat to subtidal habitat at depths that will not support native or non-native eelgrass, leading to a 100% loss in productivity of 5.53 t and 0.07 t, respectively (**Table 1**). Representative species or groups of fish that are associated with eelgrass habitat (i.e., forage fish, herring, Pacific sand lance, shiner perch, small demersal fish, juvenile Dungeness crab) would also be expected to experience 100% loss in productivity (0.50 t; **Table 1**).

Table 1 Potential loss in fish and fish habitat productivity (tonnes; t) associated with the proposed tug basin expansion for RBT2

Representative species or group	Proposed tug basin expansion area			
	Existing productivity (t)	Percent (%) loss in productivity	Loss in productivity (t)	Post-expansion productivity (t)
Chinook (adult)	<0.01	0	0.00	<0.01
Chinook (juvenile)	<0.01	0	<0.01	0.00
Chum (adult)	<0.01	0	0.00	<0.01
Chum (juvenile)	<0.01	0	<0.01	0.00
Flatfish	0.03	50	-0.01	0.01
Forage fish	0.35	100	-0.35	0.00
Pacific herring	0.08	100	-0.08	0.00
Large demersal fish	0.02	50	-0.01	0.01
Lingcod	0.25	0	0.00	0.25
Rockfish	0.18	0	0.00	0.18
Pacific sand lance	0.01	100	-0.01	0.00
Shiner perch	0.02	100	-0.02	0.00
Small demersal fish	0.01	100	-0.01	0.00
Starry flounder	0.02	50	-0.01	0.01
Marine fish subtotal	**0.96**	**-**	**-0.50**	**0.46**
Dungeness crab (adult)	0.19	0	0.00	0.19
Dungeness crab (juvenile)	0.03	100	-0.03	0.03
Infaunal bivalves	1.22	50	-0.61	0.61
Macrofauna	7.52	50	-3.76	3.76
Meiofauna	0.55	50	-0.28	0.28
Marine invertebrates subtotal	**9.51**	**-**	**-4.68**	**4.83**
Brown algae	11.70	0	0.00	11.70
Native eelgrass	5.53	100	-5.53	0.00
Non-native eelgrass	0.07	100	-0.07	0.00
Marine vegetation subtotal	**17.30**	**-**	**-5.60**	**11.70**
Total	**27.77**	**-**	**-10.78**	**16.99**

4.0 SUMMARY

To inform the analysis of net change in productivity of fish and fish habitat presented in **IR2020-1.2**, the potential effects to fish and fish habitat productivity associated with the permanent habitat alteration from the tug basin expansion were quantified. This quantification does not change the assessment conclusions of the effects on fish and fish habitat from the proposed tug basin expansion that are presented in the EIS and summarized in the response to IR7-24 (Appendidx IR7-24A , Table IR7-24-A1)[7].

The proposed tug basin expansion area represents 27.77 t (0.19%) of existing total productivity at Roberts Bank (14,321.91 t based on the 'without project' outputs of the updated RB model key run), across 24 representative species or groups included in the EIS. Overall, construction to expand the existing tug basin will result in the permanent alteration of intertidal mudflat to both soft subtidal and hard (e.g., crest protection riprap or mooring infrastructure) habitat and the potential loss in the productivity of fish and fish habitat by 5.18 t and 5.60 t, respectively, for a total of 10.78 t. Losses in productivity from the expansion of the tug basin are predicted to result from the 50% reduction in productivity of infaunal invertebrate communities (i.e., macrofauna, meiofauna, infaunal bivalves) and flatfish, and the 100% loss in productivity of eelgrass and representative species or groups associated with this habitat type, including juvenile Dungeness crab. Productivity of the subtidal soft substrates within the expanded tug basin area are anticipated to be similar or equal to subtidal soft substrates within of the adjacent existing tug basin. The addition of crest protection riprap and mooring infrastructure is expected to provide hard substrate for macroalgal communities (e.g., rockweed) to establish and for sessile invertebrates (e.g., barnacles, bay mussels) to colonize. Adult Dungeness crab are expected to continue to use the subtidal soft substrate within the expnded tug basin, and juvenile Chinook and chum salmon are expected to continue to use the water column to reach intertidal rearing habitats adjacent to the expanded tug basin.

5.0 CLOSURE

We have appreciated the opportunity of working with you on this project and trust that this report is satisfactory to your requirements. Please feel free to contact the undersigned by phone at 604.669.0424 regarding any questions or further information that you may require.

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Appendix IR2020-1.2-C

Contingency Measure Approach

Appendix IR2020-1.2-C: Contingency Measure Approach

A variety of potential contingency measures and projects are described in Section 6 of IR2020-1.1.

In the event[1] of underperformance of the proposed offsetting habitats, there are a range of contingency measures that could be considered, such as the following:

- Increase the long-term effectiveness monitoring period to provide additional time for intended functionality to be achieved and performance criteria to be met
- Intensify or modify long-term effectiveness monitoring to verify and better understand suggested underperformance
- Apply remedial measures if the cause of underperformance is known and feasible remedial measures are available
- If the cause of underperformance is not known, or if remedial measures are infeasible or ineffective, propose additional offset habitat/credit in consultation with Indigenous groups and DFO under one or more of the following scenarios:
    - Expand an existing offsetting site that is performing well to counterbalance an underperforming site
    - Expand an existing offsetting site that is not functioning completely as intended but still provides a net gain of functional habitat—to counterbalance its underperformance (with the net gain claimed for the habitat expansion area adjusted to reflect demonstrated performance)
    - Withdraw additional habitat banking credit where available and appropriate (from previously constructed, functioning, and approved habitat banking projects)
    - Implement the next most technically well-developed, suitable, and available contingency project; such contingency projects or measures may be ones that are brought forward by Indigenous groups, are being advanced through the port authority's Habitat Enhancement Program, or that could stem from the proposed Non-Conventional Offsetting Program (NCOP)

If remedial measures or alternative offsetting measures are necessary, their effectiveness monitoring period would be extended accordingly.

Based on the experience of the port authority, an enhanced monitoring effort and the successful application of remedial measures are more typical outcomes than requiring alternative offsetting projects. Furthermore, the port authority has experience successfully developing habitat enhancement projects in the Fraser River estuary as well as applying corrective measures to address occasional issues of offsetting underperformance (as described in Section 7 of IR2020-1.1)

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[1] As recognized by the RBT2 review panel, the port authority (and the engineering and biological consultants hired by the port authority) is experienced in successfully designing, constructing, and monitoring similar offsetting projects.

Appendix IR2020-1.2-D

RBT2 Proposed fish and fish habitat offsetting plan – additional technical analysis

Appendix IR2020-1.2-D RBT2 Proposed fish and fish habitat offsetting plan – additional technical analysis

Context

In his letter of August 24, 2020,[1] the minister of environment and climate change (the minister) requested the Vancouver Fraser Port Authority (the port authority) propose an offsetting plan that would address potential effects from the Roberts Bank Terminal 2 (RBT2) Project specifically for juvenile Chinook salmon, other fish, and fish habitat. **IR2020-1.2** provides information on a proposed offsetting plan, including an analysis to demonstrate how the proposed offsetting plan counterbalances potential effects of the project on fish and fish habitat, including fully offsetting project effects that remain following the implementation of avoidance and reduction measures proposed by the port authority on juvenile Chinook salmon and their habitat. In support of **IR2020-1.2**, and to respond to comments received from Fisheries and Oceans Canada (DFO) during DFO's review of a draft response to **IR2020-1.2**, the port authority conducted additional analyses, described in this appendix, pertinent to the following topics:

- The amount of fish and fish habitat productivity forecasted (using the updated Roberts Bank ecosystem model (RB model) described in **Appendix IR2020-1.2-A**) to be adversely affected by the project footprint (as reflected in reference concept design[2]) relative to the change in productivity of fish and fish habitat outside the project footprint within the biophysical local assessment area (LAA; Figures 11-1, 12-1, and 13-1 in the environmental impact statement (EIS)[3]) (see **Section 1**)
- Uncertainty relating to the extent to which indirect changes in the productivity of fish and fish habitat forecasted by the updated RB model will be realized (see **Section 2**)
- The time that may be required for the realization of indirect changes in the productivity of fish and fish habitat forecasted by the updated RB model (referred to in this appendix as temporal lag A; see **Section 3**)
- Temporal lag relating to the time between project impact (i.e., project placement) and construction of offsetting measures proposed as part of the project's proposed offsetting plan (temporal lag B; see **Section 4**)
- Temporal lag relating to the time that may be required for the offsetting measures proposed as part of the project's proposed offsetting plan (86 hectares (ha)) to become fully functional (temporal lag C; see **Section 5**)

In addition to the technical analyses listed above and described in greater detail below, DFO requested that an alternate equivalency approach be undertaken that is based on the relative importance of habitats to juvenile Chinook salmon to evaluate the degree to which the proposed offsetting plan counterbalances effects from RBT2 (**Section 6**). The purpose of this alternate equivalency approach is to provide another line of evidence, in addition to the productivity approach that was based on the updated RB model, to demonstrate the adequacy of the proposed offsetting plan.

Based on the request for an alternate equivalency approach, the relative importance to juvenile Chinook salmon was considered of all habitat types within the biophysical LAA (mapped during field surveys undertaken for the project in 2019) that are expected to overlap with the proposed project footprint

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[1] CIAR Document #2067 From the Minister of Environment and Climate Change to the Vancouver Fraser Port Authority re: Information Request. https://iaac-aeic.gc.ca/050/documents/p80054/135827E.pdf

[2] Described in CIAR Document #181 and updates provided in CIAR Document #1210.

[3] CIAR Document #181 Roberts Bank Terminal 2 Project – Environmental Impact Statement, Volume 3: Biophysical Effects Assessment, Figures. https://iaac-aeic.gc.ca/050/evaluations/document/114311

(including the potential project footprint reduction of up to 14.4 hectares (ha) described in IR2020-2.1) (see **Section 6**).

Summary

Additional analyses conducted at the request of DFO indicate that the project's proposed offsetting plan of 86 ha will conservatively result in a net gain in the productivity of fish and fish habitat by 1,773 tonnes (t) per year, even after accounting for uncertainty associated with the updated RB model and temporal lags.

This conclusion is supported by an alternate equivalency approach that considered the relative importance to juvenile Chinook salmon of habitats in the biophysical LAA. This alternate equivalency approach demonstrates that the project's proposed offsetting plan will offset all impacts to juvenile Chinook salmon and will result in a net gain of 37.45 ha of juvenile Chinook salmon habitat.

Footprint related effects on productivity

With avoidance and reduction measures (see **IR2020-1.2**), and before implementation of offsetting, footprint[4]-related losses in fish and fish habitat productivity amount to approximately 119 t/year. Four to six times the amount of this productivity loss, due to the project footprint, will be gained by offsetting (i.e., resulting in a 4:1 to 6:1 offsetting ratio).

Outside the project footprint, with avoidance and reduction measures (see **IR2020-1.2**), and before implementation of offsetting, the project is forecasted to result in an increase in fish and fish habitat productivity of approximately 1,430 t/year. This forecasted indirect productivity increase is due to project-related changes in environmental conditions and in food web interactions, and it has been discounted to account for uncertainty in the updated RB model (see **Section 2**) and for temporal lag A (**Section 3**).

Accounting for model uncertainty and temporal lags

In response to DFO's comments on the draft **IR2020-1.2** response, a total discounting of approximately 19.3% has been applied to account for potential uncertainty in the updated RB model and temporal lags. The 19.3% discounting is made up of four components: approximately 7.5% discounting to account for uncertainty in the updated RB model, and an additional of approximately 7.5%, 3.5%, and 0.8% discounting for temporal lags A, B, and C, respectively.

This 19.3% discounting amounts to approximately 425 t/year less net gain in fish and fish habitat productivity relative to the net value presented in the draft **IR2020-1.2**. Specifically, prior to discounting, net gain in productivity of fish and fish habitat (with avoidance, reduction, and offsetting measures) was equal to 2,197 t/year (as presented in the draft **IR2020-1.2**). Discounting of 19.3%, or 425 t/year, resulted in a net gain by 1,773 t/year in fish and fish habitat productivity (with avoidance, reduction, and offsetting measures).

Hence, even after discounting to account for uncertainty in the RB model and temporal lags A, B, and C, a large net gain in the productivity of fish and fish habitat is forecasted, with avoidance, reduction, and offsetting measures.

Juvenile Chinook salmon habitat relative values approach

As indicated above, an alternate equivalency approach was taken with respect to project effects on juvenile Chinook salmon habitat that considered the relative importance to juvenile Chinook salmon of

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[4] Calculations of fish and fish habitat productivity under the project footprint do not consider the project footprint reduction described in IR2020-2.1. This is because of the small size of the project footprint reduction compared to the indirect changes in fish and fish habitat productivity forecasted by the updated RB model throughout the biophysical LAA; see IR2020-2.1 for further details).

habitats in the biophysical LAA in response to a request by DFO. Based on this alternate equivalency approach, with avoidance, reduction, and offsetting measures, results indicate that the project will result in a net gain in juvenile Chinook salmon habitat of approximately 37.45 ha. This net increase in juvenile Chinook salmon habitat is conservative as an additional 22 ha of offsetting being advanced by the port authority as part of the project's offsetting plan are not included in the calculations presented in this appendix (see **IR2020-1.2** for more details on the additional 22 ha of offsetting).

Details on the additional technical analyses undertaken by the port authority that support the findings summarized here are presented in the sections below.

1. Footprint-related effects on fish and fish habitat productivity

During their review of the draft **IR2020-1.2** response, DFO commented that it is difficult to determine the extent to which proposed offsets counterbalance the direct versus indirect effects of the project. To respond to DFO's comment, additional analysis was conducted to distinguish between forecasted changes in fish and fish habitat productivity within and outside the proposed project footprint.[5] This additional analysis used the outputs of the updated RB model key run (described in **Appendix IR2020-1.2-A**).

Effects on fish and fish habitat productivity from the proposed project footprint were estimated using the outputs of the 'without project' run of the updated RB model, and by extracting the productivity of fish and fish habitat for those grid cells that overlap with the proposed project footprint (**Table IR2020-1.2-D1**). In total, the proposed project footprint overlaps with and will adversely affect approximately 119 t/year of fish (marine fish: 13 t/year; marine invertebrates: 106 t/year) and fish habitat (marine vegetation: <0.1 t/year) (**Table IR2020-1.2-D1**). Footprint-related productivity losses are attributed predominantly to infaunal bivalves (97 of 119 t/year or 82%), which inhabit subtidal sand that overlaps with the marine terminal footprint, followed by forage fish and Pacific herring (12 of 119 t/year or 10%), which are seasonally present in the water column of the subtidal area where the marine terminal is proposed to be constructed.

Forecasted changes in fish and fish habitat productivity outside the proposed project footprint (i.e., driven by project-related changes in environmental conditions behind the terminal as well as project-related changes in predator-prey interactions across the biophysical LAA) were calculated by subtracting the footprint-related productivity losses (summarized above and shown in **Table IR2020-1.2-D1**) from the updated RB model key run, after discounting for uncertainty in the updated RB model (see **Section 2**) and for temporal lag A (see **Section 3**). When considering the discounted key run outputs of the updated RB model, the project is forecasted to result in an overall increase in the productivity of fish and fish habitat at Roberts Bank outside the proposed project footprint by a total of 1,430 t/year (marine fish: –3 t/year; marine invertebrates: 537 t/year; marine vegetation: 897 t/year; **Table IR2020-1.2-D1**).

As presented and explained in **IR2020-1.2**, the productivity from 64 ha of offsetting (of the total 86 ha being advanced by the port authority) will result in approximately four times more fish and fish habitat productivity than that lost by the footprint (119 t/year) alone (not including non-footprint-related gains in productivity from RBT2). In other words, the offsetting productivity ratio is 4:1. This ratio includes discounting for uncertainty in the updated RB model and for temporal lags A, B, and C (as described below) but does not include the full 86 ha of offsetting being advanced as part of the project's proposed offsetting plan. Hence, when the full 86 ha of offsetting is considered, the total offsetting productivity ratio is likely closer to 6:1.

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[5] Note that the proposed project footprint considered in this analysis does not account for an additional reduction of up to 14.4 ha described and evaluated in IR2020-2.1. Given the potential footprint reduction evaluated reduces the marine terminal width and not the overall length, no appreciable changes are anticipated in the magnitude of project-related coastal geomorphic changes (described in IR2020-4), and in turn the changes in fish and fish habitat productivity forecasted by the updated RB model.

The inclusion of non-footprint-related gains in fish and fish habitat productivity from RBT2 alongside productivity gains from the 64 ha of offsetting results in approximately 16 times more fish and fish habitat productivity than that lost by the project footprint.

Table IR2020-1.2-D1: Forecasted changes in fish and fish habitat productivity (tonnes (t)/year) within and outside the proposed project footprint based on the outputs of the updated Roberts Bank ecosystem model (RB model) key run, after discounting for uncertainty in the updated RB model and temporal lag A

Representative species or group	**Footprint-related productivity loss (t/year)**	**Discounted[1] non-footprint-related productivity change (t/year)**	**Discounted[a] net productivity change (footprint + non-footprint; also shown in Table IR2020-1.2-D2) (t/year)**
Chinook adult	-0.039	0.047	0.008
Chinook smolt	-0.008	0.013	0.005
Chum adult	-0.029	0.002	-0.027
Chum smolt	-0.008	0.030	0.022
Flatfish	-0.289	-0.165	-0.455
Forage fish	-7.819	-5.786	-13.605
Herring	-4.507	4.118	-0.389
Large demersal fish	-0.062	-0.480	-0.542
Lingcod	-0.029	-0.551	-0.580
Rockfish	-0.013	-0.740	-0.753
Sand lance	-0.108	0.117	0.009
Shiner perch	-0.038	0.825	0.787
Small demersal fish	-0.011	-0.408	-0.419
Starry flounder	-0.039	-0.093	-0.132
Dungeness crab adult	-4.341	3.232	-1.110
Dungeness crab juvenile	-0.656	1.356	0.700
Infaunal bivalves	-97.095	-297.532	-394.628
Macrofauna	-2.395	523.346	520.951
Meiofauna	-0.001	307.813	307.812
Orange sea pen	-1.305	-1.613	-2.918
Brown algae	<-0.001	-61.709	-61.709
Native eelgrass	-0.033	177.057	177.024
Non-native eelgrass	<-0.001	4.016	4.016
Marsh	<-0.001	777.294	777.294
Marine fish subtotal	*-12.998*	*-3.074*	*-16.071*
Marine invertebrates subtotal	*-105.793*	*536.601*	*430.808*
Marine vegetation subtotal	*-0.033*	*896.658*	*896.624*
Total	**-118.824**	**1,430.185**	**1,311.361**

Notes: a. Discounting was applied to non-footprint-related changes in productivity of fish and fish habitat to account for uncertainty in the updated RB model (described in **Section 2**) and for temporal lag A (described in **Section 3**).

2. Uncertainty in indirect productivity gains forecasted by the updated Roberts Bank ecosystem model

In their comments on the draft **IR2020-1.2** response, DFO identified a need to describe potential uncertainty in the forecasts of the updated RB model of indirect gains in fish and fish habitat productivity. To account for uncertainty in the outputs of the updated RB model, additional analysis was conducted that considered the outputs of the Monte Carlo (MC) sensitivity analysis (described in **Appendix IR2020-1.2-A**).

As described in **Appendix IR2020-1.2-A**, the MC sensitivity analysis was used to evaluate how uncertainty in input parameters may influence performance of the updated RB model and robustness of model outputs. The outputs of the MC sensitivity analysis, specifically, the 50th percentile or median (shown in **Table IR2020-1.2-D2** and in **Appendix IR2020-1.2-A**, Table 3-5), were considered here as they comprise the most likely representation of the Roberts Bank ecosystem with the project once it has approached equilibrium (this takes approximately 10 years; see **Appendix IR2020-1.2-A**).

The MC sensitivity analysis showed that, except for meiofauna, the median values of the MC sensitivity analysis were generally similar or more conservative than the updated RB model key run (**Appendix IR2020-1.2-A**, Table 3-4). In comparing the outputs of the MC sensitivity analysis and the updated RB model key run, the median was approximately 7% more conservative than the key run, when meiofauna was excluded from this comparison. In contrast, the meiofauna median was 7% higher than the key run value (**Appendix IR2020-1.2-A**, Table 3-4) and as a result when the overall median of the MC sensitivity analysis was compared to the key run it was found to be slightly greater by approximately 3% with the inclusion of meiofauna. For the purpose of addressing DFO's comment, and to be conservative, a 7% difference (calculated by excluding the meiofauna) was applied as explained below to address uncertainty in the outputs of the updated RB model and to calculate net gains in fish and fish habitat productivity with avoidance, reduction, and offsetting measures.

The 7% difference was applied in the analysis based on the following steps. Temporal lag A was calculated first as described in **Section 3**. Second, a 7% was subtracted from the outputs of the temporal lag A analysis to account for uncertainty in the updated RB model. The results of discounting to address uncertainty are presented in **Table IR2020-1.2-D2** by representative species or group. The 7% difference that was applied in this analysis amounts to a total of 166 t/year, or a discounting of 7.5%, relative to the net total change in fish and fish habitat productivity of 2,197 t/year presented in the draft **IR2020-1.2**, Table IR2020-1.2-4.

3. Temporal lag A

Temporal lag A refers to the time that may be required for changes to be realized in fish and fish habitat productivity forecasted by the updated RB model. In their review of the draft **IR2020-1.2** response, DFO commented that the time lag between project impacts and the realization of potential indirect benefits has not been considered (in the productivity calculations presented in **IR2020-1.2**).

Additional analysis was undertaken to incorporate temporal lag A in the calculation of net gain in fish and fish habitat productivity, after avoidance, reduction, and offsetting measures, presented in **IR2020-1.2**. Specifically, and in addition to discounting by 7.5% to address uncertainty in the updated RB model (see **Section 2**), forecasted indirect changes in the productivity of fish and fish habitat with avoidance and reduction measures, and before offsetting, were discounted further. The approach to discounting for temporal lag A included averaging the updated RB model key run value of each representative species or group over a 10-year period (i.e., over the time period forecasted to be required for the ecosystem at Roberts Bank to approach equilibrium with the project in place). This is explained in greater detail below.

Consistent with the methods described in EIS Appendix 10-C (CIAR Document #181) and in **Appendix IR2020-1.2-A**, the updated RB model was run using two scenarios: without and with the project. In the 'with project' scenario, the project was introduced in the biophysical LAA instantaneously in year 1, and the model read project-related changes in environmental conditions using the temporal-spatial framework of Ecospace (for information on the temporal-spatial framework of Ecospace, refer to EIS Appendix 10-C, Section 2.9; CIAR Document #181). Following a total model run of 10 years, the Roberts Bank ecosystem approached equilibrium for both 'without' and 'with project' scenarios. For each representative species or group, the updated RB model key run value was calculated by subtracting the 'without project' from the 'with project' productivity output.

Figure IR2020-1.2-D1 shows how the productivity difference ('with project' minus 'without project', in t/year) of each representative species or group changes over the 10-year period following placement of the project in year 1. For each representative species or group, blue open circles represent yearly values of productivity difference forecasted by the updated RB model. The black curve line, which connects these yearly values of productivity difference, was interpolated using the spline function in the statistical computing software R (R Core Team 2020). The spline function was used to yield a smooth curve. For Chinook smolt, the interpolated curve line dipped slightly below zero between model run years 9 and 10 (**Figure IR2020-1.2-D1**). This is a computational artifact of using the spline function and in fact the updated RB model key run forecasts an increase in productivity for Chinook smolt that equilibrates at 0.005 t/year after 10 model run years (Table **IR2020-1.2-D2**).

As shown by the curve lines in **Figure IR2020-1.2-D1**, productivity difference over time following project placement varies by representative species or group. For species that associate predominantly with intertidal habitats, temporal lag A is short with productivity increases beginning to accrue relatively quickly almost immediately after project placement for marine vegetation, such as marsh and eelgrass, and within two years after project placement for species such as Chinook and chum smolts, juvenile Dungeness crab, and shiner perch. Temporal lag A is greater (ranging between four and seven years, following project placement) for species that are subtidal in their distribution (e.g., herring, adult Dungeness crab, sand lance, starry flounder, lingcod). Temporal lag A is greatest for those species for which the updated RB model forecasted an indirect loss in productivity with avoidance and reduction measures (e.g., flatfish, infaunal bivalves, orange sea pens).

To calculate an average value of productivity difference over the 10-year period, for each representative species or group the area contained within the interpolated black curve line and the x-axis (shown as a black dot-dash line on each graph in **Figure IR2020-1.2-D1**) was calculated in R using the "area_under_curve; method = spline" function in the *bayestestR* package (Makowski et al. 2019), and it was then divided by 10. Productivity difference (in t/year) averaged over 10 years is shown for each representative species or group in **Table IR2020-1.2-D2**, column "Fish and fish habitat productivity estimate to address temporal lag A (t/year)". The approach taken to address temporal lag A resulted in additional discounting of the updated RB model key run by a total of 165 t/year (**Table IR2020-1.2-D2**) or 7.5% relative to the net total change in productivity of fish and fish habitat presented in the draft **IR2020-1.2**, Table IR2020-1.2-4.

Figure IR2020-1.2-D1: Productivity difference ('with project minus without project'; tonnes (t)/year) for each representative species or group forecasted by the updated Roberts Bank ecosystem model over the 10-year model run period. Blue open circles denote yearly values of forecasted productivity difference. The black line denotes an interpolated curve used to calculate the area under the curve. The dot-dash line corresponds to the x-axis

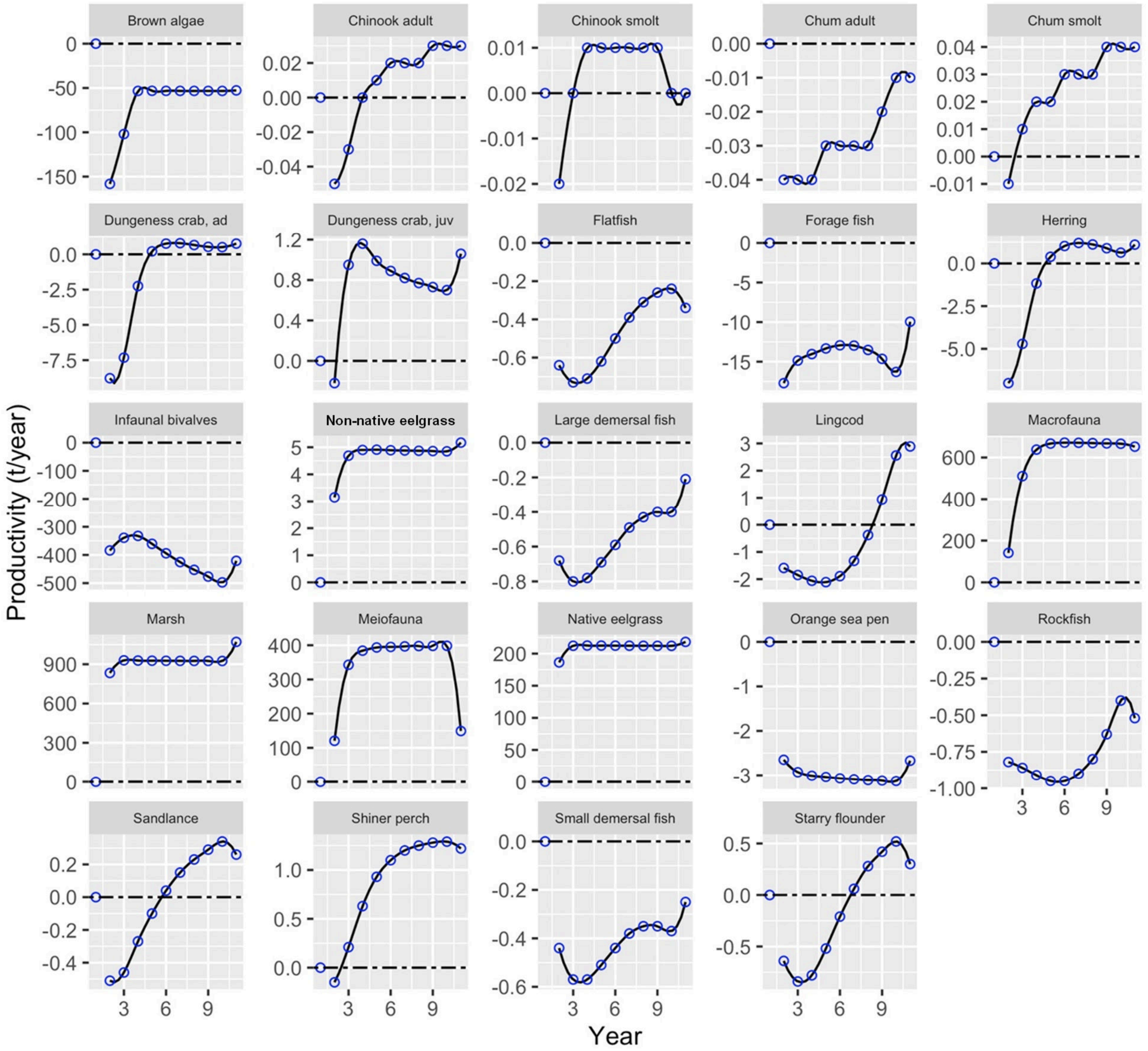

Table IR2020-1.2-D2: Change with the project in fish and fish habitat productivity (tonnes (t)/year) forecasted by the updated Roberts Bank ecosystem model (RB model) key run and discounted to account for uncertainty in the updated RB model outputs and for temporal lag A

Representative species or group	Updated RB model key run (t/year)	Fish and fish habitat productivity estimate to address temporal lag A (t/year)	Fish and fish habitat productivity estimate to address temporal lag A and uncertainty in the updated RB model (t/year)
Chinook adult	0.027	0.009	0.008
Chinook smolt	0.005	0.005	0.005
Chum adult	-0.010	-0.025	-0.027
Chum smolt	0.039	0.024	0.022
Flatfish	-0.341	-0.425	-0.455
Forage fish	-9.952	-12.715	-13.605
Herring	1.098	-0.364	-0.389
Large demersal fish	-0.213	-0.507	-0.542
Lingcod	2.885	-0.542	-0.580
Rockfish	-0.517	-0.704	-0.753
Sand lance	0.259	0.010	0.009
Shiner perch	1.218	0.846	0.787
Small demersal fish	-0.247	-0.392	-0.419
Starry flounder	0.303	-0.123	-0.132
Dungeness crab adult	0.757	-1.037	-1.110
Dungeness crab juvenile	1.057	0.753	0.700
Infaunal bivalves	-420.735	-368.811	-394.628
Macrofauna	651.893	560.162	520.951
Meiofauna	149.227	330.981	307.812
Orange sea pen	-2.667	-2.727	-2.918
Brown algae	-52.704	-57.672	-61.709
Native eelgrass	218.255	190.348	177.024
Non-native eelgrass	5.168	4.318	4.016
Marsh	1,070.767	835.800	777.294
Marine fish subtotal	*-5.448*	*-14.903*	*-16.071*
Marine invertebrates subtotal	*379.533*	*519.321*	*430.808*
Marine vegetation subtotal	*1,241.486*	*972.794*	*896.624*
Total	**1,615.571**	**1,477.212**	**1,311.361**

4. Temporal lag B

Temporal lag B refers to the time between construction of the proposed project and construction of offsetting habitats that comprise the project's proposed offsetting plan (described in **IR2020-1.1**). In their review of the draft **IR2020-1.2** response, DFO commented that the time lag between project impacts and function of offsetting measures has not yet been identified and should be included in the account of potential time lag. To respond to this DFO comment, additional analysis was conducted to incorporate temporal lag B in the calculation of net gain in fish and fish habitat productivity from proposed offsetting presented in **IR2020-1.2**, as described below.

Temporal lag B was considered equal to five years, and it was applied to the analysis of net changes in fish and fish habitat productivity. Temporal lag B of five years was considered appropriate given that the preliminary RBT2 offsetting construction schedule involves construction completion for all proposed offsetting projects within five years of RBT2 construction commencement. This approach is also conservative given that construction completion of a number of proposed offsetting projects is anticipated to occur substantially earlier than five years. For example, the South Causeway Eelgrass Project (formerly known as the Tsawwassen Eelgrass Project), the Westham Island Canoe Pass Tidal Marsh Project, the Finn Slough Enhancement Project, the Tilbury Island Peninsula Enhancement Project, and the Semiahmoo Bay-Little Campbell River Enhancement Project are all anticipated to be completed within three years of RBT2 construction commencement. Also, the rock reef component of the onsite offsetting could be completed as early as within one year of RBT2 construction commencement.

As described in IR2020-1.1 and **IR2020-1.2**, the port authority is advancing 86 ha of conventional offsetting habitats as part of the project's proposed offsetting plan. Calculation of net gains in fish and fish habitat offsetting productivity conservatively considered 64 ha of the 86 ha (and an additional 22 ha of offsetting remains as described in IR2020-1.1 that is expected to provide further gains in offsetting productivity to fish and fish habitat additional to those quantified in **IR2020-1.2**). The 64 ha of offsetting habitat considered in the offsetting productivity calculation comprise 50 ha of intertidal marsh, 10 ha of native eelgrass, and 4 ha of subtidal rock reef. Of the 50 ha of intertidal marsh, 8.3 ha comprise habitat bank projects (i.e., Salt Marsh Restoration Projects; Glenrose, Gladstone Park, and Riverfront Park Tidal Marsh Projects; Timberland Basin Habitat Project; see IR2020-1.1, Table IR2020-1.1-1).

Temporal lag B was incorporated in the calculation of net gain in fish and fish habitat offsetting productivity by applying a generic 3% discount rate (Bradford 2017) for a five-year period. This generic discount rate was applied to 41.7 ha of 50 ha intertidal marsh (excluding habitat bank projects), 10 ha of native eelgrass, and 4 ha of subtidal rock reef offsetting habitat, after accounting for the productivity value of existing underlying habitat (i.e., existing habitat overtop of which offsetting habitats are proposed to be constructed). The 8.3 ha of habitat bank projects are already established and are functioning; therefore, further discounting is not warranted.

In summary, after temporal lag B was considered, net gains in fish and fish habitat productivity were discounted by approximately 76 t/year or by 3.5% relative to the net gain in fish and fish habitat productivity of 2,197 t/year estimated in the draft **IR2020-1.2**, Table IR2020-1.2-4. Thus, conservatively taking temporal lag B into account in this manner, the analysis still demonstrates that the project will result in **net gains** in offsetting productivity of 34 t/year for fish (marine fish: 25 t/year; marine invertebrates: 9 t/year) and 458 t/year for fish habitat (marine vegetation) (**Table IR2020-1.2-D3**). As indicated in **IR2020-1.2**, the additional 22 ha that has not been included in this analysis provides even greater assurance that temporal lags have been accounted for.

5. Temporal lag C

Temporal lag C refers to the time required for the offsetting measures that are part of the project's proposed offsetting plan to become fully functional. In their review of the draft **IR2020-1.2** response, DFO commented that the time lag between construction of the offsets and their functioning of three years for native eelgrass habitat, five years for intertidal marsh, and one year for subtidal rock reef may be optimistic particularly in respect to intertidal marsh.

In response to DFO comments as described in **IR2020-1.2**, the port authority increased the temporal lag for intertidal marsh to seven years between construction and functioning of offsetting. Temporal lag C identified in the draft **IR2020-1.2** for subtidal rock reef and native eelgrass was considered appropriate due to the results of effectiveness monitoring of these offsetting habitat types in the lower Fraser River and estuary and more broadly along the southern B.C. coast (subtidal rock reef: see response to IR11-18; native eelgrass transplantation projects: see Table IR7-29-1 in the response to IR7-29; CIAR Document #934[6]). The port authority stands by its original estimate that intertidal marsh will conservatively take five years to develop and mature based on experience and precedent (see Table IR7-28-1 in the response to IR7-28; CIAR Document #934[6]). However, given feedback from DFO, the port authority increased this to seven years.

When temporal lag C was considered, net gains in fish and fish habitat productivity were discounted by approximately 18 t/year or 0.8% relative to the net gain in fish and fish habitat productivity of 2,197 t/year estimated in the draft **IR2020-1.2**, Table IR2020-1.2-4. Thus, taking both temporal lags B and C into account in this conservative manner, the analyses still demonstrate the project will result in **net gains** in offsetting productivity of 31 t/year for fish (marine fish: 22 t/year; marine invertebrates: 9 t/year) and 443 t/year for fish habitat (marine vegetation), for a total of 474 t/year (**Table IR2020-1.2-D3**). The net productivity gain presented here would be higher if the 22 ha of offsetting, which was not included in these analyses, was included. In addition, the port authority possesses notable expertise in the delivery of successful offsetting projects. The types of offsetting projects being proposed as part of the project's offsetting plan are common/conventional and effectiveness monitoring and adaptive management will ensure net productivity gains are realized.

Table IR2020-1.2-D3: Net gain in fish and fish habitat productivity (tonnes (t)/year) from proposed offsetting habitats after accounting for the productivity value of existing underlying habitat, and after incorporating temporal lags B and C (does not include the additional 22 ha that is being advanced in the offsetting plan)

Representative species or group	Offsetting productivity gain (accounts for underlying habitat value) (t/year)	Offsetting productivity gain (accounts for underlying habitat value, temporal lag B) (t/year)	Temporal lag B discount (t/year)	Offsetting productivity gain (accounts for underlying habitat value, temporal lags B and C) (t/year)	Temporal lag C discount (C – B; t/year)
Chinook adult	0.097	0.086	-0.011	0.074	-0.012
Chinook smolt	0.138	0.123	-0.015	0.105	-0.018
Chum adult	0.090	0.079	-0.011	0.068	-0.010
Chum smolt	0.168	0.147	-0.020	0.128	-0.019
Flatfish	-0.193	-0.166	0.026	-0.138	0.028
Forage fish	-0.587	-0.506	0.081	-0.407	0.099
Herring	0.525	0.453	-0.072	0.418	-0.035
Large demersal fish	0.702	0.606	-0.097	0.584	-0.022
Lingcod	1.380	1.190	-0.190	1.156	-0.035
Rockfish	1.213	1.047	-0.167	1.016	-0.030

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[5] CIAR Document #934 From the Vancouver Fraser Port Authority to the Review Panel re: Compilation of the Review Panel's Information Requests and the Vancouver Fraser Port Authority's Responses (Note: Updated February 15, 2019). https://iaac-aeic.gc.ca/050/evaluations/document/128131

Representative species or group	Offsetting productivity gain (accounts for underlying habitat value) (t/year)	Offsetting productivity gain (accounts for underlying habitat value, temporal lag B) (t/year)	Temporal lag B discount (t/year)	Offsetting productivity gain (accounts for underlying habitat value, temporal lags B and C) (t/year)	Temporal lag C discount (C – B; t/year)
Sand lance	0.008	0.007	-0.001	0.006	-0.001
Shiner perch	24.636	21.722	-2.914	18.413	-3.308
Small demersal fish	0.338	0.293	-0.046	0.274	-0.018
Starry flounder	0.049	0.043	-0.006	0.042	-0.002
Dungeness crab adult	2.049	1.767	-0.281	1.617	-0.150
Dungeness crab juvenile	0.261	0.225	-0.036	0.206	-0.019
Infaunal bivalves	-2.718	-2.345	0.373	-2.276	0.068
Macrofauna	6.462	6.432	-0.030	6.417	-0.016
Meiofauna	3.245	3.245	0.000	3.245	0.000
Orange sea pen	0.000	0.000	0.000	0.000	0.000
Brown algae	516.720	445.727	-70.993	432.745	-12.982
Native eelgrass	1.727	1.490	-0.237	1.363	-0.126
Non-native eelgrass	0.000	0.000	0.000	0.000	0.000
Marsh	11.768	10.419	-1.348	8.837	-1.582
Marine fish subtotal	*28.565*	*25.123*	*-3.442*	*21.739*	*-3.384*
Marine invertebrates subtotal	*9.298*	*9.325*	*0.027*	*9.208*	*-0.116*
Marine vegetation subtotal	*530.215*	*457.636*	*-72.578*	*442.945*	*-14.691*
Total	**568.078**	**492.084**	**-75.994**	**473.893**	**-18.191**

Notes:

- Temporal lag B refers to the time between project construction and construction of offsetting habitats that comprise the project's proposed offsetting plan (described in IR2020-1.1); conservatively assumed to be five years.
- Temporal lag C refers to the time between construction and functioning of offsetting habitats.
- Calculation of net offsetting productivity gains considered the creation of 50 ha of intertidal marsh (including 8.3 ha of habitat bank projects), 10 ha of native eelgrass, and 4 ha of subtidal rock reef, for a total of 64 ha of the 86 ha currently being advanced by the port authority.
- For intertidal marsh, temporal lag B was applied to 41.7 ha of the 50 ha considered in the calculation, as 8.3 ha of intertidal marsh included in the project's proposed offsetting plan are habitat bank projects that are already established and functioning.

6. Juvenile Chinook salmon habitat relative value

In their review of the draft **IR2020-1.2** response, and in reference to **IR2020-1.2**, Table IR2020-1.2-1, DFO requested to see a habitat balance table that includes all habitat types and their relative importance to juvenile salmon. This was requested as another line of evidence to support the productivity analysis and outcomes based on the updated RB model.

To respond to this, additional analysis and mapping (see **Figure IR2020-1.2-D1**) were conducted to determine the relative importance to juvenile Chinook salmon of all habitat types at Roberts Bank, including those that overlap with, and will be directly affected by the proposed project, and to demonstrate how the potential project effects to juvenile Chinook salmon habitat will be fully offset resulting in a net gain in juvenile salmon habitat. This additional analysis relied on the existing areal distribution of habitat types at Roberts Bank mapped using empirical information collected in 2019. The analysis here also incorporated preliminary areal extent of conventional offsetting habitats described in IR2020-1.1. The analysis did not consider, however, indirect productivity increases for marine vegetative habitat types forecasted by the updated RB model, because DFO's request was for an areal analysis.

Project placement is predicted to result in changes to physical environmental conditions behind the proposed marine terminal that will become quiescent and more conducive to growth of marine vegetation, such as intertidal marsh and native eelgrass. These indirect increases in the productivity of marine vegetation representative species or groups are described in **IR2020-1.2**, Part C. Because they are not accounted for in the analysis presented in this appendix, the results described below are considered conservative (as indicated earlier, inclusion of indirect productivity gains from project-related changes to environmental conditions behind the terminal would result in 18 times more fish and fish habitat productivity from RBT2, than lost by the proposed project footprint).

The **IR2020-1.2**, Table IR2020-1.2-1 was revised to include all habitat types at Roberts Bank that were mapped following empirical surveys undertaken in 2019 to update existing habitat conditions. Each habitat type was weighted using a ranking scale of 0–1.0 based on the relative importance of each habitat type to outmigrating juvenile Chinook salmon. Rankings were based on the use of habitat types by juvenile Chinook salmon documented during empirical surveys undertaken for the project in 2012 and 2013 (Archipelago 2014) and in other available literature. Rankings of habitat types at Roberts Bank and rationale are described below:

- Intertidal marsh provides high quality foraging and rearing habitat for juvenile Chinook salmon (Levy and Northcote 1981, 1982, Williams 2005, Archipelago 2014, Chalifour et al. 2019a,b, 2021). Within the Fraser River estuary, Chinook salmon catch by habitat type has been highest in brackish marsh habitats (Chalifour et al. 2019a). Marsh offers a less physiologically stressful and more sheltered habitat than the outer flats (Taylor 1990, Gregory and Levings 1998). As such, dense marsh habitat was ranked as high, or 1.0, and sparse marsh habitat as good, or 0.8.
- Juvenile Chinook salmon shift to more saline habitats, such as eelgrass and sand flats, as they grow larger in body size (Chalifour et al. 2020). Additionally, in studies conducted in 2016 and 2017, more juvenile Chinook salmon were caught in eelgrass than on sand flats (Chalifour et al. 2019b). Native eelgrass is a perennial marine plant and provides consistent refuge for the duration of juvenile Chinook salmon rearing at Roberts Bank, along with high quality foraging habitat. As such, dense native eelgrass was ranked as high, or 1.0, and sparse native eelgrass as good, or 0.8.
- Juvenile Chinook salmon will use shallow channel systems along the mud/sand flats as low tide refugia, with smaller fry using shore-tied beach habitats and larger juveniles slightly further offshore (Levings 1982). The intertidal mud/sand flats also provide connectivity between marine vegetative habitat types but do not provide as much refuge or foraging habitat to juvenile Chinook salmon (Williams 2005); they were ranked as fair, or 0.2.
- The importance of non-native eelgrass to rearing juvenile Chinook salmon has not been well documented. However, non-native eelgrass is an annual marine plant and, although it does have a small overwintering population, the majority of the refuge it provides will emerge in late spring to summer. Non-native eelgrass will contribute some seasonally available refuge, although not as stand-forming as native eelgrass, and foraging habitat later in the period of juvenile Chinook salmon rearing. For these reasons, dense non-native eelgrass was ranked as moderate, or 0.6, moderate density as intermediate, or 0.4, and sparse as fair, or 0.2.
- Macroalgal communities, including canopy-forming kelp species, attached on subtidal rock reef features have been shown in the literature to aggregate juvenile salmon prey and attract juvenile

salmon (Shaffer et al. 2020). At Roberts Bank, canopy-forming kelp likely provides some food and refuge opportunities to juvenile salmon individuals that outmigrate around existing marine terminal infrastructure and occupy offshore areas when the tidal flats at Roberts Bank are dry during ebb tides. For this reason, kelp was ranked as moderate, or 0.6.

- Open water offshore areas were ranked as poor, or 0.05. Juvenile salmon are pelagic and occupy open water offshore areas during ebb tides when the tidal flats are dry (e.g., Conlin et al. 1982, Macdonald 1984). Offshore distribution of juvenile salmon is wide-ranging along the Fraser River delta foreslope (and not restricted to the marine terminal footprint) where juvenile salmon form schools and seek refuge from predators within turbid waters influenced by the freshwater plume (Gregory 1993, Gregory and Levings 1998). When offshore, juvenile salmon, which are pelagic, do not associate with subtidal sand.
- Intertidal rocky habitats (i.e., rock/riprap or gravel/cobble) were ranked as 0. Rocky modifications of the shoreline can influence densities of fish, including juvenile salmon, when they extend into the upper intertidal zone (such as the causeway slope), but more prominently in shallow subtidal waters (such as along the existing Westshore Terminal) where shoreline modifications can result in deepening along and seaward of the shoreline (Toft et al. 2007). In proximity to riprap, and likely in response to predatory pressure from fish species that reside within or under riprap slopes, juvenile salmon have been documented to school from the middle of the water column to the surface, swim away, and not associate with rocky shorelines (Toft et al. 2007).

The ranking of each habitat type at Roberts Bank, along with rationale for the ranking, are summarized in **Table IR2020-1.2-D4**. The relative importance to juvenile Chinook salmon of each habitat type was weighted by multiplying the distribution of each habitat type at Roberts Bank with its ranking (described above and shown in **Table IR2020-1.2-D4**). The distribution of habitat types at Roberts Bank ranked based on their relative importance to juvenile Chinook salmon are shown on **Figure IR2020-1.2-D2**.

Weighting was undertaken by applying the rankings to both the amount of habitat directly affected by the proposed project footprint and the potential project footprint reduction of up to 14.4 ha (presented in IR2020-2.1). The resulting net change in juvenile Chinook salmon habitat was then calculated as the difference between the proposed offsetting described in IR2020-1.1 and project-related footprint loss of all habitat types (**Table IR2020-1.2-D5**).

As demonstrated on **Figure IR2020-1.2-D2**, implementation of avoidance and reduction measures (described in **IR2020-1.2**) substantially reduce direct footprint effects on more productive habitats in the intertidal zone, such as intertidal marsh and eelgrass, that provide food and refuge opportunities for juvenile salmon that rear at Roberts Bank. Notable avoidance and reduction measures that reduce effects on intertidal productive habitats include proposing placement of the marine terminal in predominantly subtidal waters (commitment #3, CIAR Document #2001[7]), including a breach to mitigate the effect of disruption to juvenile salmon migration, and designing the project such that the causeway widening has a reduced footprint (commitment #4, CIAR Document #2001). Moreover, the port authority has evaluated additional design measures, including the reduction of the proposed project footprint by up to 14.4 ha (see IR2020-2.1) and is currently advancing 86 ha of offsetting as part of the project's offsetting plan (see IR2020-1.1).

When the relative importance to juvenile Chinook salmon (as ranked in **Table IR2020-1.2-D4**) of all habitat types at Roberts Bank is considered, the current project footprint overlaps with, and will result in, the permanent loss of 28.14 ha of juvenile Chinook salmon habitat (i.e., intertidal marsh: 11.19 ha; native eelgrass: 4.35 ha; non-native eelgrass: 5.77 ha; native/non-native eelgrass: <0.01 ha; kelp: 0.02 ha; mud/sand flat/offshore: 6.80 ha; **Table IR2020-1.2-D5** and **Figure IR2020-1.2-D2**). Also, based on relative rankings, the potential project footprint reduction of up to 14.4 ha will avoid the direct loss of

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[7] CIAR Document #2001 From the Vancouver Fraser Port Authority to the Review Panel re: Updated Project Commitments (See Reference Documents #1738 and #1934). https://iaac-aeic.gc.ca/050/documents/p80054/130776E.pdf

3.19 ha of juvenile Chinook salmon habitat (i.e., intertidal marsh: 1.25 ha; native eelgrass: 0.63 ha; non-native eelgrass: 0.79 ha; native/non-native eelgrass: <0.01 ha; mud/sand flat/offshore: 0.51 ha; **Table IR2020-1.2-D5**).

With mitigation, including the proposed offsetting measures of 64 ha considered in the analysis presented in **IR2020-1.2** (i.e., 50.0 ha of intertidal marsh, 10.0 ha of native eelgrass, 4.0 ha of subtidal rock reef), the project will result in a net increase in juvenile Chinook salmon habitat by 37.45 ha, when relative rankings are considered (i.e., intertidal marsh: 40.06 ha; native eelgrass: 6.27 ha, non-native eelgrass: -4.98 ha; kelp: 2.38 ha; mud/sand flat/offshore: -6.29 ha; **Table IR2020-1.2-D5** and **Figure IR2020-1.2-D2**).

In summary, this analysis reconfirms prior findings that with avoidance, reduction, and offsetting measures, the project will result in a net gain in juvenile Chinook salmon habitat. This net gain in juvenile Chinook salmon habitat is conservative as an additional 22 ha of offsetting currently being advanced by the port authority as part of the project's offsetting plan are not included in the habitat calculations presented in this appendix. Moreover, as described above, the findings of this additional analysis do not account for indirect gains forecasted by the updated RB model in the productivity of marine vegetation representative species or groups, which will be in addition to net increases in juvenile Chinook salmon habitat presented in this appendix.

Table IR2020-1.2-D4: Habitat types at Roberts Bank, habitat ranking for relative importance to juvenile Chinook salmon, and rationale for ranking

Habitat type	Habitat ranking		Rationale
Dense high marsh	High	1.0	High quality foraging and rearing habitat, optimal salinity
Dense low marsh	High	1.0	High quality foraging and rearing habitat, optimal salinity
Dense native eelgrass	High	1.0	High quality foraging and rearing habitat, optimal salinity
Native/non-native eelgrass	Good	0.8	Mix of year-round and seasonal habitat providing refuge and foraging opportunities during periods of juvenile Chinook salmon rearing
Sparse native eelgrass	Good	0.8	Year-round but sparse habitat providing refuge and foraging opportunities during periods of juvenile Chinook salmon rearing
Sparse high marsh	Good	0.8	Sparse refuge and foraging habitat, optimal salinity
Sparse low marsh	Good	0.8	Sparse refuge and foraging habitat, optimal salinity
Dense non-native eelgrass	Moderate	0.6	Seasonally available refuge and foraging habitat during periods of juvenile Chinook salmon rearing
Kelp	Moderate	0.6	Seasonally available subtidal habitat during migration and offshore rearing
Non-native eelgrass of moderate density	Intermediate	0.4	Seasonally available refuge habitat
Sparse non-native eelgrass	Fair	0.2	Seasonally available sparse refuge habitat
Green film	Fair	0.2	Limited cover and prey productivity
Mud/sand (intertidal)	Fair	0.2	Connectivity of low tide refugia tidal channels and high-quality foraging and rearing habitat, such as marsh and eelgrass
Mud/sand/offshore (subtidal)	Poor	0.05	Juvenile salmon are pelagic schooling at or near the surface, no association with subtidal sandy substrates
Rock (riprap)	None	0.0	Intertidal: limited productivity, foraging or refuge; subtidal: habitat not used
Gravel/cobble	None	0.0	Intertidal: limited productivity, foraging or refuge; subtidal: subtidal benthic habitat not used

Note: Habitat types are based on the 2019 RBT2 habitat map.

Table IR2020-1.2-D5: Net increase in area (hectares; ha) of habitats at Roberts Bank with mitigation, including avoidance, reduction, and offsetting measures, based on rankings of relative importance to juvenile Chinook salmon

Juvenile Chinook salmon habitat	Tidal zone	Overlap with current project footprint with avoidance measures (ha)	Ranking (Table IR2020-1.2-D4)	Weighted overlap with current project footprint with avoidance measures (ha)	Avoided habitat loss with potential additional footprint reduction (ha; IR2020-2.1)	Weighted avoided habitat loss with potential additional footprint reduction (ha)	Offsetting (ha; IR2020-1.1)	Net habitat increase (ha)	Weighted net habitat increase (ha)
Dense high marsh	Intertidal	-1.20	1.0	-1.20	0.04	0.04	50		
Sparse high marsh	Intertidal	-0.20	0.8	-0.16	0.00	0.00			
Dense low marsh	Intertidal	-2.39	1.0	-2.39	0.14	0.14			
Sparse low marsh	Intertidal	-9.30	0.8	-7.44	1.35	1.08			
Subtotal		***-13.09***		***-11.19***	***1.52***	***1.25***	***50***	***38.43***	***40.06***
Dense native eelgrass	Intertidal	-2.47	1.0	-2.47	0.00	0.00	10		
Dense native eelgrass	Subtidal	-0.59	1.0	-0.59	0.24	0.24			
Sparse native eelgrass	Intertidal	-1.55	0.8	-1.24	0.48	0.39			
Sparse native eelgrass	Subtidal	-0.07	0.8	-0.05	0.01	0.01			
Subtotal		***-4.68***		***-4.35***	***0.73***	***0.63***	***10***	***6.05***	***6.27***
Dense non-native eelgrass	Intertidal	-4.17	0.6	-2.50	0.77	0.46	0	-3.40	-2.04
Sparse non-native eelgrass	Intertidal	-16.35	0.2	-3.27	1.65	0.33		-14.70	-2.94
Subtotal		***-20.52***		***-5.77***	***2.42***	***0.79***	***0***	***-18.09***	***-4.98***
Native/non-native eelgrass	Intertidal	-<0.01	0.8	-<0.01	<0.01	0.00	0	0.00	0.00
Subtotal		***-<0.01***		***-<0.01***	***<0.01***	***0.00***	***0***	***0.00***	***0.00***

Juvenile Chinook salmon habitat	Tidal zone	Overlap with current project footprint with avoidance measures (ha)	Ranking (Table IR2020-1.2-D4)	Weighted overlap with current project footprint with avoidance measures (ha)	Avoided habitat loss with potential additional footprint reduction (ha; IR2020-2.1)	Weighted avoided habitat loss with potential additional footprint reduction (ha)	Offsetting (ha; IR2020-1.1)	Net habitat increase (ha)	Weighted net habitat increase (ha)
Kelp	Intertidal	-0.01	0.6	-0.01	0.00	0.00	4	-0.02	-0.01
Kelp	Subtidal	-0.02	0.6	-0.01	0.01	0.00		3.99	2.39
Subtotal		***-0.03***		***-0.02***	***0.00***	***0.00***	***4***	***3.97***	***2.38***
Mud/sand	Intertidal	-2.63	0.2	-0.53	0.19	0.04	0	-2.43	-0.49
Mud/sand/offshore	Subtidal	-125.59	0.05	-6.28	9.50	0.47		-116.10	-5.80
Subtotal		***-128.22***		***-6.80***	***9.69***	***0.51***	***0***	***-118.53***	***-6.29***
Gravel/cobble	Intertidal	-5.87	0.0	0.00	0.00	0.00	0	-5.87	0.00
Subtotal		***-5.87***		***0.00***	***0.00***	***0.00***	***0***	***-5.87***	***0.00***
Rock	Intertidal	-2.20	0.0	0.00	0.02	0.00	0	-2.18	0.00
Rock	Subtidal	-0.01	0.0	0.00	0.02	0.00		0.01	0.00
Subtotal		***-2.21***		***0.00***	***0.04***	***0.00***	***0***	***-2.17***	***0.00***
TOTAL		**-174.61**		**-28.14**	**14.40**	**3.19**	**64**	**-96.21**	**37.45**

Note: Habitat types are based on the 2019 RBT2 habitat map.

Conclusion

At the request of DFO, the port authority undertook i) additional technical analyses to account for uncertainty in the updated RB model and temporal lags; and ii) alternate equivalency approach to consider the relative importance to juvenile Chinook salmon of all habitat types in the biophysical LAA to provide another line of evidence to support the findings of the productivity approach and further evaluate the degree to which proposed offsetting addresses potential effects to juvenile Chinook salmon habitat.

Results of these new analyses, and the additional equivalency approach, confirm the findings presented in earlier draft offsetting plan materials that the proposed RBT2 offsetting plan fully mitigates effects of the project on juvenile Chinook salmon, and fish and fish habitat, and in fact will result in net gains. The confidence of this finding is supported by two lines of independent analysis.

Firstly, the productivity approach, with additional uncertainty analyses factored in, estimates that a total of 64 ha of offsetting is required to offset the effects of the project. Secondly, the results of the juvenile Chinook salmon relative habitat values analysis also support this conclusion which estimates a net gain of 37.45 ha.

Further, the port is developing an additional 22 ha of habitat than is required to offset the effects of the project so that with the project in place there will be both a net gain in juvenile salmon productivity and higher quality juvenile salmon habitat.

The results of these analyses are not surprising and make intuitive sense given the majority of the project footprint was deliberately placed in deeper subtidal less productive habitat away from sensitive higher productive juvenile salmon habitats. This was a key avoidance measure decision by the port authority, which is reflected in the predicted amount of offsetting required to offset the effects of the project.

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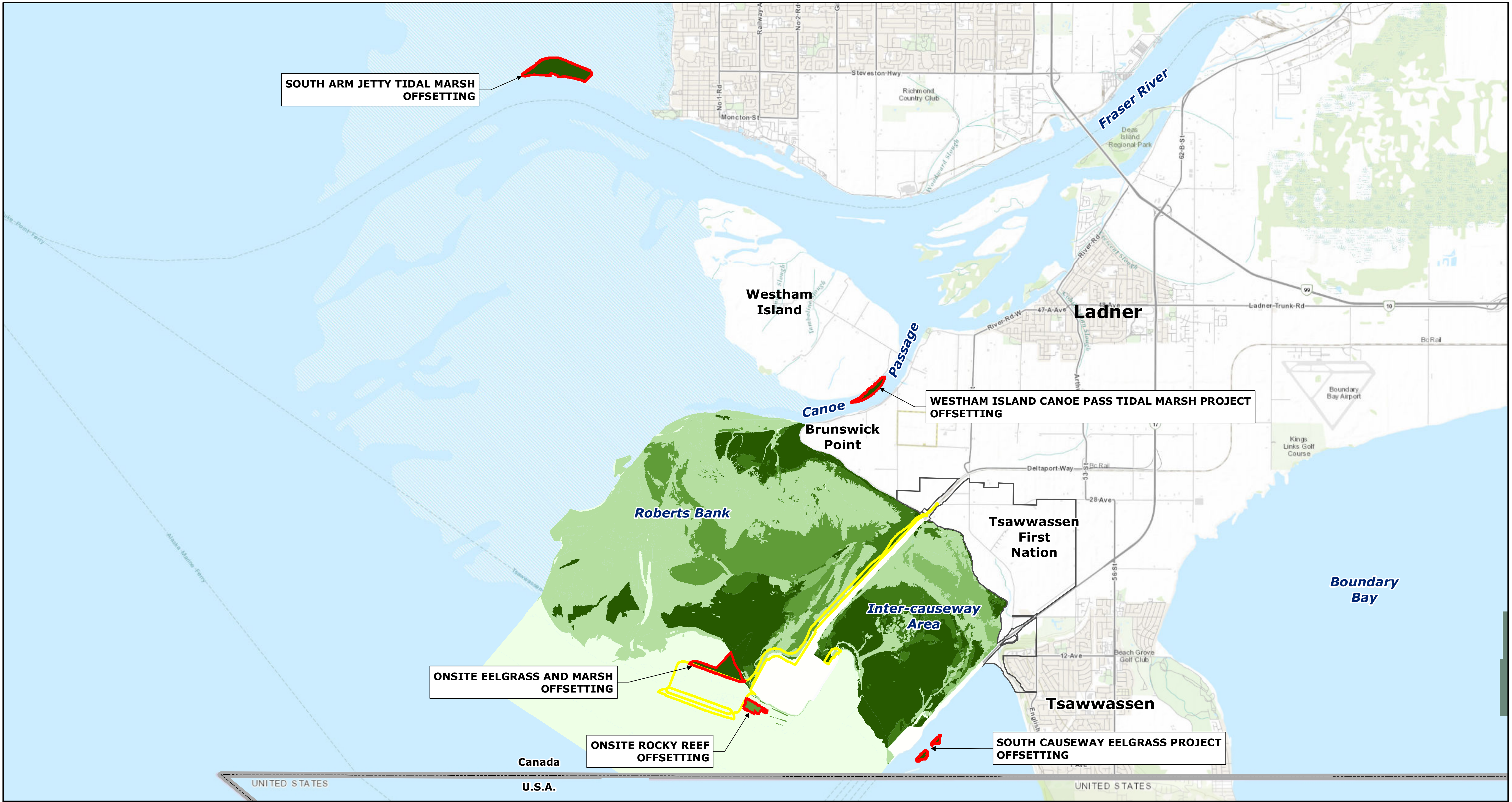
Figure IR2020-1.2-D2 Distribution of habitats at Roberts Bank based on the 2019 RBT2 habitat map and rankings of relative importance to juvenile Chinook salmon

Path: S:\Geomatics\Projects\102738\10\Juvenile_Salmon_Monitoring\mxd\DFO_Habitat\Fig3__102738_10_JS_Offsetting_210714.mxd



Legend

- 🟨 BOUNDARY OF PROJECT AREA
- 🟥 HABITAT OFFSETTING AREA
- ---- U.S.A.-CANADA BORDER

RELATIVE RANKING

🟩	HIGH	🟩	INTERMEDIATE
🟩	GOOD	🟩	FAIR
🟩	MODERATE	⬜	POOR

0 1 2
Kilometres
1:75,000
NAD 1983 UTM Zone 10N

N

PORT of vancouver

ROBERTS BANK TERMINAL 2

RELATIVE VALUE OF JUVENILE CHINOOK SALMON HABITAT WITH THE PROJECT AND OFFSETTING

DATE:	FIG No.
14/07/2021	IR2020-1.2-D2

Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Appendix IR2020-1.2-E

Avoidance, reduction, and offsetting measures considered in the analysis of project effects on juvenile Chinook salmon, fish and fish habitat, in support of the proposed RBT2 offsetting plan

Table IR2020-1.2-E1: Summary of avoidance, reduction, and offsetting measures that are described in the updated project commitments (CIAR Document #2001) or have been proposed after the public hearing (new) and are considered in IR2020-1.2 analysis of project effects on juvenile Chinook salmon, fish and fish habitat, in support of the proposed offsetting plan for the Roberts Bank Terminal 2 Project

#	Source	Mitigation measure short title	Mitigation measure description
Avoidance measures			
1	CIAR Document #2001	Placement of the marine terminal in subtidal waters	Proposing placement of the marine terminal in predominantly subtidal waters (commitment #3), thereby avoiding direct footprint effects on more productive habitats in the intertidal zone, such as intertidal marsh and eelgrass, that provide food and refuge opportunities for juvenile salmon that rear at Roberts Bank. Placement of the marine terminal in predominantly subtidal waters is also predicted to indirectly increase juvenile salmon productivity due to environmental and physical changes behind the proposed terminal (see Part (b) in this response).
2	CIAR Document #2001	Tug basin expansion re-design	Redesigning the footprint of the tug basin (commitment #3) to promote drainage during tidal exchanges and maintain good water quality in this localized area of the inter-causeway area, thereby reducing potential effects on the adjacent native eelgrass bed.
3	CIAR Document #2001	Widened causeway re-design	Designing the project such that the causeway widening has a reduced footprint (commitment #4), to reduce overlap with habitat in the high intertidal zone, including intertidal marsh, that contributes to the productivity of juvenile salmon.
4	New, IR2020-2.1	Potential additional project footprint reduction	Reducing the size of the marine terminal and of the widened causeway to further reduce project-related effects to productive juvenile salmon habitat in the intertidal zone. This has resulted in a further reduction to juvenile salmon habitat by 1.5 ha (see **IR2020-2.1**).
5	CIAR Document #2001	Containment dyke construction measures	Designing and constructing the project to reduce the effects of tidal channel formation from dyke construction (commitment #5), thereby reducing the risk of potential encroachment and erosion within eelgrass habitat in the low intertidal and shallow subtidal zones that provides rearing opportunities to juvenile salmon.
6	CIAR Document #2001	Rounded northwest corner of marine terminal	Designing the terminal with a rounded northwest corner to reduce the potential for seabed scour and associated sediment deposition post-project construction (commitment #6), thereby reducing the risk for sediment deposition and smothering of nearby eelgrass habitat important to juvenile salmon.
Reduction measures			
7	New, IR2020-2.2	Potential breaching mitigation	Implementing a breach for fish passage, which will mitigate the potential for disruption of juvenile Chinook salmon migration.
8	CIAR Document #2001	Removal of the ITP	Constructing the project without the use of the intermediate transfer pit (ITP) for sand storage in the marine environment (commitment #10), thereby reducing potential effects on fish (including juvenile salmon) and fish habitat through physical disturbance or changes in water quality during temporary storing of sediment at the ITP and sediment reclaiming for project infilling.
9	CIAR Document #2001	Marine Species Management Plan (timing windows)	Throughout project construction, scheduling in-water works below –5 metres chart datum (m CD) outside of the fisheries sensitive window for Dungeness crab (i.e., outside of the time period between October 15 and March 31), unless agreed to by Fisheries and Oceans Canada (DFO) (commitment #49) and above –5 m CD outside of the fisheries sensitive window for juvenile salmon (i.e., outside of the time period between March 1 and August 15), unless agreed to by DFO (commitment #53), as described in the project's Marine Species Management Plan (commitment #34) that will form part of the project's Construction Environmental Management Plan.
10	CIAR Document #2001	Marine Species Management Plan (salvage)	Prior to the start of construction, developing a Marine Species Management Plan (commitment #34) as part of the project's Construction Environmental Management Plan, to be implemented during project construction, that will outline the standard processes and procedures to salvage and relocate marine species. This plan will also describe the process and procedures for the Orange Sea Pen Transplant Program, as well as crab salvage mitigation (commitment #51). This reduction measure does not relate directly to juvenile salmon but reduces effects to fish and fish habitat, as orange sea pens are considered fish, according to the *Fisheries Act*.
11	CIAR Document #2001	Underwater Noise Management Plan	Prior to the start of construction, developing an Underwater Noise Management Plan (commitment #37) as part of the project's Construction Environmental Management Plan to be implemented during project construction and to reduce the risk of injury to marine fish, including juvenile Chinook salmon, from impact pile driving during project construction.
12	CIAR Document #2001	Light Management Plans	Prior to the start of construction, developing Light Management Plans (commitment #24) as part of the project's Construction and Operational Environmental Management Plans to be implemented during project construction and operation (commitment #24). The Light Management Plans will provide for measures to reduce excess artificial lighting from the project, including directing light away from the marine environment and limiting use of lights to active work areas. These mitigation measures are intended to reduce the potential for adverse effects to juvenile salmon from project-related changes in the light environment, including the potential for disruption to juvenile salmon migration.
13	New, IR2020-2.2	Additional operational lighting mitigation	Proposing to update the mitigation included in the Light Management Plan for project operation to emphasize reducing the potential for effects to the marine environment, including migrating juvenile salmon. Also, proposing to update the Light Trespass and Sky Glow Effects Predictions and Mitigation Effectiveness follow-up program element to expand monitoring in the marine environment to verify effectiveness of project infrastructure lighting mitigation.

#	Source	Mitigation measure short title	Mitigation measure description
14	New, IR2020-2.2, IR2020-3	Additional operational mitigation for underwater noise	Identifying and evaluating operational mitigation measures to reduce the potential for effects to southern resident killer whales from underwater noise during project operation. Further reduction to underwater noise levels in the marine environment near the proposed terminal will also be generally beneficial to all marine species, including juvenile salmon. Measures to reduce underwater noise during project operation that could benefit juvenile salmon at Roberts Bank are summarized in IR2020-2.2 and described in greater detail in IR2020-3.
15	New, IR2020-2.2	Timing of maintenance dredging at the expanded tug basin	Undertaking maintenance dredging at the expanded tug basin (below –5 m CD), should it be required, outside of the juvenile salmon fisheries-sensitive window (i.e., outside of the time period between March 1 and August 15). Implementation of this additional measure would avoid interaction with, and potential adverse effects from associated increases in light and underwater noise, to juvenile salmon that rear in the inter-causeway area in spring and summer.
Offsetting measures			
16	New, IR2020-1.1	Offsetting projects to restore and enhance up to 86 ha of fish habitat (see list of offsetting projects and opportunities below)	See detailed descriptions of offsetting project listed below.
16	New, IR2020-1.1	Habitat bank projects (Glenrose Tidal Marsh Project, Gladstone Park Tidal Marsh Project, Riverfront Park Tidal Marsh Project, and Timberland Basin Habitat Project)	The Glenrose Tidal Marsh Project, Gladstone Park Tidal Marsh Project, Riverfront Park Tidal Marsh Project, and Timberland Basin Habitat Project in the port authority's habitat bank involved the creation of intertidal marsh habitat, an important habitat type for juvenile salmon. Juvenile salmon, such as ocean-type Chinook salmon of the Harrison River and South Thompson River and chum salmon, use marsh habitats as they outmigrate from the lower Fraser River, through the Fraser River estuary, and into the marine environment, while acclimatizing to increasing salinity (e.g., Levy and Northcote 1982, Levings 2016, Chalifour et al. 2019)
16	New, IR2020-1.1	Habitat bank projects (Salt Marsh Restoration Projects)	The Salt Marsh Restoration Projects in the port authority's habitat bank involved the restoration of intertidal marsh habitat through removal of accumulated logs, the benefits of which to juvenile salmon are described above. Two of these projects are located on Tsawwassen First Nation (TFN) lands, and restoration work was undertaken by TFN's Joint Venture partnership and TFN will play a role in both the monitoring and stewardship of the sites – expanding the benefits of these projects
16	New, IR2020-1.1	Onsite offsetting (intertidal marsh, native eelgrass, subtidal rock reef)	Optimized onsite offsetting currently being advanced includes the creation of intertidal marsh and subtidal native eelgrass habitat. In addition to the benefits of intertidal marsh habitat to juvenile salmon, are described above. Native eelgrass habitat provides important rearing opportunities to juvenile Chinook salmon that have adapted physiologically to higher salinities and are capable of transitioning to rearing habitats such as native eelgrass away from the river mouth, including north and south of the Roberts Bank causeway (e.g., MacDonald 1984, Bottom et al. 2005, Chalifour et al. 2019). Constructing intertidal marsh and native eelgrass habitats will therefore increase survival and growth of juvenile salmon and recruitment success to the parent stock. The importance of intertidal marsh and native eelgrass to priority species and life stages like juvenile salmon has been noted by Indigenous groups, including TFN, Musqueam Indian Band (Musqueam), Semiahmoo First Nation, T'suubaa-asatx First Nation, Malahat Nation, Cowichan Nation Alliance, and Tseycum First Nation, as well as organizations such as the Lower Fraser Fisheries Alliance.
16	New, IR2020-1.1	Offsite offsetting (South Arm Jetty Tidal Marsh Project)	The South Arm Jetty Tidal Marsh Project involves the creation of intertidal marsh habitat. Along with the marsh benefits to juvenile salmon mentioned above, the network of tidal channels proposed as part of this offsetting project will provide accessible fish habitat over an even longer part of the tidal cycle and increase habitat complexity. In turn, this will increase rearing opportunities for juvenile salmon outmigrating from the Fraser River. Synergistic features such as removal of piles, logs, and other debris, as suggested by Indigenous groups will also be integrated, as appropriate, to further increase the value of this project to juvenile salmon and other fish
16	New, IR2020-1.1	Offsite offsetting (South Causeway Eelgrass Project)	The South Causeway Eelgrass Project involves the creation of subtidal native eelgrass habitat. The habitat structure and complexity provided by eelgrass beds attracts diverse assemblages of marine invertebrates, including important prey for juvenile salmon (e.g., MacDonald 1984, Bottom et al. 2005, Knight et al. 2015, Kennedy et al. 2018), and offers refuge for fish species, including outmigrating juvenile salmon (e.g., Levings 2016). Eelgrass also supports species of cultural importance and priority to Indigenous groups (in particular, Pacific salmon species like Chinook and chum, and Dungeness crab), and so is an important part of the offsetting plan
16	New, IR2020-1.1	Offsite offsetting (Westham Island Canoe Pass Tidal Marsh Project)	The Westham Island Canoe Pass Tidal Marsh Project involves converting lower-value intertidal sand flat into an expanded high-value brackish intertidal marsh habitat to benefit a broad range of fish and wildlife species and life stages (including juvenile Pacific salmon such as estuarine-rearing Chinook salmon) and to provide a variety of ecological functions and services. This offsetting project is also expected to involve the restoration of intertidal marsh through the removal of accumulations of historically-deposited anthropogenic logs (i.e., saw-cut logs from the forestry sector), which would increase marsh productivity by reversing vegetation smothering and soil compaction, reducing the risk of toxic chemical leaching from creosote-treated logs (if present), and preventing the clogging of tidal channels, all of which will benefit out-migrating juvenile salmon. This project will address concerns raised by Indigenous groups, such as TFN, Musqueam, Tsleil-Waututh Nation, Semiahmoo First Nation, T'suubaa-asatx First Nation, and Malahat Nation, who have noted concerns with potential chemical leaching (creosote) from accumulated logs. Numerous groups have expressed support for efforts to address log accumulation. Canoe Pass is considered a prime location for estuarine-rearing juvenile salmon to forage and acclimatize to increasing salinity (particularly Chinook and chum), hence offsetting here is anticipated to directly benefit juvenile salmon.

#	Source	Mitigation measure short title	Mitigation measure description
16	New, IR2020-1.1	Offsite offsetting (Tilbury Island Peninsula Enhancement Project)	The Tilbury Island Peninsula Enhancement Project includes the creation of intertidal marsh habitat and creation of interconnected off-channel habitat, both of which benefit juvenile salmon rearing and are relatively lacking in this part of the lower Fraser River. This offsetting project is considered to align with Musqueam's vision of creating a mosaic of habitat enhancement throughout the Fraser River estuary—to contribute to a "ladder" of increased feeding, rearing, and refuge opportunities for a range of priority species and life stages, including juvenile salmon. Musqueam has emphasized the importance of intertidal marsh for juvenile salmon and highlighted that this offsetting project will help restore an important link in the juvenile salmon rearing network in this area of the Fraser River. TFN has also expressed priority interest in the project, noting the effects of ongoing industrial developments at Tilbury Island on fish and wildlife habitat.
16	New, IR2020-1.1	Offsite offsetting (Finn Slough Enhancement Project)	The Finn Slough Enhancement Project involves the restoration of intertidal marsh habitat through removal of accumulated logs, and the enhancement of tidal channel habitat and access through the reconnection of a slough channel. The location of this offsetting project in the south arm of the Fraser River is considered an ecologically important area for juvenile salmon, including by Musqueam, who brought this offsetting opportunity forward.
16	New, IR2020-1.1	Offsite offsetting (Semiahmoo Bay-Little Campbell River Enhancement Project)	The Semiahmoo Bay-Little Campbell River Enhancement Project, identified by Semiahmoo First Nation, includes the creation of intertidal marsh and the removal of creosote-treated wood, the benefits of which for juvenile salmon are described above. Additionally, this offsetting project involves the implementation of large woody debris complexes to encourage the formation of pool habitat, and provide cover and holding areas, for migratory fish like juvenile salmon, increasing the value of this project.
16	New, IR2020-1.1	Other available offsetting opportunities and potential contingency measures and projects	Other available offsetting opportunities have been identified, including the Tsawwassen Marshlands Project brought forward by Tsawwassen First Nation, a complementary measure to investigate the causes of local marsh recession (as also identified by TFN), and the Non-Conventional Offsetting Program (NCOP) (see below). The NCOP could deliver projects that provide the best conservation and enhancement outcomes for priority species (e.g., Chinook salmon) and other species such as bivalves and herring. Potential contingency projects are available should proposed offsetting projects not perform as intended. The port authority has identified two potential contingency projects, which are close to the proposed project. Offsetting projects delivered through an operational (i.e., established) NCOP could also be considered potential contingency projects. The next most technically well-developed, suitable and available projects from the port authority's Habitat Enhancement Program could also be considered suitable offsite offsetting contingency, and would likely involve the restoration, enhancement, or creation of intertidal marsh habitat.
16	New, IR2020-1.1	Proposed development of a Non-Conventional Offsetting Program (NCOP)	The NCOP is an innovative program proposed by the port authority to deliver projects that benefit fish and fish habitat. It is intended that the NCOP focus on projects that deliver the best conservation and enhancement outcomes for priority species and habitats, by addressing limiting factors, bottlenecks, and emerging needs. The port authority will continue to develop the NCOP, and projects delivered through an operational NCOP could provide additional RBT2 offsetting contingency projects, should they be needed.

Notes: CIAR Document #2001 From the Vancouver Fraser Port Authority to the Review Panel re: Updated Project Commitments (See Reference Documents #1738 and #1934). https://iaac-aeic.gc.ca/050/documents/p80054/130776E.pdf

– number of mitigation measures corresponds to numbered list as presented in **IR2020-1.2**, Table IR2020-1.2-1

Table IR2020-1.2-E2: Avoidance, reduction and offsetting measures that influence productivity of juvenile Chinook salmon habitat considered in IR2020-1.2 analysis in support of the proposed offsetting plan for the Roberts Bank Terminal 2 Project

#	Mitigation measure	Description	Analysis of project effects
			Juvenile Chinook salmon habitat
			Productivity
Avoidance measures			
1	Placement of the marine terminal in subtidal waters	Project design-related avoidance measures, including measures 1, 3, 5, and 6, are incorporated in the current project footprint which was used as input into the updated RB model. The updated RB model was used to forecast direct and indirect productivity increases in fish and fish habitat with the project. Forecasted increases in fish and fish habitat productivity are attributed to quiescent conditions that are predicted to establish behind the proposed marine terminal and will become conducive to growth of marine vegetation (such as intertidal marsh and native eelgrass) and will favour population expansion and increase in the productivity of infaunal macroinvertebrate communities. These productivity increases in lower trophic levels organisms are forecasted to cascade to higher trophic level organisms (e.g., fish) through predator-prey interactions in the food web of the Roberts Bank ecosystem. Technical information on the updated RB model is provided in **Appendix IR2020-1.2-A**. In response to DFO input, forecasts of the updated RB model were discounted to account for uncertainty in the model outputs and for time that may be required for forecasted productivity increases to be realized (temporal lag A; see **Appendix IR2020-1.2-D**).	✓
2	Tug basin expansion re-design	The tug basin expansion footprint has been re-designed to reduce effects on fish and fish habitat (by promoting drainage during tidal exchanges and maintaining good water quality in this localized area of the inter-causeway area). Technical information on the calculation of losses in productivity of fish habitat associated with construction for the expansion of the tug basin is provided in **Appendix IR2020-1.2-B**.	✓
3	Widened causeway re-design	See description for #1 above.	✓
4 (new)	Potential additional project footprint reduction	The port authority has evaluated additional project design options to further reduce effects on juvenile Chinook salmon habitat (described in **IR2020-2.1**). A potential reduction of the current project footprint by up to 14.4 ha (Measure 4 in Part (a) of the response) will avoid the loss of combined intertidal marsh and native eelgrass productivity of approximately 0.001 t per year (see **Appendix IR2020-2.1-A**, Table 4-1). Such potential reduction in direct loss of juvenile Chinook salmon habitat productivity is small relative to productivity increases forecasted by the updated RB model. Hence, benefits to the productivity of intertidal marsh and native eelgrass associated with a potential additional reduction in the current project footprint are not considered in the overall productivity calculations for juvenile Chinook salmon habitat, which are thus considered conservative.	●
5	Containment dyke construction measures	Measures proposed to avoid effects relating to potential tidal channel formation, as a result of dyke construction, will reduce the risk that such channels may affect the productivity of juvenile Chinook salmon habitat. However, it is not possible to predict or quantify the extent of this hypothetical construction effect and data on the amount of juvenile Chinook salmon habitat that will be protected by this avoidance measure is not available.	●
6	Rounded northwest corner of marine terminal	See description for #1 above.	✓
Reduction measures			
7 (new)	Potential breaching mitigation	Potential breaching mitigation of any kind is not considered in the calculation of net change in the productivity of juvenile Chinook salmon habitat shown in **Table IR2020-1.2-3**. As described earlier (and in **IR2020-2.2**), a breach at the marine terminal location is not predicted to adversely affect juvenile Chinook salmon habitat. However, a potential risk was identified for a minor adverse effect on juvenile Chinook salmon habitat productivity for all three causeway breach location options due to tidal channel formation. Should a breach be implemented at the causeway, there is potential for a reduction in the net productivity increase in juvenile Chinook salmon habitat shown in **Table IR2020-1.2-3**. However, the potential magnitude of the effect is uncertain and cannot be quantified due to the inherent uncertainty in the extent of tidal channel formation from a causeway breach and it was not considered in the calculations shown in **Table IR2020-1.2-3**.	●
8	Removal of the intermediate transfer pit (ITP)	Constructing the project without the use of the ITP will avoid potential losses in productivity of juvenile Chinook salmon habitat in the inter-causeway area through physical disturbance or changes in water quality.	●
9	Marine Species Management Plan (timing windows)	Prior to the start of construction, developing a Marine Species Management Plan (commitment #34) as part of the project's Construction Environmental Management Plan, to be implemented during project construction, that will outline the standard processes and procedures to salvage and relocate marine species. This plan will also describe the process and procedures for the Orange Sea Pen Transplant Program, as well as crab salvage mitigation (commitment #51). This reduction measure does not relate directly to juvenile salmon but reduces effects to fish and fish habitat, as orange sea pens are considered fish, according to the *Fisheries Act.*	×
10	Marine Species Management Plan (salvage)	Throughout project construction, scheduling in-water works below –5 metres chart datum (m CD) outside of the fisheries sensitive window for Dungeness crab (i.e., outside of the time period between October 15 and March 31), unless agreed to by Fisheries and Oceans Canada (DFO) (commitment #49) and above –5 m CD outside of the fisheries sensitive window for juvenile salmon (i.e., outside of the time period between March 1 and August 15), unless agreed to by DFO (commitment #53), as described in the project's Marine Species Management Plan (commitment #34) that will form part of the project's Construction Environmental Management Plan.	×

#	Mitigation measure	Description	Analysis of project effects
			Juvenile Chinook salmon habitat
			Productivity
11	Underwater Noise Management Plan	Prior to the start of construction, developing an Underwater Noise Management Plan (commitment #37) as part of the project's Construction Environmental Management Plan to be implemented during project construction and to reduce the risk of injury to marine fish, including juvenile Chinook salmon, from impact pile driving during project construction.	×
12	Light Management Plans	Prior to the start of construction, developing Light Management Plans (commitment #24) as part of the project's Construction and Operational Environmental Management Plans to be implemented during project construction and operation (commitment #24). The Light Management Plans will provide for measures to reduce excess artificial lighting from the project, including directing light away from the marine environment and limiting use of lights to active work areas. These mitigation measures are intended to reduce the potential for adverse effects to juvenile salmon from project-related changes in the light environment, including the potential for disruption to juvenile salmon migration.	×
13 (new)	Additional operational lighting mitigation	Proposing to update the mitigation included in the Light Management Plan for project operation to emphasize reducing the potential for effects to the marine environment, including migrating juvenile salmon. Also, proposing to update the Light Trespass and Sky Glow Effects Predictions and Mitigation Effectiveness follow-up program element to expand monitoring in the marine environment to verify effectiveness of project infrastructure lighting mitigation.	×
14 (new)	Additional operational mitigation for underwater noise	Identifying and evaluating operational mitigation measures to reduce the potential for effects to southern resident killer whales from underwater noise during project operation. Further reduction to underwater noise levels in the marine environment near the proposed terminal will also be generally beneficial to all marine species, including juvenile salmon. Measures to reduce underwater noise during project operation that could benefit juvenile salmon at Roberts Bank are summarized in IR2020-2.2 and described in greater detail in IR2020-3.	×
15 (new)	Timing of maintenance dredging at the expanded tug basin	Undertaking maintenance dredging at the expanded tug basin (below –5 m CD), should it be required, outside of the juvenile salmon fisheries-sensitive window (i.e., outside of the time period between March 1 and August 15). Implementation of this additional measure would avoid interaction with, and potential adverse effects from associated increases in light and underwater noise, to juvenile salmon that rear in the inter-causeway area in spring and summer.	×
Offsetting measures			
16 (new)	Offsetting projects to restore and enhance up to 86 ha of fish habitat	Analysis of net gain in productivity of habitat used by juvenile Chinook salmon considered 64 ha of the 86 ha currently being advanced by the port authority. Additional gains in fish habitat productivity will be realized with the implementation of the additional 22 ha not included in the analysis.	✓

Notes:

– number of mitigation measures corresponds to numbered list as presented in **IR2020-1.2**, Table IR2020-1.2-1
✓ – considered quantitatively in the analysis
● – considered qualitatively in the analysis (empirical data not available)
× – does not apply to juvenile Chinook salmon habitat as no interaction with RBT2 and no pathway of effect has been identified in the EIS; measure is directly relevant to and has been considered in the analysis for juvenile Chinook salmon

Table IR2020-1.2-E3: Avoidance, reduction and offsetting measures that influence area of juvenile Chinook salmon habitat considered in IR2020-1.2 analysis in support of the proposed offsetting plan for the Roberts Bank Terminal 2 Project

#	Mitigation measure	Description	Analysis of project effects
			Juvenile Chinook salmon habitat
			Area
Avoidance measures			
1	Placement of the marine terminal in subtidal waters	The project footprint (defined in the project construction update (CIAR Document #1210 and referred to herein as the current project footprint) overlaps with fish habitat. This direct footprint effect on habitat used by juvenile Chinook salmon was calculated by overlaying the current project footprint on the 2019 Roberts Bank habitat map developed following surveys undertaken for the project in 2019 (**Appendix IR2020-1.2-A**, Figure 2-1). This effect calculation considers that approximately 72%[1] of the project footprint is proposed to be constructed in subtidal waters. Other avoidance measures integrated in the current project footprint include measures 2, 3, and 6.	✓
2	Tug basin expansion re-design	The tug basin expansion footprint has been re-designed to reduce effects on fish and fish habitat (by promoting drainage during tidal exchanges and maintaining good water quality in this localized area of the inter-causeway area). Technical information on the calculation of losses in areal extent of fish habitat associated with construction for the expansion of the tug basin is provided in **Appendix IR2020-1.2-B**. See also description for #1 above.	✓
3	Widened causeway re-design	See description for #1 above.	✓
4 (new)	Potential additional project footprint reduction	A potential further reduction of the current project footprint by up to 14.4 ha would further reduce direct effects to habitat. When the relative importance to juvenile Chinook salmon is considered, this reduction of direct effects to habitat amounts to 3.2 ha (**Table IR2020-1.2-5**). This potential reduction of the current project footprint and related reduced effects on fish and fish habitat are described in detail in **IR2020-2.1**.	✓
5	Containment dyke construction measures	Measures proposed to avoid effects relating to potential tidal channel formation, as a result of dyke construction, will reduce the risk that such channels may affect juvenile Chinook salmon habitat, namely marsh and eelgrass. However, it is not possible to predict or quantify the extent of this hypothetical construction effect and data on the amount of habitat used by juvenile Chinook salmon that will be protected by this avoidance measure is not available.	●
6	Rounded northwest corner of marine terminal	See description for #1 above.	✓
Reduction measures			
7 (new)	Potential breaching mitigation	Potential breaching mitigation of any kind is not considered in the calculation of net change in the area of habitat used by juvenile Chinook salmon shown in **Table IR2020-1.2-5**. Based on evaluations of breaching mitigation described in **IR2020-2.2**, the marine terminal breach location does not overlap with, and will not adversely affect, juvenile Chinook salmon habitat. A potential risk for a minor adverse effect on juvenile Chinook salmon habitat was identified for all three causeway breach location options due to tidal channel formation. Should a breach be implemented at the causeway, there is potential for a reduction in the net areal increase in juvenile Chinook salmon habitat shown in **Table IR2020-1.2-5**. Due to the inherent uncertainty in the extent of tidal channel formation from a causeway breach, the potential extent of effects to juvenile Chinook salmon habitat due to a causeway breach is uncertain and it was not considered in the calculations shown in **Table IR2020-1.2-5**.	●
8	Removal of the intermediate transfer pit (ITP)	Constructing the project without the use of the ITP for sand storage in the marine environment will avoid potential effects on fish and fish habitat in the inter-causeway area through physical disturbance or changes in water quality during sediment placement for temporary storage at the ITP and sediment reclaiming for project infilling. Potential effects on fish and fish habitat that will be avoided with the removal of the ITP as part of project construction are not accounted for in the calculation, as it is not possible to predict or quantify the extent of this potential beneficial measure.	●
9	Marine Species Management Plan (timing windows)	Prior to the start of construction, developing a Marine Species Management Plan (commitment #34) as part of the project's Construction Environmental Management Plan, to be implemented during project construction, that will outline the standard processes and procedures to salvage and relocate marine species. This plan will also describe the process and procedures for the Orange Sea Pen Transplant Program, as well as crab salvage mitigation (commitment #51). This reduction measure does not relate directly to juvenile salmon but reduces effects to fish and fish habitat, as orange sea pens are considered fish, according to the *Fisheries Act*.	×
10	Marine Species Management Plan (salvage)	Throughout project construction, scheduling in-water works below –5 metres chart datum (m CD) outside of the fisheries sensitive window for Dungeness crab (i.e., outside of the time period between October 15 and March 31), unless agreed to by Fisheries and Oceans Canada (DFO) (commitment #49) and above –5 m CD outside of the fisheries sensitive window for juvenile salmon (i.e., outside of the time period between March 1 and August 15), unless agreed to by DFO (commitment #53), as described in the project's Marine Species Management Plan (commitment #34) that will form part of the project's Construction Environmental Management Plan.	×
11	Underwater Noise Management Plan	Prior to the start of construction, developing an Underwater Noise Management Plan (commitment #37) as part of the project's Construction Environmental Management Plan to be implemented during project construction and to reduce the risk of injury to marine fish, including juvenile Chinook salmon, from impact pile driving during project construction.	×
12	Light Management Plans	Prior to the start of construction, developing Light Management Plans (commitment #24) as part of the project's Construction and Operational Environmental Management Plans to be implemented during project construction and operation (commitment #24). The Light Management Plans will provide for measures to reduce excess artificial	×

#	Mitigation measure	Description	Analysis of project effects
			Juvenile Chinook salmon habitat
			Area
		lighting from the project, including directing light away from the marine environment and limiting use of lights to active work areas. These mitigation measures are intended to reduce the potential for adverse effects to juvenile salmon from project-related changes in the light environment, including the potential for disruption to juvenile salmon migration.	
13 (new)	Additional operational lighting mitigation	Proposing to update the mitigation included in the Light Management Plan for project operation to emphasize reducing the potential for effects to the marine environment, including migrating juvenile salmon. Also, proposing to update the Light Trespass and Sky Glow Effects Predictions and Mitigation Effectiveness follow-up program element to expand monitoring in the marine environment to verify effectiveness of project infrastructure lighting mitigation.	×
14 (new)	Additional operational mitigation for underwater noise	Identifying and evaluating operational mitigation measures to reduce the potential for effects to southern resident killer whales from underwater noise during project operation. Further reduction to underwater noise levels in the marine environment near the proposed terminal will also be generally beneficial to all marine species, including juvenile salmon. Measures to reduce underwater noise during project operation that could benefit juvenile salmon at Roberts Bank are summarized in IR2020-2.2 and described in greater detail in IR2020-3.	×
15 (new)	Timing of maintenance dredging at the expanded tug basin	Undertaking maintenance dredging at the expanded tug basin (below –5 m CD), should it be required, outside of the juvenile salmon fisheries-sensitive window (i.e., outside of the time period between March 1 and August 15). Implementation of this additional measure would avoid interaction with, and potential adverse effects from associated increases in light and underwater noise, to juvenile salmon that rear in the inter-causeway area in spring and summer.	×
Offsetting measures			
16 (new)	Offsetting projects to restore and enhance up to 86 ha of fish habitat	Analysis of net gain in habitat used by juvenile Chinook salmon considered 64 ha of the 86 ha currently being advanced by the port authority. Additional areal gains in fish habitat will be realized with the implementation of the additional 22 ha not included in the analysis.	✓

Notes:

\# – number of mitigation measures corresponds to numbered list as presented in **IR2020-1.2**, Table IR2020-1.2-1
✓ – considered quantitatively in the analysis
● – considered qualitatively in the analysis (empirical data not available)
× – does not apply to juvenile Chinook salmon habitat as no interaction with RBT2 and no pathway of effect has been identified in the EIS; measure is directly relevant to and has been considered in the analysis for juvenile Chinook salmon

[1] Approximately 126.3 ha out of 175.5 ha of the current project footprint overlapping with the wetted environment at Roberts Bank are proposed to be located below 0 m CD (i.e., the mean lower low water that defines the seaward boundary of the intertidal zone).

Table IR2020-1.2-E4: Avoidance, reduction and offsetting measures that influence productivity of juvenile Chinook salmon considered in IR2020-1.2 analysis in support of the proposed offsetting plan for the Roberts Bank Terminal 2 Project

#	Mitigation measure	Description	Analysis of project effects
			Juvenile Chinook salmon
			Productivity
Avoidance measures			
1	Placement of the marine terminal in subtidal waters	Project design-related avoidance measures, including measures 1, 3, 5, and 6, are incorporated in the current project footprint which was used as input into the updated RB model. The updated RB model was used to forecast direct and indirect productivity increases in fish and fish habitat with the project. Forecasted increases in fish and fish habitat productivity are attributed to quiescent conditions that are predicted to establish behind the proposed marine terminal and will become conducive to growth of marine vegetation (such as intertidal marsh and native eelgrass) and will favour population expansion and increase in the productivity of infaunal macroinvertebrate communities (e.g., macrofauna, which are food for juvenile Chinook salmon). These productivity increases in lower trophic levels organisms are forecasted to cascade to juvenile Chinook salmon through food provisioning and predator-prey interactions in the food web of the Roberts Bank ecosystem. Technical information on the updated RB model is provided in **Appendix IR2020-1.2-A**. In response to DFO input, forecasts of the updated RB model were discounted to account for uncertainty in the model outputs and for time that may be required for forecasted productivity increases to be realized (temporal lag A; see **Appendix IR2020-1.2-D**).	✓
2	Tug basin expansion re-design	With mitigation, changes in productivity of juvenile Chinook salmon associated with the expansion of the tug basin are expected to be negligible. The existing productivity of juvenile Chinook salmon associated with the proposed tug basin expansion area is estimated to be <0.01 t, as this area represents a small proportion of the overall productive area for salmon at Roberts Bank. Following expansion of the tug basin, and the permanent alteration of intertidal mudflat to subtidal soft substrate habitat, it is anticipated that juvenile Chinook salmon will continue to use the water column to reach intertidal rearing habitats adjacent to the expanded tug basin. For additional information on calculations of fish and fish habitat productivity changes from expansion of the tug basin see **Appendix IR2020-1.2-B**.	●
3	Widened causeway re-design	See description #1 above.	✓
4 (new)	Potential additional project footprint reduction	The portion of the project footprint that was incorporated in the updated RB model does not account for potential additional footprint reductions by up to 14.4 ha described in **IR2020-2.1**. Potential reduction in footprint-related effects to the productivity of juvenile Chinook salmon should this potential additional footprint reduction be implemented are described qualitatively in **IR2020-2.1**. Direct and indirect effects of the project forecasted by the updated RB model presented in **Table IR2020-1.2-7** are therefore considered conservative.	●
5	Containment dyke construction measures	Measures proposed to avoid effects relating to potential tidal channel formation, as a result of dyke construction, will reduce the risk that such channels may affect the productivity of fish habitat and in turn juvenile Chinook salmon productivity. However, it is not possible to predict or quantify the extent of this hypothetical construction effect and data on the amount of juvenile Chinook salmon habitat that will be protected by this avoidance measure is not available.	●
6	Rounded northwest corner of marine terminal	See description #1 above.	✓
Reduction measures			
7 (new)	Potential breaching mitigation	The port authority has evaluated breaching (i.e., fish passage) mitigation at four potential locations, one at the east end of the proposed marine terminal, and three locations along the Roberts Bank causeway (see **IR2020-2.2**, Figure IR2020-2.2-1). As currently designed, all four breach location options are considered effective in facilitating movements of juvenile Chinook salmon between north and south of the project. Breaching mitigation at a causeway location would also provide direct access from the north side of the causeway to the inter-causeway area. Thus, implementation of breaching mitigation would avoid a potential project-related disruption of juvenile Chinook salmon migration equivalent to approximately 7% to 14% of juvenile Chinook salmon biomass produced in the inter-causeway area, or approximately of 0.002 to 0.004 t/year. For additional information on the evaluation of breaching mitigation effectiveness, refer to **IR2020-2.2**.	✓
8	Removal of the ITP	Constructing the project without the use of the ITP will avoid potential losses in productivity of juvenile Chinook salmon in the inter-causeway area through physical disturbance or changes in water quality; hence, they are not considered in the calculation of net productivity change.	●
9	Marine Species Management Plan (timing windows)	With mitigation, potential losses in juvenile Chinook salmon productivity from injury and direct mortality will be avoided; hence, they are not considered in the calculation of net productivity change. Specifically, the port authority has committed to scheduling marine construction activities in waters shallower than –5 m CD outside of the juvenile salmon fisheries-sensitive window (outside of the time period between March 1 and August 15; measure 9), thus avoiding interactions between construction activities and juvenile Chinook salmon rearing at Roberts Bank. Moreover, the port authority has committed to salvaging and relocating marine species, including juvenile Chinook salmon, prior to infilling during construction as part of land reclamation activities (measure 10 below).	●
10	Marine Species Management Plan (salvage)	See description #9 above.	●

#	**Mitigation measure**	**Description**	**Analysis of project effects**
			Juvenile Chinook salmon
			Productivity
11	Underwater Noise Management Plan	With mitigation, potential project effects on juvenile Chinook salmon productivity from changes in the acoustic environment are expected to be negligible and to not materially influence the calculation of net productivity change. The port authority will prevent injury, and potential mortality, to juvenile Chinook salmon by maintaining underwater noise levels below thresholds that will be prescribed in the Underwater Noise Management Plan (measure 11). Also, juvenile Chinook salmon are considered hearing generalists and are not known to be sensitive to continuous noise that will be generated during project construction and operation (as explained in the EIS). Nevertheless, the port authority has been working since the public hearing to identify additional mitigation measures to further reduce impacts from underwater noise to the marine environment during project operation (**IR2020-3**, summarized in **IR2020-2.2**; measure 14 below). These potential additional measures will generally benefit all marine species, including juvenile Chinook salmon.	●
12	Light Management Plans	With mitigation, potential project effects on juvenile Chinook salmon productivity from changes in the light environment are expected to be negligible and to not materially influence the calculation of net productivity change shown in **Table IR2020-1.2-7**. The port authority committed to comprehensive measures (measure 12) to reduce adverse effects to juvenile salmon from project-related changes in the light environment. As described in **IR2020-2.2**, the port authority also proposes to expand the Light Management Plan to emphasize the importance of reducing effects to the marine environment, including migrating juvenile salmon (measure 13 below). Further reducing lighting effects to the marine environment, including light trespass, will further reduce the risk of potentially attracting juvenile Chinook salmon within lit areas, delaying outmigration, and increasing susceptibility to predators. The port authority also intends to expand monitoring in the marine environment to verify effectiveness of project infrastructure lighting mitigation; the objective is to get as close as possible to a no-net increase in light (due to the project) in the marine environment (see **IR2020-2.2**).	●
13 (new)	Additional operational lighting mitigation	See description #12 above.	●
14 (new)	Additional operational mitigation for underwater noise	See description #11 above.	●
15 (new)	Timing of maintenance dredging at the expanded tug basin	With respect to project operation, should maintenance dredging be required at the expanded tug basin in waters deeper than –5 m CD, the port authority will conduct such works outside of the juvenile salmon fisheries-sensitive window (i.e., outside of the time period between March 1 and August 15). As such, interaction with, and potential adverse effects to (including productivity), rearing juvenile Chinook salmon will be avoided.	●
Offsetting measures			
16 (new)	Offsetting projects to restore and enhance up to 86 ha of fish habitat	Analysis of net gain in juvenile Chinook salmon productivity considered 64 ha of the 86 ha currently being advanced by the port authority. Additional gains in juvenile Chinook salmon productivity will be realized with the implementation of the additional 22 ha not included in the analysis.	✓

Notes:

– number of mitigation measures corresponds to numbered list as presented in **IR2020-1.2**, Table IR2020-1.2-1
✓ – considered quantitatively in the analysis
● – considered qualitatively in the analysis (empirical data not available)

Table IR2020-1.2-E5: Avoidance, reduction, and offsetting measures that influence fish and fish habitat productivity considered in IR2020-1.2 analysis in support of the proposed offsetting plan for the Roberts Bank Terminal 2 project

#	Mitigation measure	Description	Analysis of project effects
			Fish and fish habitat
			Productivity
Avoidance measures			
1	Placement of the marine terminal in subtidal waters	Project design-related avoidance measures, including measures 1, 3, 5, and 6, are incorporated in the current project footprint which was used as input into the updated RB model. The updated RB model was used to forecast direct and indirect productivity increases in fish and fish habitat with the project. Forecasted increases in fish and fish habitat productivity are attributed to quiescent conditions that are predicted to establish behind the proposed marine terminal and will become conducive to growth of marine vegetation (such as intertidal marsh and native eelgrass) and will favour population expansion and increase in the productivity of infaunal macroinvertebrate communities. These productivity increases in lower trophic levels organisms are forecasted to cascade to higher trophic level organisms (e.g., fish) through predator-prey interactions in the food web of the Roberts Bank ecosystem. Technical information on the updated RB model is provided in **Appendix IR2020-1.2-A**. In response to DFO input, forecasts of the updated RB model were discounted to account for uncertainty in the model outputs and for time that may be required for forecasted productivity increases to be realized (temporal lag A; see **Appendix IR2020-1.2-D**).	✓
2	Tug basin expansion re-design	The tug basin expansion footprint has been re-designed to reduce effects on fish and fish habitat (by promoting drainage during tidal exchanges and maintain good water quality in this localized area of the inter-causeway area). Technical information on the calculation of losses in fish and fish habitat productivity associated with construction for the expansion of the tug basin is provided in **Appendix IR2020-1.2-B**.	✓
3	Widened causeway re-design	See description #1 above.	✓
4 (new)	Potential additional project footprint reduction	The portion of the project footprint that was incorporated in the updated RB model does not account for potential additional footprint reductions by up to 14.4 ha described in **IR2020-2.1**. Potential reduction in footprint-related effects to fish and fish habitat productivity should this potential additional footprint reduction be implemented are described qualitatively in **IR2020-2.1**. A potential additional reduction in the current project by up to 14.4 ha would avoid 4.7 ha of vegetative habitat and 9.7 ha of bare sand/mud and rock resulting in a reduction to direct and indirect effects to primary and secondary productivity associated with the habitat types that will be avoided (**IR2020-2.1** and **Appendix IR2020-2.1-A**). For example, avoiding 0.7 ha of native eelgrass could reduce footprint overlap with this habitat type by 31%, compared to what was assessed in the EIS, that would provide food and refuge to juvenile stages of Chinook salmon, Dungeness crab, and forage fish, as well as spawning substrate for adult herring. These potential reductions in effects to fish and fish habitat productivity are described qualitatively in **IR2020.2.1**; they are not tallied quantitatively in the overall productivity calculations for fish and fish habitat shown in **Table IR2020-1.2-9**, which are thus considered conservative.	●
5	Containment dyke construction measures	Measures proposed to avoid effects relating to potential tidal channel formation, as a result of dyke construction, will reduce the risk that such channels may affect fish and fish habitat, namely marsh and eelgrass. However, it is not possible to predict or quantify the extent of this hypothetical construction effect and data on the amount of marsh and eelgrass habitat (and therefore fish and fish habitat) protected by this avoidance measure is not available.	●
6	Rounded northwest corner of marine terminal	See description #1 above.	✓
Reduction measures			
7 (new)	Potential breaching mitigation	Implementation of a breach (i.e., fish passage for migrating juvenile salmon) will mitigate potential project-related disruption to juvenile salmon migration. A description of potential breach locations and associated reduction in project-related effects to juvenile salmon is provided in **IR2020-2.2**.	✓
8	Removal of the intermediate transfer pit (ITP)	Constructing the project without the use of the ITP for sand storage in the marine environment will avoid potential effects on fish and fish habitat in the inter-causeway area through physical disturbance or changes in water quality during sediment placement for temporary storage at the ITP and sediment reclaiming for project infilling. Potential effects on fish and fish habitat that will be avoided with the removal of the ITP as part of project construction are not accounted for in the calculation, as it is not possible to predict or quantify the extent of this potential construction effect and data on the amount of fish and fish habitat that will be protected by this reduction measure is not available.	●
9	Marine Species Management Plan (timing windows)	Adherence to timing windows will reduce effects to fish from in-water project construction activities. Throughout project construction, in-water works below –5 metres chart datum (m CD) will be scheduled outside of the fisheries sensitive window for Dungeness crab (i.e., outside of the time period between October 15 and March 31), unless agreed to by Fisheries and Oceans Canada (DFO), and above –5 m CD outside of the fisheries sensitive window for juvenile salmon (i.e., outside of the time period between March 1 and August 15), unless agreed to by DFO, as described in the project's Marine Species Management Plan (commitment #34) that will form part of the project's Construction Environmental Management Plan. Given the lack of quantitative data specific to fish that will be protected by this reduction measure, the contribution of this measure to reducing project effects on fish is not included in productivity estimates presented in **Table IR2020-1.2-9**.	●
10	Marine Species Management Plan (salvage)	Effects on fish from project construction activities outside the fisheries sensitive windows will be reduced through additional measures that will be described in the project's Marine Species Management Plan. Given the lack of quantitative data specific to fish that will be protected by this reduction measure, the contribution of this measure to reducing project effects on fish is not included quantitatively in productivity estimates presented in **Table IR2020-1.2-9**. For example, transplantation of approximately 10% of	●

#	Mitigation measure	Description	Analysis of project effects
			Fish and fish habitat
			Productivity
		the orange sea pen aggregation will reduce effects to this species. However, quantification of this transplantation into productivity reductions has not been undertaken yet, as it is dependent on the orange sea pen density expected to be present in the marine terminal footprint prior to commencement of construction activities. Therefore, potential effects to this group, as described in **Table IR2020-1.2-9**, are overestimated. Similarly, reduction measures (such as salvage) specific to Dungeness crabs that will be undertaken in advance of project construction will reduce the amount of productivity lost by this species (as presented in **Table IR2020-1.2-9**). However, quantification of salvage mitigation into productivity reductions was also not undertaken, as it is dependent on the abundance of Dungeness crab expected to be present in the marine terminal footprint prior to commencement of construction activities.	
11	Underwater Noise Management Plan	Measures to reduce the amount of underwater noise from project construction will reduce effects to fish and fish habitat (such measures include use of a vibratory hammer instead of an impact hammer, use of sound attenuation measures during impact piling, gradual start of in-water construction activities).	✓
12	Light Management Plans	Potential changes in the productivity of fish from project-related changes in the light environment were accounted for in the analysis qualitatively and consistent with the biophysical effects assessment presented in the EIS. With avoidance and reduction mitigation measures (not including offsetting), potential changes in fish productivity from changes in the light environment would be negligible and would not materially influence the calculation of net productivity change shown in **Table IR2020-1.2-9**.	●
13 (new)	Additional operational lighting mitigation	See description #12 above. Also, the port authority committed to comprehensive measures to reduce adverse effects to fish, including juvenile salmon, from project-related changes in the light environment. As described in **IR2020-2.2**, the port authority also proposes to expand the Light Management Plan to emphasize the importance of reducing effects to the marine environment. The port authority will also expand monitoring in the marine environment to verify effectiveness of project infrastructure lighting mitigation; the objective is to get as close as possible to a no-net increase in light (due to the project) in the marine environment (see **IR2020-2.2**).	●
14 (new)	Additional operational mitigation for underwater noise	See description #11 above. Additional measures that will be implemented by the port authority to reduce underwater noise during project operation are described in **IR2020-3**.	●
15 (new)	Timing of maintenance dredging at the expanded tug basin	Maintenance dredging below –5 m CD will not be conducted during fisheries sensitive windows for juvenile salmon or crab. Effects on fish from maintenance dredging at the expanded tug basin outside the fisheries sensitive windows will be reduced through measures that will be described in the project's Marine Species Management Plan. Given the lack of quantitative data specific to fish that will be protected by this reduction measure, the contribution of this measure to reducing project effects on fish is not included in productivity estimates presented in **Table IR2020-1.2-9**.	●
Offsetting measures			
16 (new)	Offsetting projects to restore and enhance up to 86 ha of fish habitat	Analysis of net gain in fish and fish habitat productivity considered 64 ha of the 86 ha currently being advanced by the port authority. Additional gains in fish and fish habitat productivity will be realized with the implementation of the additional 22 ha not included in the analysis.	✓

Notes:

– number of mitigation measures corresponds to numbered list as presented in **IR2020-1.2**, Table IR2020-1.2-1
✓ – considered quantitatively in the analysis
● – considered qualitatively in the analysis (empirical data not available)