APPENDIX 15-A

Coastal Bird Species of Conservation Concern with the Potential to Occur in the Local Assessment Area

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Appendix 15-A Coastal Bird Species of Conservation Concern with the Potential to Occur in the Local Assessment Area

Table 15-A Coastal Bird Species of Conservation Concern with the Potential to Occur in the Local Assessment Area

Common Name	Scientific Name	Sub-Component	B.C. List Status[1]	*SARA*[2]	COSEWIC[3]
Brandt's Cormorant	*Phalacrocorax penicillatus*	Diving Birds	Red	-	-
Common Murre	*Uria aalge*	Diving Birds	Red	-	-
Double-crested Cormorant	*Phalacrocorax auritus*	Diving Birds	Blue	-	NAR (May 1978)
Long-tailed Duck	*Clangula hyemalis*	Diving Birds	Blue	-	-
Surf Scoter	*Melanitta perspicillata*	Diving Birds	Blue	-	-
Western Grebe	*Aechmophorus occidentalis*	Diving Birds	Red	-	SC (Jul 2014)
California Gull	*Larus californicus*	Gulls and Terns	Blue	-	-
Caspian Tern	*Hydroprogne caspia*	Gulls and Terns	Blue	-	NAR (May 1999)
Great Blue Heron, fannini subspecies	*Ardea herodias fannini*	Herons	Blue	1-SC (Feb 2010)	SC (Mar 2008)
American Bittern	*Botaurus lentiginosus*	Herons	Blue	-	-
Green Heron	*Butorides virescens*	Herons	Blue	-	-
Barn Swallow	*Hirundo rustica*	Passerines	Blue	-	T (May 2011)
Barn Owl	*Tyto alba*	Raptors	Blue	1-SC (Jun 2003)	T (Nov 2010)
Short-eared Owl	*Asio flammeus*	Raptors	Blue	1-SC (Jul 2012)	SC (Mar 2008)
Snowy Owl	*Bubo scandiacus*	Raptors	Blue	-	-
Gyrfalcon	*Falco rusticolus*	Raptors	Blue	-	NAR (May 1987)
Peregrine Falcon, anatum subspecies	*Falco peregrinus anatum*	Raptors	Red	1-SC (2012)	SC (Apr 2007)
Red-necked Phalarope	*Phalaropus lobatus*	Shorebirds	Blue	-	-
Short-billed Dowitcher	*Limnodromus griseus*	Shorebirds	Blue	-	-
Brant	*Branta bernicla*	Waterfowl	Blue	-	-
Tundra Swan	*Cygnus columbianus*	Waterfowl	Blue	-	-

Notes: See **Appendix 10-A Species at Risk – Information on Federal and Provincial** Designations for definitions of status terms.

[1]B.C. Status: Red=Threatened, Endangered, or Extirpated; Blue=Special Concern; Yellow=Apparently secure; Exotic=Alien, foreign, introduced, non-indigenous and non-native.

[2]*SARA*: 1=Schedule 1; SC=Special Concern; T=Threatened; E=Endangered.

[3]COSEWIC: SC=Special Concern; T=Threatened; E=Endangered.

APPENDIX 15-B

Shorebird Foraging Opportunity during Migration

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ROBERTS BANK TERMINAL 2

TECHNICAL REPORT

Coastal Birds

Shorebird Foraging Opportunity during Migration

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HEMMERA 20 YEARS 1994 – 2014

Technical Report / Technical Data Report Disclaimer

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

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

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

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

EXECUTIVE SUMMARY

The Roberts Bank Terminal 2 Project (RBT2 or Project) is a proposed new three-berth marine terminal at Roberts Bank in Delta, B.C. that could provide 2.4 million TEUs (twenty-foot equivalent unit containers) of additional container capacity annually. The project is part of Port Metro Vancouver's (PMV) Container Capacity Improvement Program, a long-term strategy to deliver projects to meet anticipated growth in demand for container capacity to 2030.

The Fraser River estuary (FRE) represents important habitat for shorebirds such as the western sandpiper (*Calidris mauri*) and the Pacific dunlin (*Calidris alpina pacifica*). Shorebirds are abundant in the FRE throughout much of the year, but are especially dense during northward and southward migration periods. The study's primary objective was to summarise the shorebird foraging opportunity that currently exists during migrations and changes that may result from the RBT2 project. Foraging opportunity was defined as a measure of energy available to shorebirds taking into consideration tidal exposure and site safety (i.e., predation danger). The foraging opportunity of three food sources (i.e., biofilm, meiofauna and macrofauna) was considered within the area most likely to be affected by the Project. Additional objectives were as follows: investigate the overlap between foraging opportunity and usage; estimate capacity of the affected area to accommodate shorebirds given predicted changes in biomass; investigate the impact of freshet event size on estimates of biomass change to determine the sensitivity of results to variation in flow from the Fraser River; assess partitioning of biomass and usage across all major intertidal mudflats in the FRE (e.g., Sturgeon Bank, Roberts Bank, Boundary Bay) to place estimates predicted with Project change within the context of the entire functional area.

The first requirement to meeting these objectives was the creation of abundance estimates for each food source both within the area potentially affected by the proposed Project and across the FRE as a whole. Food abundance estimates were created at a resolution of 1 hectare (ha) using spatially explicit models (i.e., regression-kriging models) that incorporated data from field sampling programs and geomorphology modelling as well as other known landscape variables. Models were tailored to the goals of estimating abundance in either the affected area or the FRE. Predictions of abundance in the affected area were created under both existing conditions, and conditions expected under the Project described by geomorphology modelling data.

To determine foraging opportunity for shorebirds, abundance estimates along with measures of site safety and site availability (i.e., controlling for tidal exposure) were combined to generate foraging opportunity topologies, which illustrate the amount of available biomass for a combination of safety and food abundance (i.e., food density in 1-ha areas). Foraging opportunity topologies were generated for existing conditions and conditions expected under the proposed Project for both northward and southward migration periods. The overlap between foraging opportunity and usage was also investigated. Usage topologies were created using the same abundance and safety criteria, but with a measure of

usage derived from spatial interpolations of shorebird droppings data. Comparisons of the shape and form of usage and opportunity topologies were made to assess how opportunity is currently being used by shorebirds and to help inform on how changes in opportunity under with Project conditions will influence usage.

Two lines of evidence were examined to assess the capacity of the investigated food sources to support migratory shorebird populations under with Project conditions. First, biomass availability and shorebird usage was used to estimate the lower bound of capacity (i.e., the highest potential proportion of biomass consumed) for each food source by converting usage into an estimate of biomass consumption. A second estimate of capacity was generated for biofilm using data from a hyperspectral survey to provide an estimate of biofilm daily standing stock and consumption by migratory shorebirds based on historical population sizes, published daily energy expenditures and diet compositions.

Estimated changes in total available biomass predicted under proposed Project conditions were generally small and, due to large confidence intervals associated with high natural variability in the system, were not statistically significant; however, all investigated food sources were predicted to decline and larger changes cannot be ruled out. In all cases changes in biomass between existing and with Project conditions were driven by salinity changes in the affected area as predicted by hydrodynamic models.

The general nature of foraging opportunity under predicted Project conditions remained largely unchanged relative to existing conditions. While opportunity topologies did show some variation associated with predicted biomass changes, areas of high opportunity (i.e., available biomass) tended to remain in areas with similar safety and food abundance. Foraging opportunity and usage were also well aligned in many cases (e.g., biofilm and macrofauna), verifying the potential for foraging opportunity to summarise shorebird food resources.

Despite the estimates of biomass decline, use of conservative assumptions and a worst-case scenario, results consistently indicated excess capacity would still exist for biofilm, macrofauna, and meiofauna for shorebirds under typical population sizes within the area likely to be affected by the proposed Project. Furthermore, the predicted changes in capacity were generally small relative to estimates of existing capacity. For example, biofilm during the northward migration showed the smallest estimated capacity, with an existing lower bound capacity estimate of 45% (i.e., up to 55% consumption). Under the proposed Project this estimate was reduced slightly to 42%, with a worst-case estimate of 29%. Infauna capacities were generally higher with existing lower bound capacities ranging from 71% to 95%, with a small percentage point reduction (≤5%) under the proposed Project.

The second independent estimate of biofilm capacity, which modelled daily resource consumption more directly, showed an even greater capacity of the affected area to support shorebirds under the proposed Project. In this case biofilm standing stock often exceeded daily energetic requirements by 10 fold even during the period of highest daily demand. Biofilm was only predicted to be in limited supply on 0.2% of days within the northward migration, when daily population sizes of shorebirds exceeded one million individuals.

Estimates of change in capacity under the proposed Project were based on dynamics observed during a 1 in 25 year freshet event. The higher freshwater input resulted in lower salinity levels and different salinity patterns compared to more typical freshet event size. A sensitivity analysis using salinity conditions expected under more a typical freshet event size showed smaller changes and in some cases (e.g., biofilm) the possibility of higher biomass during migration periods under proposed Project conditions.

Finally, biomass estimates across the FRE showed a large standing stock of biofilm, macrofauna and meiofauna outside the area likely to be affected by the proposed Project. While capacity of the FRE as a whole was not estimated, the comparable levels of biomass suggest large food resources exist for shorebirds outside of the area likely to be affected.

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GLOSSARY/LIST OF ACRONYMS

General Terminology/Acronyms

Akaike Information Criterion (AIC)	Akaike Information Criterion is a measure of the model support given the data set and candidate model set. AIC attempts to find a balance between model fit (minimising the information loss) and the number of modelling parameters (avoid over-fitting).
CI	Confidence Interval
DEE	Daily Energy Expenditure
DUNL	Pacific dunlin
Inverse Distance Weighting (IDW)	Inverse Distance Weighting is a deterministic spatial model that does not rely on an underlying statistical model.
FRE	Fraser River estuary
MPB	Microphytobenthos
PMV	Port Metro Vancouver
psu	Practical Salinity Unit
Regression-kriging	A geospatial technique that is a hybrid regression and Kriging techniques to produce geospatial predictions along with an estimate of error.
RMSE	Root Mean Squared Error
TOC	Total Organic Carbon
TRIM	Terrain Resources Inventory Management
WESA	Western sandpiper

Document Specific Terminology/Acronyms

Abundance	Density measure of either infauna (g/m^2) or biofilm (i.e., chlorophyll *a*; mg/m^2).
Availability	The amount of tidal exposure (i.e., emersion time) a site or grid cell is expected to receive within a period of one week.
Available biomass	The amount of biomass in a grid cell multiplied by the grid cell availability. Available biomass for a set of grid cells is computed by summing the individual grid cell estimates. Used as a proxy for energy.
Biomass	Conversion of an abundance measure (e.g., mg/m^2 or g/m^2) into an estimate of mass (e.g., mg or g) within a grid cell or for a set of grid cells.
Food abundance	A synonym for abundance.
Foraging opportunity topology	A three-dimensional space illustrating the relationship between safety, food abundance (i.e., density) and available biomass (i.e., a measure of energy). For display purposes the three-dimensional space was projected to two-dimensions (safety and food abundance), with the third-dimension (total energy) represented by colour gradients and contour lines.
Grid cells	1 hectare (ha: 10,000 m^2) areas which were overlaid in a contiguous distribution over areas of interest (i.e., the LSA or RSA).
LSA	Local Study Area
RSA	Regional Study Area
Safety index	The distance (m) to the nearest shoreline in the LSA; either the natural shoreline or the Roberts Bank causeway.
SFOM	Shorebird Foraging Opportunity Model
TAG	Technical Advisory Group
Total biomass	Estimate of the amount of biomass found in the LSA as a whole, or within an LSA zone.
Total available biomass	Estimate of the amount of available biomass found in the LSA as a whole, or within an LSA zone.

1.0 INTRODUCTION

1.1 PROJECT BACKGROUND

The Roberts Bank Terminal 2 Project (RBT2 or Project) is a proposed new three-berth marine terminal at Roberts Bank in Delta, B.C. that could provide 2.4 million TEUs (twenty-foot equivalent unit containers) of additional container capacity annually. The project is part of Port Metro Vancouver's (PMV) Container Capacity Improvement Program, a long-term strategy to deliver projects to meet anticipated growth in demand for container capacity to 2030.

Port Metro Vancouver has retained Hemmera to undertake environmental studies to inform a future effects assessment for the Project. This technical report (TR) describes the results of the Shorebird Foraging Opportunity Study completed by Hemmera, LGL and Dr. Ron Ydenberg of Simon Fraser University.

1.2 SHOREBIRD FORAGING OPPORTUNITY DURING MIGRATION OVERVIEW

A review of existing information and state of knowledge was completed for the Shorebird Foraging Opportunity Study to identify key data gaps and areas of uncertainty within the general RBT2 area. This TR describes the study findings for key components identified from the gap analysis. Study components, major objectives, and a brief overview are provided in **Table 1**.

Table 1 Shorebird Foraging Opportunity Study Components and Major Objectives

Component	Major Objective	Brief Overview
1) Estimate 'Existing' and 'With Project' shorebird foraging opportunity in the area most likely to be affected by the Project (Local Study Area (LSA))	• Generate estimates of **abundances** for food sources that comprise the majority of shorebirds' intertidal diet (i.e., biofilm, meiofauna, and macrofauna) under Existing and With Project conditions. • Combine estimates of abundance, with measures of safety and **availability** to create a **foraging opportunity topology** for each food source. • Compare foraging opportunity under Existing and With Project conditions.	• Develop a **regression-kriging** model to estimate the abundance (i.e., mg/m^2 or g/m^2) of food sources across the LSA (1-ha resolution) under Existing and With Project conditions based on data from field sampling programs as well as geomorphology modelling data and other landscape variables. • Convert abundance estimates to an estimate of **total biomass** (i.e., g or mg) in each 1 ha area. • Determine safety and availability of each 1 ha site using measures of distance to shore and tidal exposure, respectively. • Determine foraging opportunity topologies based on safety, availability, and biomass. Topologies display the **total available biomass** (e.g., g x hr) for a given safety and abundance co-ordinate. • Compare foraging topologies between Existing and With Project predictions for all three food sources.
2) Compare and validate foraging opportunity inference with shorebird usage data.	• Derive estimates of usage in the study area. • Create a usage topology using the same safety and abundance co-ordinates as used for foraging opportunity. • Compare pattern and form of usage and foraging opportunity topologies.	• Use shorebird dropping data from field sampling programs to create a spatial interpolation of usage across the LSA based on dropping densities. • Use spatially interpolated dropping densities to derive estimates of usage across the LSA. • Summarise usage in the LSA with a topology similar to foraging opportunity by determining total usage for every safety and **food abundance** co-ordinate (i.e., usage summed across areas for a given combination of site safety and availability). • Compare usage and foraging opportunity topologies to validate topologies and provide information on shorebird foraging habits.

Component	Major Objective	Brief Overview
3) Estimate the capacity of the LSA for shorebirds (i.e., the percentage of available biomass unused by shorebirds) based on usage data and biomass data for all three food sources.	• Derive a method to estimate an upper bound of current consumption (i.e., maximum possible consumption) of food sources based on distributions of current usage and available biomass. • For all food sources determine a lower bound (i.e., minimum possible) estimate of capacity, based on the upper bound estimate of consumption. • Compare capacities between Existing and With Project conditions.	• Summarise available biomass and usage distributions in the LSA. • Standardise biomass distributions by area and migration period. • Convert the Existing usage distribution to an estimate of maximum possible consumption by standardising levels of use to levels of available biomass under the conservative assumption that areas receiving the highest level of use represent complete consumption of biomass (i.e., consumption equal to available biomass). • Estimate the minimum possible Existing capacity based on the upper bound estimate of consumption for each migration period and all food sources. • Estimate capacity under With Project conditions by using estimates of Project related biomass change.
4) Derive a second estimate of biofilm capacity based on hyperspectral estimates of biofilm daily standing stock and estimates of consumption rates of migrating shorebird populations.	• Simulate the changes in biofilm standing stock (i.e., biomass) based on daily consumption and biofilm recovery rates. • Compare the ability of biofilm stocks to support migratory shorebird populations under Existing and With Project conditions. • Provide an additional method to verify biofilm capacity estimated in Component 3.	• Estimate the daily biofilm consumption rates for western sandpiper (WESA) and dunlin (DUNL) based on historical migratory population sizes at Roberts Bank, documented daily consumption rates, and diet composition. • Develop a simulation that considers variation in daily biofilm demand and measured biofilm recovery rates. • Compare the ability of Existing and With Project conditions to support consumption by determining capacity and the frequency of supply limitations.
5) Investigate the impact of freshet event size on estimates of foraging capacity under With Project conditions.	• Determine how geomorphology processes differ under more typical freshet events. • Estimate and compare With Project biomass changes under more typical freshet events.	• Components 1 to 3 predict With Project biomass changes based on geomorphology modelling predictions derived under a 1 in 25 year freshet event. • Use historical Fraser River flow rates to determine 2012 modelling data that best represented more typical freshet events. • Compare estimates of With Project biomass change under more typical conditions to estimates of change based on 2012 (25-year freshet) conditions.

2.0 REVIEW OF EXISTING LITERATURE AND DATA

The expansive mudflat, marsh, and agricultural areas of the Fraser River estuary (FRE) provide habitat designated a ‘Wetland of International Importance’ (Ramsar Convention 2014), ‘Important Bird Area’ (IBA Canada 2013), and ‘Site of Hemispheric Importance’ for shorebirds (Western Hemisphere Shorebird Reserve Network 2005). These designations are, in part, due to use of the estuary by globally important proportions of the western sandpiper (*Calidris mauri*; also referred to as WESA) population during spring migration (Butler and Vermeer 1994, Fernández et al. 2010).

Shorebirds are the most abundant group of birds in the FRE during migration (Butler and Vermeer 1994, Sutherland et al. 2000). The most abundant shorebird in the FRE during migratory periods is the western sandpiper followed by the Pacific dunlin (*Calidris alpina pacifica;* also referred to as DUNL).

Migrations occur in two phases (i.e., northward and southward) with stopovers in the FRE on both occasions. The northward migration of WESA occurs between mid-April and early May, encompassing a period of three to four weeks (Butler et al. 1987). Over the course of the northward migration, an average of 600,000 WESA and 200,000 DUNL use habitat in the vicinity of Brunswick Point on Roberts Bank north of the existing Roberts Bank terminals (Drever et al. 2014). By contrast, the southward migration is more protracted, with the majority of adults passing through the FRE in July, followed by juveniles in August and September (Butler et al. 1987, Ydenberg et al. 2004). During migration, sandpipers primarily use mud- and sand flats (hereafter, collectively referred to as ‘mudflats’) as foraging habitat and supplement their diet by foraging in agricultural fields adjacent to the intertidal zone.

Calidrid shorebirds use a variety of feeding behaviours (e.g., probing, pecking) and have been documented feeding on macrofaunal and meiofaunal invertebrates (Sutherland et al. 2000, Mathot et al. 2010). Sandpipers, including DUNL, also graze extensively on biofilm (i.e., a dense mixture of microbes and organic detritus trapped within a mucilaginous matrix secreted by benthic bacteria and microphytobenthos bound up with sediment particles) by using keratinized spines on their tongues (Elner et al. 2005, Mathot et al. 2010). Biofilm can account for an average of 68% and 18% of daily energy requirements for WESA and DUNL, respectively, during their northward migration (Kuwae et al. 2008, 2012). Shorebird distribution and **abundance** across mudflats are likely influenced by the spatial distribution and abundance of benthic invertebrates (i.e., meiofauna and macrofauna) and biofilm.

Recent field research has also shown that shorebirds select feeding and resting sites not only on the basis of food **availability**, but also on a site's safety from predators, primarily peregrine falcon (*Falco peregrinus*) and merlin (*Falco columbarius*) (Dekker 1998). Consequently, safety attributes may be as important as food availability in determining a site's overall quality. Peregrine falcons are common within the FRE and play a significant role in influencing shorebird feeding and roosting habits (Lank et al. 2003, Pomeroy et al. 2006, Ydenberg et al 2010). Construction of RBT2 could alter the level of predation risk to staging shorebirds in the intertidal zone near the site by confining shorebirds to areas that are safe from predation, but less rich in food resources, or alternately, by providing perching structures that favour falcons, allowing them to prey on shorebirds at close range. The primary factor correlated with increased predation danger is the distance a shorebird feeding or roosting site is to a visual obstruction (e.g., shoreline vegetation, a causeway, or a terminal; Pomeroy et al. 2006). Safer sites are well away from obstacles that falcons might use to hide their approach and surprise their prey (Dekker and Ydenberg 2004).

Detailed shorebird foraging use studies for the purpose of evaluating potential effects from the Project are lacking. From the perspective of a migrating shorebird, one of the greatest potential effects resulting from the construction of RBT2 would be direct and/or indirect effects to bird foraging habitat. A worst-case scenario would be loss of **food abundance** that hinders the ability to efficiently add fat reserves required to successfully migrate to subsequent stopover sites.

2.1 TECHNICAL ADVISORY GROUP PROCESS

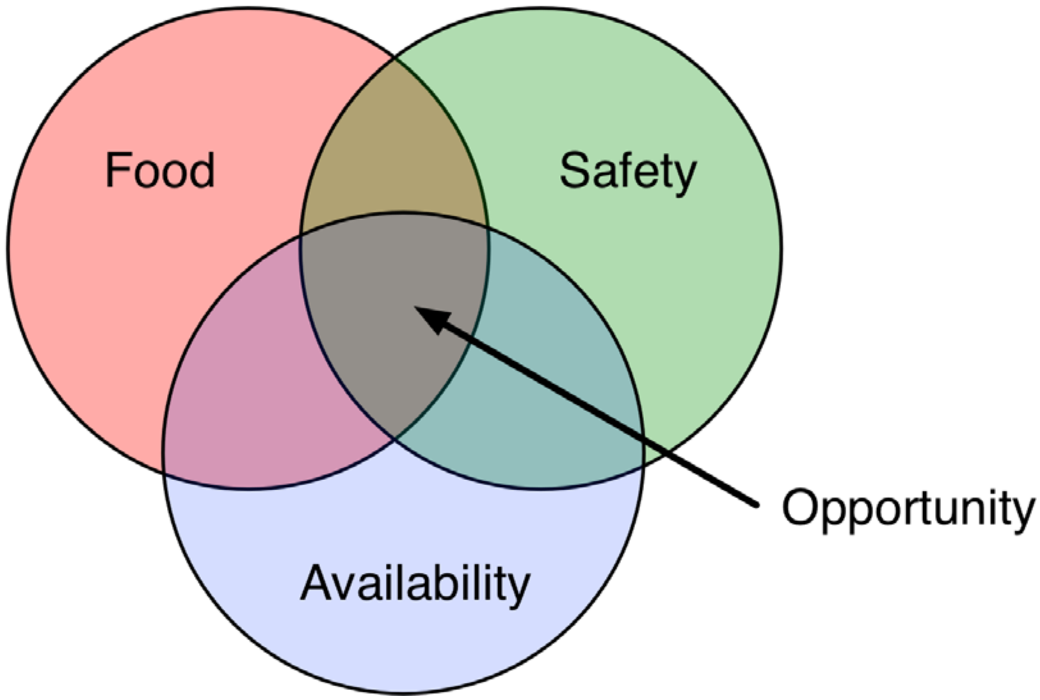
Port Metro Vancouver initiated a Technical Advisory Group (TAG) process to ensure studies were of high quality (Compass Resource Management Ltd. 2013). A recommendation from the Biofilm and Shorebird TAG was to assess potential effects to migrating shorebirds resulting from RBT2 by investigating changes in shorebird foraging opportunity (**Figure 1**). Shorebird foraging opportunity was defined in the TAG as a measure of energy available to a shorebird to feed on at any one location, weighted against site safety, and considering other factors such as tidal exposure (Compass Resource Management Ltd. 2013).

In response to the Biofilm and Shorebird TAG recommendations, the Project team developed a foraging model that entailed:

1. Assigning a food value to each spatial increment of the mudflat;
2. Assigning site safety scores to the same spatial increment;
3. Inferring shorebird opportunity at each spatial increment;
4. Validating shorebird opportunity inference with shorebird usage data;
5. Predicting shorebird opportunity post-RBT2; and
6. Evaluating change in shorebird opportunity as a result of RBT2.

This TR presents how the modelling approach was implemented, termed the Shorebird Foraging Opportunity Model (SFOM). Foraging opportunity was determined for biofilm, and infauna (i.e., meiofauna and macrofauna) under current conditions (termed ‘Existing’), and post-RBT2 (termed ‘With Project’).

Figure 1 Conceptual Relationship Between Food, Safety and Availability



3.0 METHODS

The focus of this TR is the presentation of methods, results, and discussion of pertinent information from the SFOM relevant to the RBT2 project. The descriptions herein relate mainly to the creation of the SFOM, with some discussion of the spatial and temporal scopes of the various studies used as data sources (see **Section 3.3** for a complete list).

3.1 STUDY AREA

The SFOM has two primary spatial scopes, the local study area (LSA) (**Figure 2**), and the regional study area (RSA) (**Figure 3**)**.** The LSA was used to investigate changes in foraging opportunity in the area most likely to undergo geomorphological changes as a result of the proposed Project. Estimates of foraging opportunity, as defined in the Biofilm and Shorebird TAG, are only investigated within this area. The RSA encompasses a large portion of the FRE and was used to place LSA changes within the context of a larger functional area.

3.1.1 Local Study Area

For the purpose of the SFOM, the LSA was defined as extending from Canoe Passage to the Roberts Bank causeway (**Figure 2**). Within the RSA, the LSA was termed the Brunswick Point stratum (**Figure 3**). The LSA is the only area predicted to undergo geomorphological changes (Northwest Hydraulic Consultants 2014). Areas adjacent to the LSA, such as the Inter-causeway Area and Westham Island (**Figure 3**), were not expected to experience geomorphological changes due to the proposed Project and thus were excluded from the LSA. Inclusion of these areas would have resulted in reduced estimates of change (whether positive or negative). The LSA (and the Inter-causeway Area) also had the highest spatial resolution of geomorphology modelling data within the RSA, which facilitated SFOM development (see Northwest Hydraulic Consultants 2014). The SFOM requires associations between geomorphology modelling data and **biomass** measurements in order to make biomass predictions under With Project conditions. Because of the increased spatial distance between modelling points, these associations tended to be weak outside the LSA, requiring reliance on variables that cannot adequately be predicted under With Project conditions (see **Section 4.5**).

3.1.1.1 Local Study Area Zones

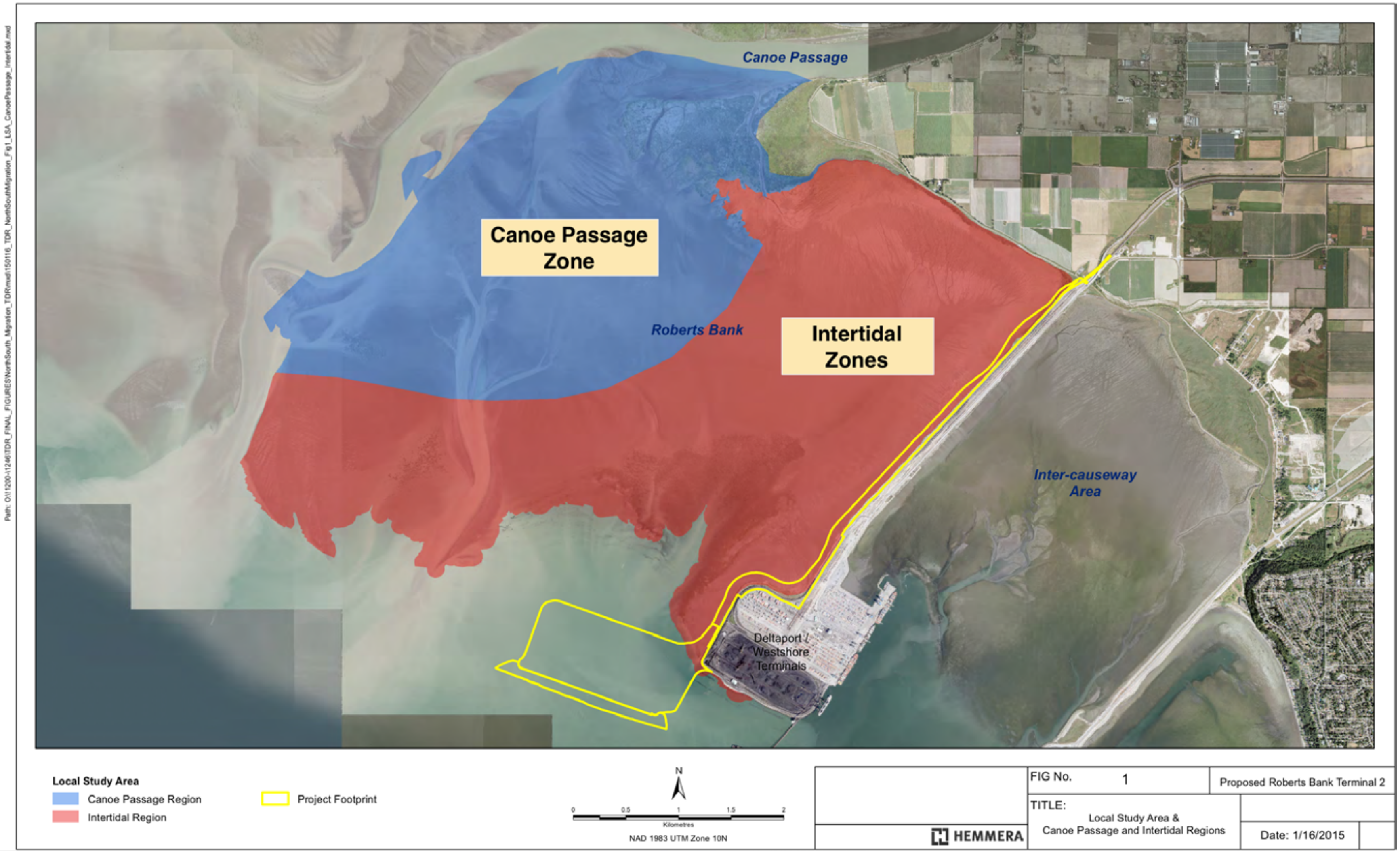
WorleyParsons (2015a) proposed four distinct zones (i.e., Canoe Passage, Upper, Mid-, and Lower intertidal) within the LSA. These designations were retained in the SFOM for macrofauna and meiofauna analyses, with the exception that the Upper, Mid- and Lower intertidal zones were combined into a single zone (the Intertidal Zones; **Figure 2**). The Canoe Passage and Intertidal Zones designations were retained because each zone was believed to represent distinct conditions that may affect abundances of biofilm, meiofauna, and macrofauna.

Model predictions for biofilm, meiofauna and macrofauna were restricted to the spatial area encompassed by field sediment sample collection (i.e., within 3.3 km to 3.5 km of the natural shoreline). For biofilm this included the first 3.5 km of Canoe Passage and the Upper and Mid-intertidal zones (**Figure 4**). For infauna samples (i.e., meiofauna and macrofauna) model inference was restricted to the first 3.3 km of both Canoe Passage and the Intertidal Zones (**Figure 5**).

3.1.2 Regional Study Area

The RSA encompasses a large proportion of the FRE, starting just south of the Vancouver International Airport (Sturgeon Bank) and extending south and east through Sturgeon Bank, Roberts Bank, and Boundary Bay (**Figure 3**). The RSA was further broken up into five main study stratum: Sturgeon Bank, Westham Island, Brunswick Point, Inter-causeway, and Boundary Bay. For the purposes of this study, Mud Bay was included within the Boundary Bay stratum. Further designations include the West Bank (i.e., Sturgeon Bank, Westham Island, and Brunswick Point) and the South Bank (i.e., Inter-causeway and Boundary Bay). The stratum and bank designations were believed to represent differing environmental conditions (e.g., differences in sediment quality) and were incorporated into RSA abundance models as required.

Figure 2 Local Study Area Zones used in the Foraging Opportunity Assessment

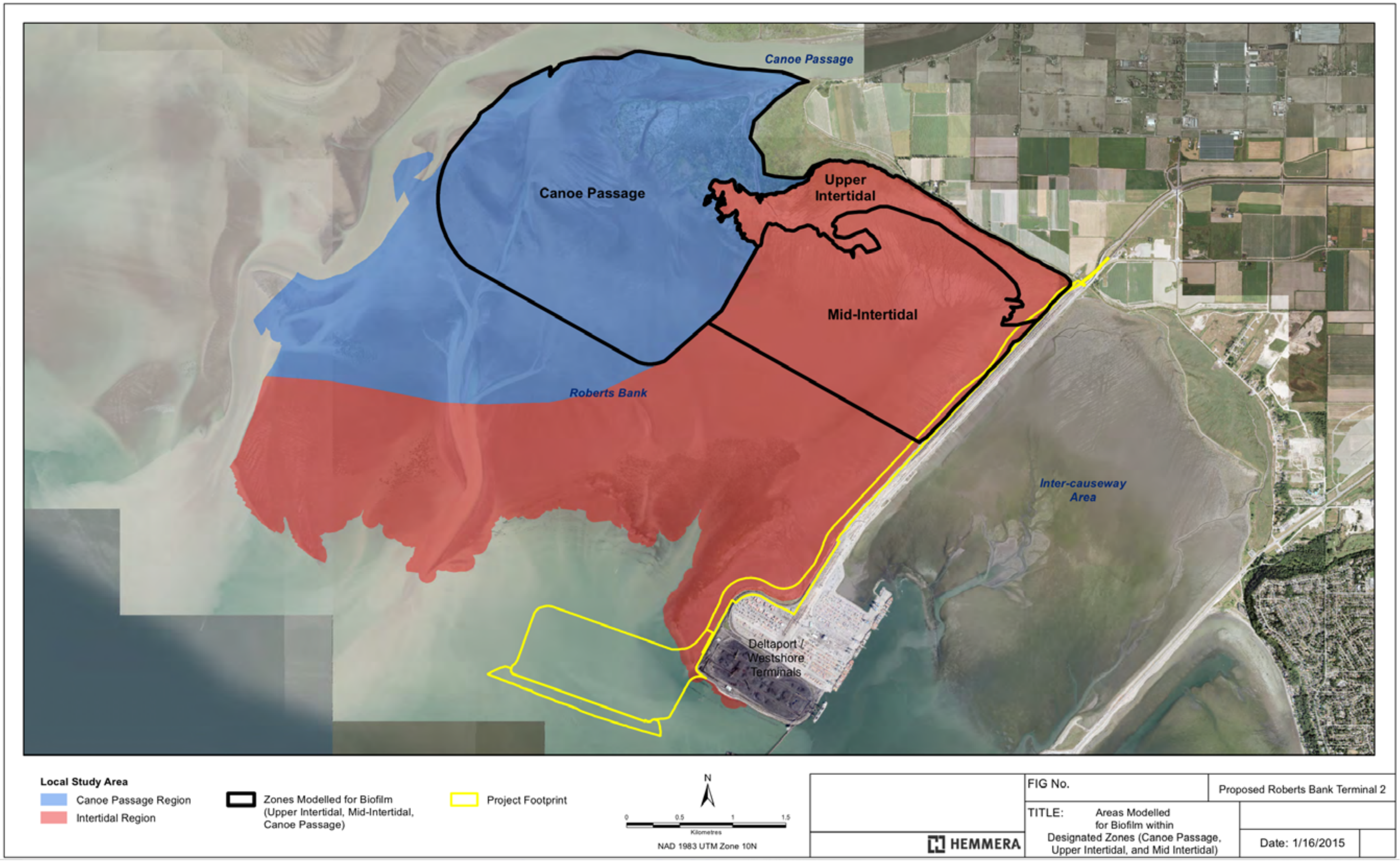


Note: WorleyParsons (2015a) proposed four distinct zones (i.e., Canoe Passage, Upper, Mid-, and Lower intertidal) within the LSA. These designations were retained, with the exception that all intertidal zones were combined into a single designation.

Figure 3 Regional Study Area with Stratum Used in Assessment Study

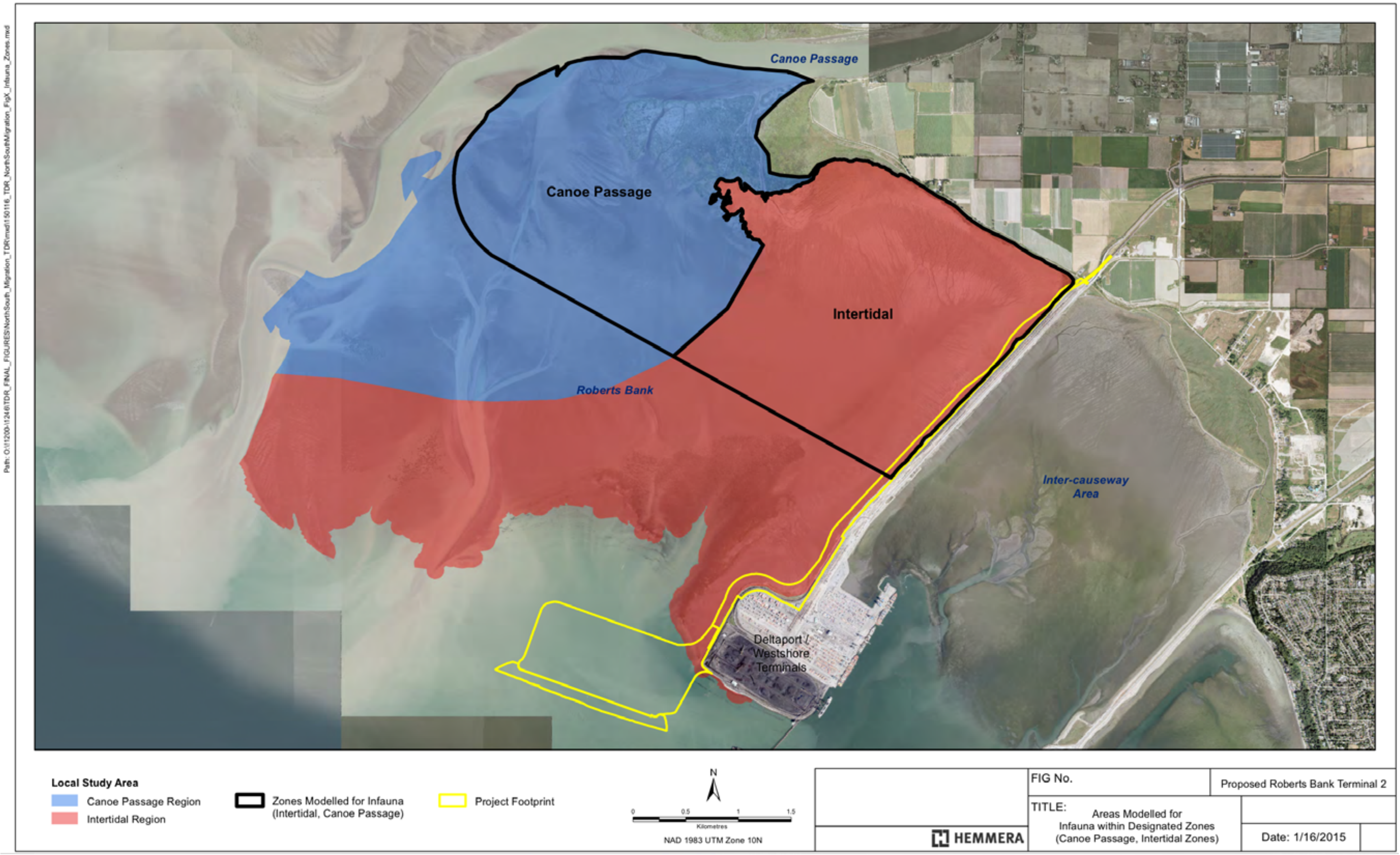
Note: The five stratum designations where chosen for the differing environmental conditions represented within each area. Initial exploratory analyses revealed differences in the variables of interest within these five areas. The LSA (**Figure 2**) consists of the Brunswick Point stratum. The West Bank was defined as Sturgeon Bank, Westham Island, and Brunswick Point, while the South Bank was defined as the Inter-causeway and Boundary Bay. The 1 ha **grid cells** used in the SFOM are indicated.

Figure 4 Area of Inference for Biofilm Analyses within the Local Study Area



Note: Due to the spatial extent of biofilm sampling, study results for the LSA were restricted to the first 3.5 km of the Canoe Passage zone, and all of the upper and mid-intertidal zones. Area of biofilm inference is highlighted with the solid line.

Figure 5 Area of Inference for Infauna Analyses within the Local Study Area



Note: Due to the spatial extent of infauna sampling, study results for the LSA were restricted to the first 3.3 km of both Canoe Passage and the Intertidal Zones.

3.2 TEMPORAL SCOPE

Shorebird foraging opportunity studies were intended to establish the current-day (Existing conditions) food abundances (and by extension foraging opportunity) in the LSA (**Figure 2**) and the RSA (**Figure 3**). Because migrations occur in two phases (i.e., northward and southward; Butler et al. 1987), sampling of food abundances and usage occurred within these migration windows (**Table 2**). Sampling also occurred over multiple years (2012 and 2013) so that year-to-year variation may also be included. Northward migration typically occurs from mid-April to early May (Butler et al. 1987, Drever et al. 2014). Southward migration is more protracted starting in July and extending to mid-September (Butler et al. 1987). The biofilm hyperspectral survey was performed on July 31, 2012 (ASL Environmental Sciences 2013).

Table 2 Summary of the Temporal Scope of Study Sampling Programs

Sampling Program	2012		2013	
	Northward	Southward	Northward	Southward
Biofilm	Apr 18 – May 7	Jul 31	Apr 25 – May 7	Aug 17 – Aug 23
Infauna (Meiofauna/Macrofauna)	Apr 18 – May 7	Jul 2 – Aug 28	Apr 16 – May 7	Jul 11 – Sep 6
Dropping Counts (Usage)	Apr 17 – May 7	Jul 2 – Sep 18	Apr 15 – May 7	Jul 14 – Sep 9

3.3 STUDY METHODS

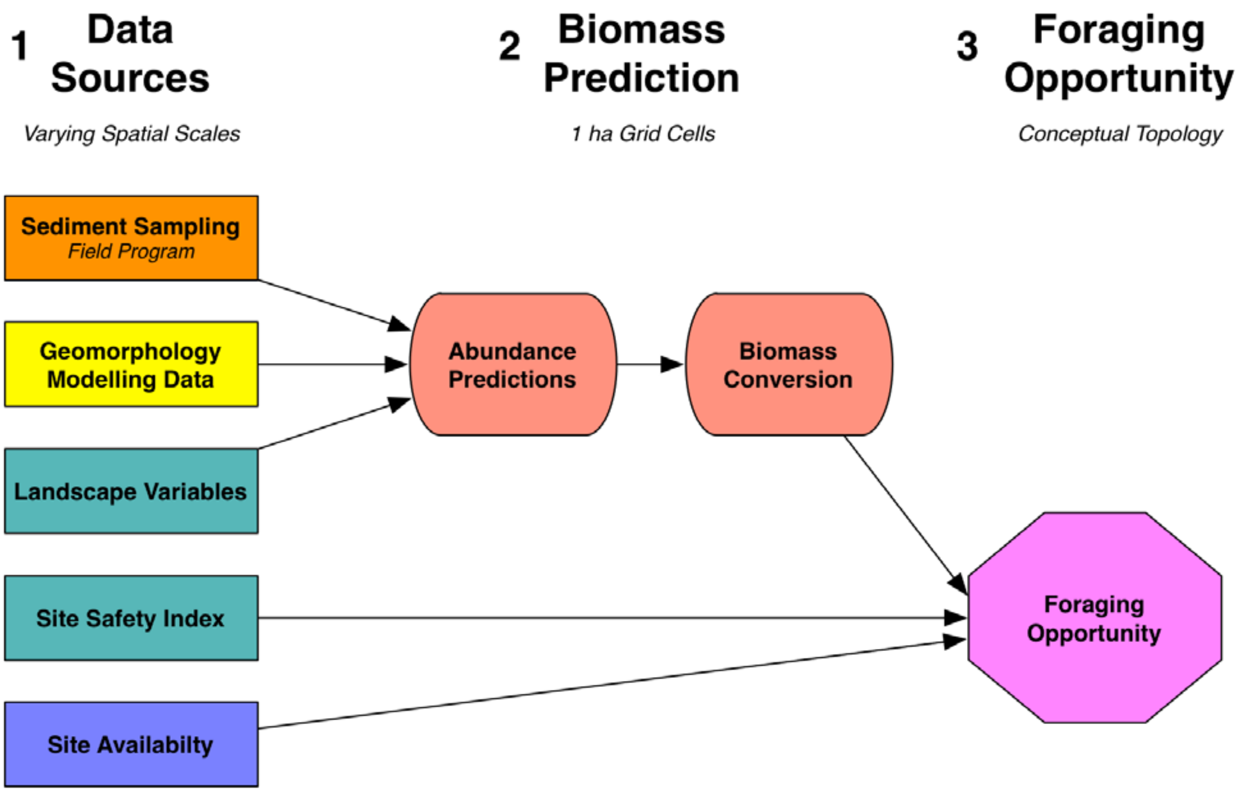
For procedures detailing collection, processing, and analyses of biofilm, sediment samples and hyperspectral data, see WorleyParson (2015a, b). For procedures detailing the hyperspectral survey assessing chlorophyll *a* as a measure of biofilm abundance in the LSA, see ASL Environmental Sciences (2013). For procedures detailing methods pertaining collection and processing of infauna samples, see Hemmera (2014a). For procedures detailing methods pertaining to collection of shorebird droppings distribution, see Hemmera (2014b).

3.4 DATA ANALYSIS

3.4.1 Overview of Approach to the Shorebird Foraging Opportunity Model

The SFOM, as specified by the Biofilm and Shorebird TAG, represents a multi-step approach that relies on a mixture of statistical models and a type of 'ledger sheet' approach in order to quantify opportunity (**Figure 6**). As a first step, estimates of food abundance (mg/m^2 or g/m^2) were determined across the LSA, or the RSA, for a series of contiguous 1 hectare (ha: 10,000 m^2) **grid cells** (**Figure 7**). These estimates were derived from spatially explicit models (i.e., **regression-kriging** models) that incorporated data on food abundances, sediment characteristics from samples taken in the LSA and RSA (Hemmera 2014a, b; WorleyParson 2015a, b), geomorphology modelling data, and other known landscape variables. Models were tailored to the goals of estimating abundances in either the LSA or the FRE.

Figure 6 Workflow for the Shorebird Foraging Opportunity Model



Note: Sediment sampling involved taking samples of food sources and sediments in the intertidal mudflats in the LSA and RSA. The geomorphology modelling data predicted physical processes occurring within the LSA under Existing and With Project conditions. Other landscape variables (e.g., distance to shore, distance to marsh) and site safety were determined by GIS tools. Site availability was based on a combination of high-resolution elevation and tidal data.

Within the LSA, abundance models included the 2012 geomorphology modelling data (Northwest Hydraulic Consultants 2014). Geomorphology modelling results made under the existing 2012 conditions were used to generate Existing condition abundance estimates, while geomorphology modelled results made with the Project in place were used to generate With Project abundance predictions. Abundance values for each grid cell were then converted to biomass (i.e., g or mg) and combined with measures of site safety and tidal availability to produce final estimates of foraging opportunity for each scenario (**Figure 6**). Comparisons of Existing and With Project opportunity were only made within the LSA due to the spatial scope of predicted geomorphological changes.

Estimates of Existing foraging opportunity were compared to 2012 shorebird usage data within the LSA as the verification step proposed by the TAG. Usage estimates were based on shorebird dropping density surveys conducted at the same time as infauna and biofilm sampling (Hemmera 2014a, b; WorleyParson 2015a, b). Usage estimates in the LSA were summarised to the same 1 ha grid used for abundance estimates so that usage and opportunity could be directly compared.

As an added component, current shorebird usage and the capacity of the LSA to support shorebirds was also estimated so that any changes in foraging opportunity could be compared between Existing conditions and the With Project scenarios.

Finally, estimates of existing abundance and biomass for each food source, along with usage, were also generated across the RSA so that characteristics of shorebird foraging opportunities in the LSA could be compared to surrounding areas. RSA abundance models did not include geomorphology modelling data because of a lower spatial resolution in areas outside of the LSA.

Figure 7 Local Study Area Overlaid with Grid Cells

Note: Each grid cell has an area of 1 ha. Food source abundance and shorebird usage predictions were generated on a per grid cell basis. Analyses using the predicted grid cells that were less than 1 ha in size (e.g., edge cells) were either excluded from the analysis or values were adjusted to account for the smaller area.

3.4.2 Spatial Abundance Predictions of Food Sources

Abundance predictions were made using regression-kriging models using `gstat` package for geospatial modelling (Pebesma 2004) in the R statistical environment (R Core Team 2014). Abundance predictions were created for each 1 ha grid cell and were in a density unit (e.g., mg/m^2 or g/m^2) which reflected the measurement unit used in the sediment sampling program. Predictions were made for biofilm (using chlorophyll *a* as a proxy), meiofauna, and macrofauna abundance based on the biofilm (WorleyParsons 2015a) and infauna (Hemmera 2015a) sampling programs respectively. Chlorophyll *a* sampling and predictions were in units of mg/m^2, while infauna sampling and predictions were in units of g/m^2. The LSA models only used samples taken in the Brunswick Point stratum, while all available samples were used for the RSA models (see **Table 3** for chlorophyll *a* sample sizes and **Table 4** for infauna sample sizes).

Table 3 Sample Sizes for Biofilm (Chlorophyll *a*) Sediment Sampling Program

Stratum	2012		2013		TOTAL
	Northward	Southward	Northward	Southward	
Boundary Bay	34	–	–	–	**34**
Brunswick Point	56	33	42	42	**173**
Inter-causeway	15	8	5	5	**33**
Sturgeon Bank	37	–	–	–	**37**
Westham Island	24	–	–	–	**24**
All Areas Combined	**166**	**41**	**45**	**49**	**301**

Note: Brunswick Point samples were used for the LSA analyses. For details on the sampling program and spatial distribution of sampling locations see WorleyParsons (2015a).

Table 4 Sample Sizes for the Infauna Sediment Sampling Program

Stratum	2012		2013		TOTAL
	Northward	Southward	Northward	Southward	
Boundary Bay	42	58	30	28	**158**
Brunswick Point	55	66	28	33	**182**
Inter-causeway	14	23	15	15	**67**
Sturgeon Bank	32	52	30	30	**144**
Westham Island	23	31	20	17	**91**
All Areas Combined	**166**	**230**	**123**	**123**	**642**

Note: Brunswick Point samples were used for the LSA analyses. For details on the sampling program and spatial distribution of sampling locations see Hemmera (2015a).

3.4.2.1 Regression-kriging General Procedure

Regression-kriging combines standard generalised least squares regression techniques with kriging techniques that consider spatial autocorrelation. The fitting of a regression-kriging model is done in stages. First the regression (trend) between response or target variables (food source abundance), and potential explanatory variables must be determined or assumed. The regression structure was determined by using the sediment samples to investigate associations between food source abundances and potential explanatory variables. To be considered as a potential explanatory variable, a value needed to be known for all grid cells in the prediction area, otherwise an abundance prediction is not possible. Observations and predictions in close proximity can be expected to be more similar due to spatial proximity. Once the regression structure was known, the spatial auto correlational structure was determined using an empirical variogram. Anisotropy (i.e., non-symmetrical auto correlation) was checked and adjustments were made to the auto correlation model when required. The auto correlational structure allowed the abundance models to correct for spatial proximity.

After the regression trend and auto correlational structures were determined, regression-kriging was then fit to the sediment sampling points, and biomass predictions were generated for the spatial area of interest. These predictions were then saved and used in downstream opportunity analyses. As part of the model fitting process, leave-one-out cross validation was also used to investigate model fit (Hengl 2009, Pebesma 2004). Leave-one-out cross validation refits the regression-kriging model leaving out each observation once. On each refit, a biomass prediction for excluded observation was made and compared to the original value. These residuals were then checked for assumptions of normality and used to provide an estimate how much variation in the observations was explained by the model.

Finally, for models predicting biomass in the LSA, focus was placed on incorporating the geomorphology modelling data (see Northwest Hydraulic Consultants 2014). Outside of the LSA, exploratory analyses revealed that the geomorphology modelling data were not at a sufficient spatial resolution to make accurate biomass predictions. For biomass predictions across the RSA a different set of explanatory variables were used (see **Section 4.5.1**).

3.4.2.2 Determining the Regression Structure

Due to the large number of available variables, a two-step approach was taken when determining the regression model structure. The model needed to adequately describe variation, yet remain relatively general to ensure predictions could be as robust as possible, especially when extrapolating under With Project conditions.

Visualization techniques were used to choose a set of explanatory variables that were then passed to a model ranking routine used to choose the final regression model. Visualizations consisted of scatter plots of biofilm, meiofauna, and macrofauna abundances derived from sediment samples plotted against all possible remaining explanatory variables (see **Section 3.4.2.3**). To look for consistent trends, scatterplots were repeated for each study stratum (**Figure 3**) and by season and year. Appropriate data transformations for explanatory variables were also chosen at this time (e.g., logit transformation for proportions, square root for distances, and log transformations for any heavily skewed variables). Transformations were chosen to reduce characteristics such as skew, as well as to produce linear relationships with the target variable (e.g., food abundance).

In all cases, visualizations used log transformation of the target variable (i.e., measured abundance values) due to the highly skewed nature of all three measures (i.e., chlorophyll *a*, meiofauna and macrofauna) and the Gaussian assumption required for regression-kriging methods. For chlorophyll *a* abundance values, corrected residuals of log transformed values were used in place of raw log transformed abundances (see Known Confounding Factors; **Section** 3.4.2.3). Once a correction for sampling technique was applied to sediment chlorophyll *a* measurements, observed trends became much more consistent and overlaid well between years.

Explanatory variables (see **Section 3.4.2.3**) shown to have strong descriptive power were iteratively included, a revised model was then fit, and resulting model residuals were compared to remaining explanatory variables not currently included in the fitted model. This process was repeated until the remaining factors contributed little to explaining remaining model variability. Identified explanatory variables were then passed to the final selection process (see Final Model Selection). In cases of high multicollinearity between explanatory variables, a subset of variables was chosen that minimised multicollinearity.

Final Model Selection

In order to create the final regression model used for inference, the main set of explanatory variables identified by the visualization techniques along with secondary interactions terms were then passed to a stepwise regression procedure using the **Akaike Information Criterion** (AIC) statistic as the selection criteria. All descriptive variables were also scaled and centered by subtracting the mean value of the respective variable and dividing by the respective standard deviation for that variable. Descriptive variables used in the model selection process had mean of zero and a standard deviation of one. The use of centered and scaled explanatory variables allowed variance inflation factors (a measure of multicollinearity) to be more interpretable (especially for polynomial terms) and ensured that computer round-off errors were minimised.

3.4.2.3 Explanatory Variables

The explanatory variables used for the regression model fell into two broad categories, geomorphology modelling data (see Northwest Hydraulic Consultants 2014) and other GIS landscape variables available at the time of analysis.

Geomorphology Modelling Data

Geomorphology modelling data included four main parameters (i.e., water column salinity, wave height, shear stress, and bottom velocities) and was based on the conditions in the year 2012. Modelled data were available as monthly percentiles (i.e., 10^{th}, 50^{th}, and 90^{th} percentiles) and as a percentile computed from May to July. As options were investigated, monthly percentiles were determined to be more strongly correlated with sampled abundance values than percentiles computed over the interval of May to July. For water column salinity, monthly 50^{th} percentile values showed the strongest and most consistent correlation with abundance measurements, while for wave height, shear stress, and bottom velocities, the 90^{th} percentile values showed the strongest and most consistent correlation. For the northward shorebird migration, May percentiles were used, while for the southward migration, July percentiles were used, as these best matched the sediment sampling periods.

Other Auxiliary Landscape Variables

Other landscape variables also considered included:

- A variety of distance measures including:
    - Distance to fresh water (separated into three discharge size classes);
    - Distance to the natural shoreline; and
    - Distance to seasonal marsh line based on the Terrain Resources Inventory Management (TRIM) database.
- Sediment texture (percent sand 0.063mm to 2.0 mm);
- Total organic carbon (TOC); and
- Habitat type.

From these explanatory variables, sediment texture and TOC were excluded in the LSA analyses because they were not known across the landscape and were known to be highly correlated with the geomorphology modelling parameters. For the RSA predictions, sediment texture and TOC were included after first creating prediction surfaces for each variable.

Known Confounding Factors

The biofilm sediment sampling technique changed between 2012 and 2013, with a 10 mm core depth used in 2012 and a 2 mm core depth in 2013 (WorleyParsons 2015a). As a result, the core collected in 2012 contained a larger volume of material and likely more chlorophyll *a* for the same area sampled. A preliminary analysis showed that a simple offset appeared to largely correct for this difference producing similar trends with other explanatory variables after the correction was applied. This approach was later expanded to also include the elevation of the sample (see **Section 4.1.1**), which can be viewed as a proxy for expected abundance because the difference between sampling techniques can be expected to change with the underlying abundance level. The change in technique was also confounded with year effects. As such, it is not possible to comment on whether the offset used actually accounts for sampling technique differences, differences between years, or both effects combined.

3.4.3 Predicting Abundance of Food Sources under Existing and with Project Conditions

Abundance predictions of shorebird food sources from the models were made on the log scale, and then back transformed to the anti-log scale (i.e., regular scale). Back transformations were generated based on the formula for the log-normal distributions, as original model predictions should be normal on the log scale.

With Project abundance predictions in the LSA were made using the same fitted model as predictions under Existing conditions, but predictions were made using geomorphology modelling data that reflected With Project conditions instead of Existing conditions. The geomorphology modelling data associated with sediment samples, and used to estimate correlational relationships, was not altered. All other explanatory variables remained the same between Existing and With Project predictions. Finally, all chlorophyll *a* predictions represent abundance that would be observed in 2 mm sampling cores, and correspond to the chlorophyll *a* present in the first 2 mm of sediment within the mudflat.

3.4.3.1 Estimating Change in Total Biomass and Total Available Biomass

Grid cell abundance estimates were converted to estimates of biomass by expanding the abundance estimate (i.e., mg/m^2 or g/m^2) by the grid cell area (i.e., 10,000 m^2). These estimates of biomass were then combined to derive an estimate of **total biomass** for an area of inference (e.g., Canoe Passage) in the LSA. **Total available biomass** estimates were derived in a similar manner, except grid cell specific biomass estimates were further multiplied by the weekly tidal exposure period (see **Appendix A: Figure 41**) before summing together individual contributing grid cells. Estimates of total biomass and total available biomass were determined for both Existing conditions and With Project conditions by using the respective abundance predictions. All With Project estimates of total biomass and total available biomass excluded grid cell values associated with the proposed Project footprint.

A percent change statistic for both total biomass and total available biomass was then computed relative to Existing conditions. Because grid cell abundance predictions were not independent, error propagation of the percent change statistics was investigated using Monte Carlo techniques. This allowed the impacts of spatial covariance on percent change biomass calculations to be determined. Predictions from regression-kriging models involve contributions from the regression component as well as the spatial error component. The spatial error component contributes to varying degrees of covariance between grid cell predictions, which in turn can affect how the various biomass percent change calculations vary. Stochastic Conditional Gaussian Simulations, as implemented in the gstat package (Pebesma 2004), were used to generate a distribution of abundance surfaces under Existing and With Project conditions.

In total 1,000 abundance surfaces were generated under each condition. For each set of abundance surfaces (i.e., Existing and With Project), the total biomass and total available biomass percent change statistics were computed providing a distribution of percent change statistics. This final distribution was used as an approximation for the true sampling distribution. The average percent change was used as an estimate of the mean, and 95% confidence intervals were determined based on the 2.5 and 97.5% distribution percentiles.

3.4.4 Assessing Usage and Total Usage

Shorebird usage of the FRE was assessed using methods developed by the Centre for Wildlife Ecology (CWE) and described in Pomeroy (2005). Dropping (i.e., fecal) densities (# droppings/15 m^2) were counted along transects across the LSA and RSA (Hemmera 2014b). Dropping densities provide a sensitive and convenient measure of the intensity of spatial usage because they are produced frequently by foraging shorebirds (e.g., 0.5 droppings/minute for WESA) and are washed away during high tide periods (Pomeroy 2005). Estimates of usage on a 1-ha grid cell basis were determined and then used to inform estimates of total usage in a given area.

3.4.4.1 Assessing Usage at Each 1-ha Grid Cell

Data were based on droppings surveys that occurred concurrently with the biofilm and infauana sampling (see **Table 5** for sample sizes). The usage data was highly skewed and suffered from zero inflation; therefore, droppings data were transformed $\left(\log(1+x)\right)$and **inverse distance weighting** (IDW) was used to interpolate shorebird dropping densities to the 1-ha grid cells across the intertidal mudflats (Shepard 1968). IDW is a deterministic spatial interpolation method that makes no statistical assumptions. Zero inflation prevented the use of statistical methods such as an ordinary Kriging surface or regression-kriging as the higher zero counts could not be sufficiently explained with the available explanatory variables, resulting in model lack-of-fit.

The high zero count likely resulted from shorebird usage being a dynamic process combined with the narrow observational window (droppings are removed after each tidal cycle). While these zeros are real, they do necessarily reflect the lack of usage in that area over the period of interest (i.e., the migration period) rather than part of a single day (e.g., tidal cycle). As a result, the IDW interpolation may be a useful approximation of usage at each 1-ha grid cell, as it will integrate information across multiple days within a period. Back transformed values can be viewed as an estimate for the geometric mean weighted by distance, a measure of center that is similar to other measures (e.g., median), in that it is not strongly influenced by data skew. Interpolations on the log scale were, however, used to derive estimates of total usage on the anti-log scale (see **Section 3.4.4.2**). Separate IDW surfaces were fit for each year and migration period (**Table 5**).

Table 5 Sample Sizes for the Shorebird Dropping Density Surveys

Stratum	2012		2013		TOTAL
	Northward	Southward	Northward	Southward	
Boundary Bay	2,208	2,662	1,773	2,215	**8,858**
Brunswick Point	520	1,265	913	927	**3,625**
Inter-causeway	409	325	221	309	**1,264**
Sturgeon Bank	1,423	1,429	974	831	**4,657**
Westham Island	440	1,203	476	652	**2,771**
No Designation	218	659	530	493	**1,900**
All Areas Combined	**5,218**	**7,543**	**4,887**	**5,427**	**23,075**

Note: Brunswick Point samples were used for the LSA analyses. For details on the sampling program and spatial distribution of sampling locations see Hemmera (2014b). No designation indicates samples outside of defined strata. These samples were included to help inform interpolated values near a stratum boarder.

3.4.4.2 Estimating Total Usage

Total usage for a given stratum (e.g., Inter-causeway, Boundary Bay) or another subset of grid cells was computed by first estimating mean and standard deviation of the usage density, based on the 1-ha grid cell IDW interpolation (see **Section 3.4.4.1**). Estimates of total usage (on the anti-log scale) were then computed based on the assumption that, when present, dropping counts followed a log-normal distribution. Values from the IDW interpolation for the stratum of interest were combined to provide an estimate of mean and standard deviation on the log scale. The mean (anti-log scale) usage for the area was then determined using the expected value of a log-normal distribution, where $\mathrm{E}[X] = e^{\mu + \sigma}$ is the expected value for the log-normally distributed random variable X and μ and σ are respectively the mean and standard deviation of the variable's natural logarithm. This provided an estimate of average dropping density (# droppings/15 m^2), which was then expanded by the total area to provide an estimate of the total usage.

Similar to the 1-ha grid cell estimates of usage, the reported total usage is a proxy for actual usage. This approach also down-weights the importance of zero counts that may simply represent instantaneous moments in time without usage and not reflect the lack of usage over the migration period of interest.

3.4.5 Creation of the Foraging Opportunity Topology and Total Usage Topologies

Foraging opportunity and total usage topologies were created to visualise the interplay between safety, food abundance, and either total available biomass or total usage across the landscape. Topologies were constructed by first creating a series of two-dimensional bins of the 1-ha grid cells based on food abundance (x-axis) and **safety index** (y-axis) values. Food abundance values were based on kriging-regression predictions and the safety index was measured as the distance (m) to the nearest shoreline; either the natural shoreline or the Roberts Bank causeway. Shoreline represents obstructive cover which can heighten vulnerability to predation (Pomeroy 2006, Pomeroy et al. 2008). Usage could be summarised in a similar manner because the regression-kriging models did not employ any sharp cut-offs. As a result, abundance levels were predicted for every grid cell (some at very low levels) allowing usage to be summarised effectively even for areas with high usage and very low food abundances.

For each two-dimensional bin grouping of 1-ha grid cells, either total available biomass or total usage was computed and used to define the respective topology surface. Total available biomass was computed by expanding the abundance estimate of each grid cell (either mg/m^2 or g/m^2) by the area and total tidal exposure time (see **Appendix A: Figure 41**) to provide an estimate of available biomass for each grid cell (mg x hrs or g x hrs). Grid cell-specific estimates were then combined for an estimate of available biomass for a particular combination of safety and abundance. Total usage was computed for each two-dimensional bin separately as specified in **Section 3.4.4.2**. The resulting measure of available biomass represents energy (z-axis) and was used as the height of the topology surface for a given combination of safety and food abundance. This topology was used to define the foraging opportunity for a given food source. The total usage topology was created in the same way, but topology height (z-axis) represents total usage within an opportunity coordinate rather than energy.

After total available biomass and total usage were computed for every two-dimensional bin, a local polynomial trend surface was fit to these bin values to smooth out noise related to how the bins were constructed (e.g., number of bins and choice of cut-points). The local polynomial trend surface was fit using the `loess` procedure in R (R Core Team 2014). The resulting surface was then normalised to ensure that the total energy or total usage matched the original two-dimensional bin totals. After the smoothed surface was fit, the resulting topology surface was compared to topologies constructed using raw bin values to ensure the major features were retained and that the general form and structure remained consistent.

3.4.6 Capacity Analyses during the Northward and Southward Migration Periods

An additional component added to this TR, beyond the TAG recommendations, were estimates of system capacity during the northward and southward migration periods. Capacity analyses attempted to assess the consumption of shorebird foods (i.e., biomass) in the LSA during the migration periods based on Existing conditions. Two approaches were taken to assess capacity in the LSA. The first approach compared the distribution of total available food and total usage, ignoring safety. Using the simplifying assumption that consumption cannot exceed food availability, an upper bound to utilization was developed. This approach was used to assess biofilm, meiofauna, and macrofauna capacity during the 2012 northward and southward migration periods. The second approach, termed the biofilm standing stock capacity analysis, compared the total biofilm biomass (derived from chlorophyll *a* concentrations) available in the LSA on a given day (based on the hyperspectral survey; ASL Environmental Sciences

2013) to the energetic demands produced by historical daily numbers of shorebirds during migration (Drever et al. 2014). This approach provided a second assessment of utilization and potential capacity of the system to accommodate change.

Neither capacity analysis considered safety or predation risk. While safety is known to affect individual foraging decisions (e.g., Lank et al. 2003, Pomeroy 2006, Pomeroy et al. 2008), individuals may also change their risk tolerance in response to current environmental conditions and food quality. The nature of future trade-offs cannot be known and, as such, investigations into capacity needed to exclude considerations of safety.

3.4.6.1 Capacity 1 – Estimating Capacity by Comparing Available Biomass and Usage Distributions

The distribution of available biomass and usage were created using a similar approach as the foraging opportunity and usage topologies (**Section 3.4.5**). Instead of creating two-dimensional bins of grid cells based on predicted food abundance and the measured safety index, equally spaced one-dimensional bins were created based on the range of predicted food abundances. For each bin the associated grid cells were identified and available biomass (i.e., g meio/macrofauna x hr or mg biofilm x hr; see **Section 3.4.5**) and total usage (i.e., droppings per ha; **Section 3.4.4.2**) values were computed. These bin totals could be visualised in a manner akin to a histogram, with height representing available biomass (a proxy measure of energy) or total usage, rather than frequency of occurrence. Instead of presenting bin totals, a smooth function (spline; R Core Team 2014) was fit to the center of the bin heights and the area was normalised to one in order to create an approximation of a density curve. Density curves were then further scaled to match the maximum energy or usage for a particular comparison. For example, total available biomass was computed based on LSA zones (**Figure 2**) and migration period. The availability density curve of the zone by migration combination with the highest total available energy was set to an area of one. Density curves for other zone by migration combinations were then scaled down (i.e., areas less than one) to reflect ratio total available biomass relative to the maximum. Total usage density curves were scaled in a similar manner, but based on the maximum zone by migration of total usage. All total usage curves where then further scaled by an equal amount such that for all zone by migration combinations, usage could not exceed availability. The overlapping area of the two curves was viewed as representing current consumption, while the area outside the usage curve was considered excess capacity. This additional usage scaling also assumed that shorebirds (e.g., WESA) spent the majority of their time foraging in 2012.

3.4.6.2 Capacity 2 – Estimating Biofilm Capacity, the Biofilm Standing Stock Analysis

Biofilm capacity was also estimated through a Monte Carlo simulation using a energetics approach and an independent estimate of biofilm standing stock (ASL Environmental Sciences 2013). The single day hyperspectral survey provided an estimate of the total biofilm available (i.e., the standing stock) in the LSA. Because biofilm productivity has been shown to vary by roughly 20% between neap and spring tides and the hyperspectral survey was conducted at a time of higher biofilm productivity (WorleyParsons 2014b), the standing stock was reduced by a further 10% to account for differences in day-to-day productivity. The biofilm standing stock was determined for each day of the 31-day period (April 15 to May 15) of the northward migration by drawing down the standing stock based on changes to daily demand by shorebirds and allowing for a period of daily recovery. Biofilm capacity was measured daily as the ratio between supply and demand, with a daily ratio of 10 indicating that biofilm standing stock was 10 times the required biofilm to support a given population size. The process was then repeated under differing estimates of With Project biomass change. For each scenario, 1,000 independent population draws were considered in order to estimate the distribution of daily energy ratios.

Daily biofilm demand was determined based on historical WESA and DUNL abundance surveys conducted during northward migration from 1991 to 2014 (see Drever et al. 2012). The random effects model estimated by Drever et al. (2012) was used to generate local population sizes for each day of the 31-day period, and corresponding feeding demands were determined in units of daily dry mass chlorophyll *a* consumption. First, the biofilm energy content per unit of dry mass chlorophyll *a* was determined (**Table 6**), which was then used to determine the likely rate of dry mass chlorophyll *a* consumption for WESA (**Table 7**) and DUNL (**Table 8**) based on estimates of daily energy expenditures (DEE) and contribution of biofilm to the daily energy requirements. The DEE used for WESA was 108 kJ/d (Kuwae et al. 2008). The DUNL DEE was estimated at 180 kJ/day using the methods of Kuwae et al. (2012), but with substituted parameters including a species-specific BMR for DUNL (49 kJ/day, Kelly and Weathers 2002, Gutiérrez et al. 2011) and a fattening rate at the high end of the typical range documented for *Calidris* sandpipers (ca. 2%, Zwarts et al. 1990) to provide a conservatively high estimate of energy consumption (as described in St. Clair 2012). Estimates of individual daily consumption were then expanded against the respective daily population sizes in order to determine total chlorophyll *a* (i.e., biofilm) demand on a given day.

Daily biofilm recovery was determined based a daily recovery curve (**Appendix A: Figure 47**), which was based on results from lab and field experiments (Tolhurst et al. 2007, WorleyParsons 2014).

Table 6 Estimation of Biofilm Energetics Based on Chlorophyll *a* Content

Measurement	Values	Reference
Microphytobenthos carbon content per mg of chlorophyll *a* (dry weight); *A*	40x	deJonge (1980)
Microphytobenthos carbon contribution to total biofilm total carbon content; *B*	7%	Per comm, Kuwae, 2014
Amount of carbon per unit dry biomass in biofilm in the top 2 mm of intertidal soil; *C*	40%	Per comm, Kuwae , 2014
Energy content of biofilm (J/mg dry mass); *D*	0.83[1]	Kuwae et al. (2008)
Biofilm energy content per mg chlorophyll *a* (dry biomass); *E* = (*A* * (100/*B*) * (100/*C*)) * D	1.18 kJ/mg	This study

[1]Original value quoted in kJ/g.

Table 7 Estimated Daily Consumption of Dry Weight Chlorophyll *a* by WESA

Measurement	Values	Reference
Daily energy requirement; *F*	108 kJ/d	Kuwae et al. (2008)
Biofilm contribution to daily energy expenditure; *G*	68%[1]	Kuwae et al. (2008)
Biofilm assimilation efficiency; *H*	75%	Kuwae et al. (2008)
Proportion of biofilm micropatch that can be harvested profitably; *J*	50%[2]	Pers. comm. Ron Ydenberg, Centre for Wildlife Ecology, SFU, 2014
Daily biofilm related dry mass chlorophyll *a* consumption (mg/d); WESA = ((*F* * (*G/100*)* (100/H) * (100/J) / E) / 1000 g/mg	165.2 mg/d	This study

1Estimate includes the potential for nocturnal foraging by WESAs.
[2]Estimated that it could be as high as 100%; however, due to lack of empirical evidence a conservative estimate of 50% was used.

Table 8 Estimated Daily Consumption of Dry Weight Chlorophyll *a* by DUNL

Measurement	Values	Reference
Daily energy requirement; *K*	180 kJ/d	This study
Biofilm contribution to daily energy expenditure; *L*	14%	Kuwae et al. (2012)
Biofilm assimilation efficiency; *H*	75%[1]	Kuwae et al. (2008)
Proportion of biofilm micropatch that can be harvested profitably; *J*	50%[2]	Pers. comm. Ron Ydenberg, Centre for Wildlife Ecology, SFU, 2014
Daily chlorophyll *a* dry mass consumption (mg/d); DUNL = ((*K* * (100/*L*)* (100/H) * (100/J) / E) / 1000 g/mg	56.7 mg/d	This study

[1]Assumed to be the same as WESA
[2] Estimated that it could be as high as 100%; however, due to lack of empirical evidence a conservative estimate of 50% was used.

4.0 RESULTS

4.1 BIOFILM FORAGING OPPORTUNITY IN THE LOCAL STUDY AREA

4.1.1 Predicting Abundance of Biofilm

4.1.1.1 Regression Model

The final regression model used to predict the chlorophyll *a* abundance was of the form:

> *Log Chlorophyll a ~ Technique + Elevation + Technique*Elevation + Seasonal Wave Height + Seasonal Salinity + (Seasonal Salinity)^2 + Marsh Distance + Seasonal Marsh Distance * Elevation*

Variance inflation factors were computed for each of the centered and scaled explanatory variables in the model. All values were within acceptable limits (i.e., less than 10) indicating that multicollinearity was not a problem. The response was log transformed in order to meet statistical assumptions of the regression-kriging approach, which assumes a spatial Gaussian process. The definition of each model parameter is outlined in **Table 9**.

The *Technique* parameter represents the change in the response on the log scale depending on whether a 2 mm core or 10 mm core was used, which is also confounded with year effects. The difference between core depths can be expected to change depending on the underlying chlorophyll *a* abundance. This was represented by the interaction term (*Technique*Elevation*), which allows the difference between techniques to change with elevation. Here elevation is being used as a proxy for underlying abundance, as there is a general increase in chlorophyll *a* with elevation as one moves up the mudflat toward the natural shoreline. As a general rule of thumb, main effects (*Elevation)* are included when an interaction involving that term is also included. The main effect *Elevation* was also supported by the stepwise regression procedure.

The *Seasonal Wave Height* term represents the geomorphology modelling wave height predictions based on 90th percentile computed for either May (northward migration) or July (southward migration). This could represent wave energy and the impact of physical agitation on biofilm.

The *Seasonal Salinity* + *(Seasonal Salinity)*^{2} terms represent the geomorphology modelling water column salinity values (psu) based on 50th percentiles computed over either May (northward migration) or July (southward migration). The support for a second-degree polynomial indicates optimal water column salinity may exist for chlorophyll *a* abundance.

Finally, *Seasonal Marsh Distance* represents the distance to the seasonal marsh line. The interaction term with elevation (*Seasonal Marsh Distance * Elevation)* indicates that the relationship between log chlorophyll *a* abundance and either elevation or distance to marsh is not a strictly additive relationship.

Table 9 Chlorophyll *a* Regression Model Parameters, Role, and Applied Transformations

Model Parameter	Type	Transformation	Description / Interpretation
Log Chlorophyll a	Response	Natural Log	Natural log transformed chlorophyll *a* values (mg/m^2). Regression model predicts changes in terms of orders of magnitude.
Technique	Explanatory	None	Categorical variable accounting for technique used (2 mm or 10 mm cores). Also confounded with year effects.
Seasonal Wave Height	Explanatory	None	Seasonal 90th percentile of the geomorphology wave height modelling value. A May percentile was used for the northward migration and a July percentile for the southward migration. Extreme wave events predict log chlorophyll *a* abundance in a linear manner.
Seasonal Salinity	Explanatory	None	Seasonal 50th percentile of the geomorphology water column salinity modelling value. A May percentile was used for the northward migration and a July percentile for the southward migration. Median salinity predicts log chlorophyll *a* abundance in parabolic fashion (inverted-U) indicating an optimal salinity range.
Seasonal Salinity^2	Explanatory	Squared	
Seasonal Marsh Distance	Explanatory	Square root	Square root transformed distance to the nearest seasonal marsh. Based on spring and summer marsh lines from the TRIM dataset.
Elevation	Explanatory	None	Elevation based on the following datasets, in order of precedence: 1) Lidar 2011; 2) Lidar 2013; and 3) NRCan Multibeam.

Note: All explanatory variables were standardised and scaled prior to fitting the regression model. Variance inflation factor analysis was used to assess multicollinearity of centered and scaled explanatory variables. In all cases, multicollinearly was found to be within acceptable levels.

4.1.1.2 Spatial Abundance Predictions

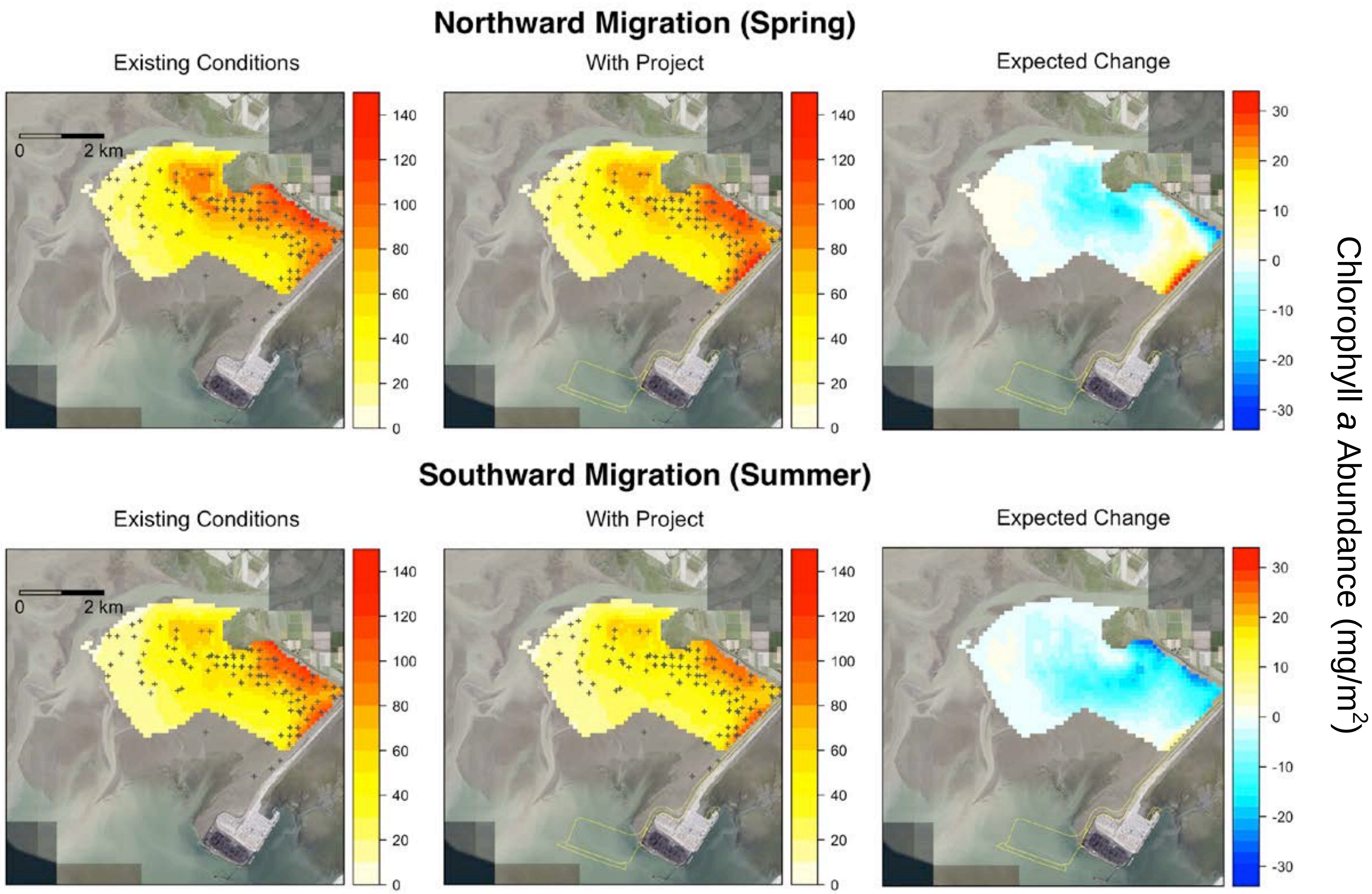
Using the top supported regression model, a regression-kriging surface of chlorophyll *a* abundance (mg/m^2) was created for the northward and southward migration periods under both Existing and With Project conditions (**Figure 8**). Because geomorphology modelling data only predicted conditions for 2012 and because biofilm sampling technique changed between years (i.e., 10 mm sampling cores in 2012; 2 mm sampling cores in 2013), there is no available information to predict year-to-year changes. The surfaces therefore can be interpreted as either predicting chlorophyll *a* abundances found in 2 mm sampling cores, and/or in the year 2013. For the purpose of the study, the surface will be interpreted as predicting values representing chlorophyll *a* abundance in a 2 mm core sample. As all comparisons are being done within a given year/technique combination, this distinction does not impact the investigation into predicted changes to chlorophyll *a* abundance and resulting biofilm foraging opportunity that may result under With Project conditions.

Leave-one-out cross-validation indicated that the model explained roughly 75% of the variation in observed log chlorophyll *a* abundance, which is satisfactory. Investigation of model residuals from leave-one-out cross-validation indicated well-behaved residuals with no indication of a lack-of-fit.

Under Existing conditions, the highest chlorophyll *a* abundances were found close to shore (both the natural shoreline and the Roberts Bank causeway) and away from Canoe Passage (**Figure 8**). Northward migration also showed generally higher biofilm abundances than during the southward migration, which coincides with larger freshwater Fraser River outflows associated with the seasonal freshet.

Under With Project conditions, the overall spatial distribution of biofilm was similar to the distribution under Existing conditions during northward and southward migration, respectively; however, with a shift to lower abundances (**Figure 8**). The change in season specific abundances under With Project conditions can be observed by inspecting the expected change plots (third column; **Figure 8**). Generally, the decrease was reasonably uniform with a decrease along the natural shoreline predicted during both the northward and southward migration periods. While chlorophyll *a* abundances under With Project conditions showed decreases, increases were also predicted to occur along the Roberts Bank causeway, which were largest during the northward migration.

Figure 8 Estimated Chlorophyll *a* Abundance (mg/m²) under Existing and With Project Conditions for the Northward and Southward Migration Periods



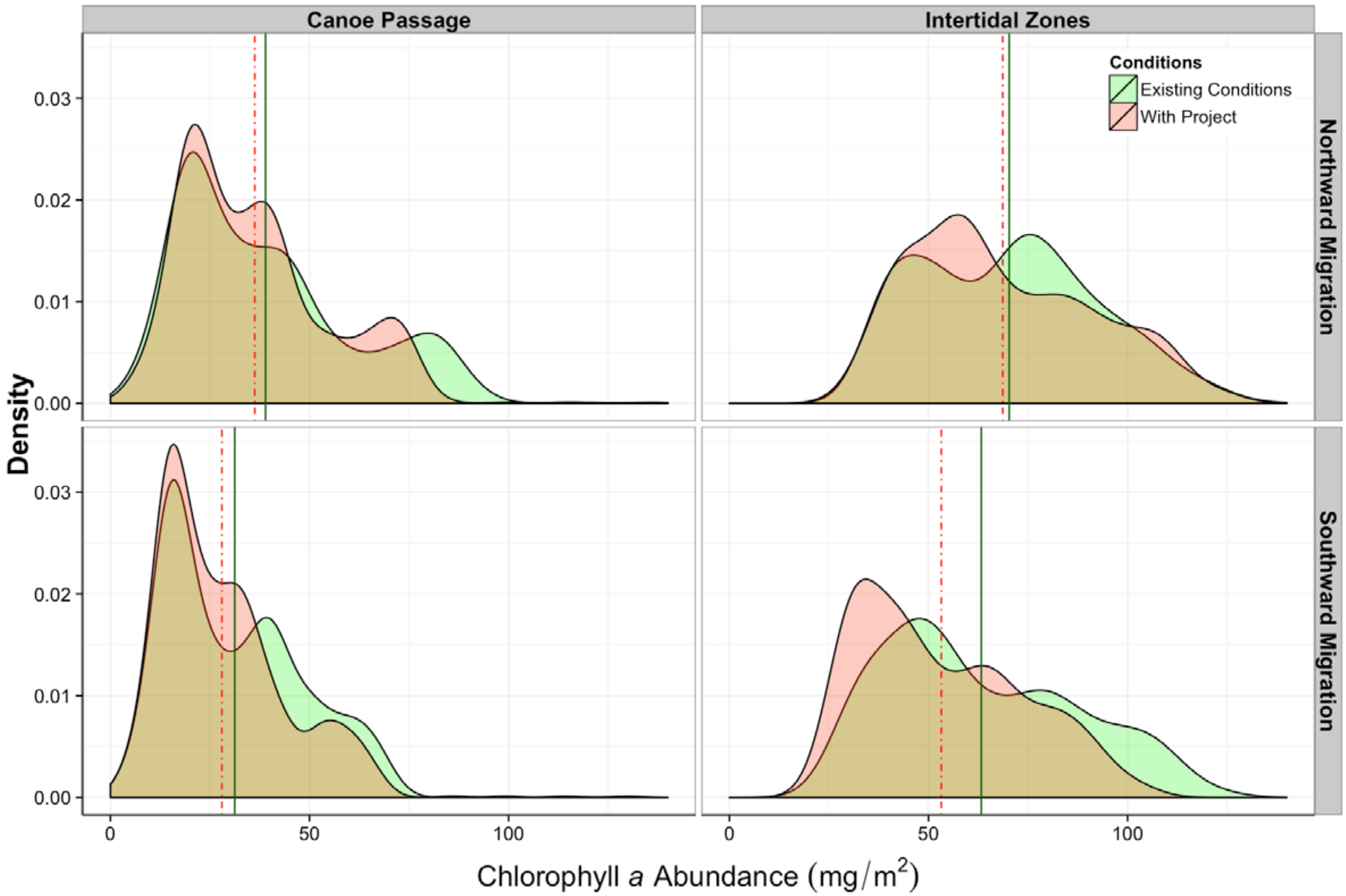
Note: Rows show abundance estimates and change for a particular seasonal configuration. Columns indicate Existing and With Project conditions and the associated difference in biofilm (chlorophyll *a*) abundance between conditions. Symbols in the abundance plots indicate chlorophyll *a* sampling location.

4.1.1.3 Distributional Changes in Biofilm Abundance

Biofilm density can change in response to environmental conditions (e.g., salinity; WorleyParsons 2015a). While spatial plots of chlorophyll *a* abundance can be useful, it can be difficult to assess what proportion of the landscape is predicted to support a particular level of chlorophyll *a* abundance. As such, the spatial dimension was removed from consideration and the distribution of predicted chlorophyll *a* abundances was investigated by area (i.e., Canoe Passage and Intertidal Zones) and by individual biofilm zones (i.e., Canoe Passage, Upper Intertidal, and Mid Intertidal; see **Figure 4** for definitions). The abundance distribution was summarised by a density distribution plot, which represents the relative frequency of different chlorophyll *a* abundance values within a given area or biofilm zone (**Figure 9** and **Figure 10** respectively). Care needs to be taken when considering changes in frequency for sites at different abundance levels, as small increases in higher abundance sites can offset loss in frequency of lower abundance sites. As a result, average change in chlorophyll *a* between Existing and With Project conditions was also included.

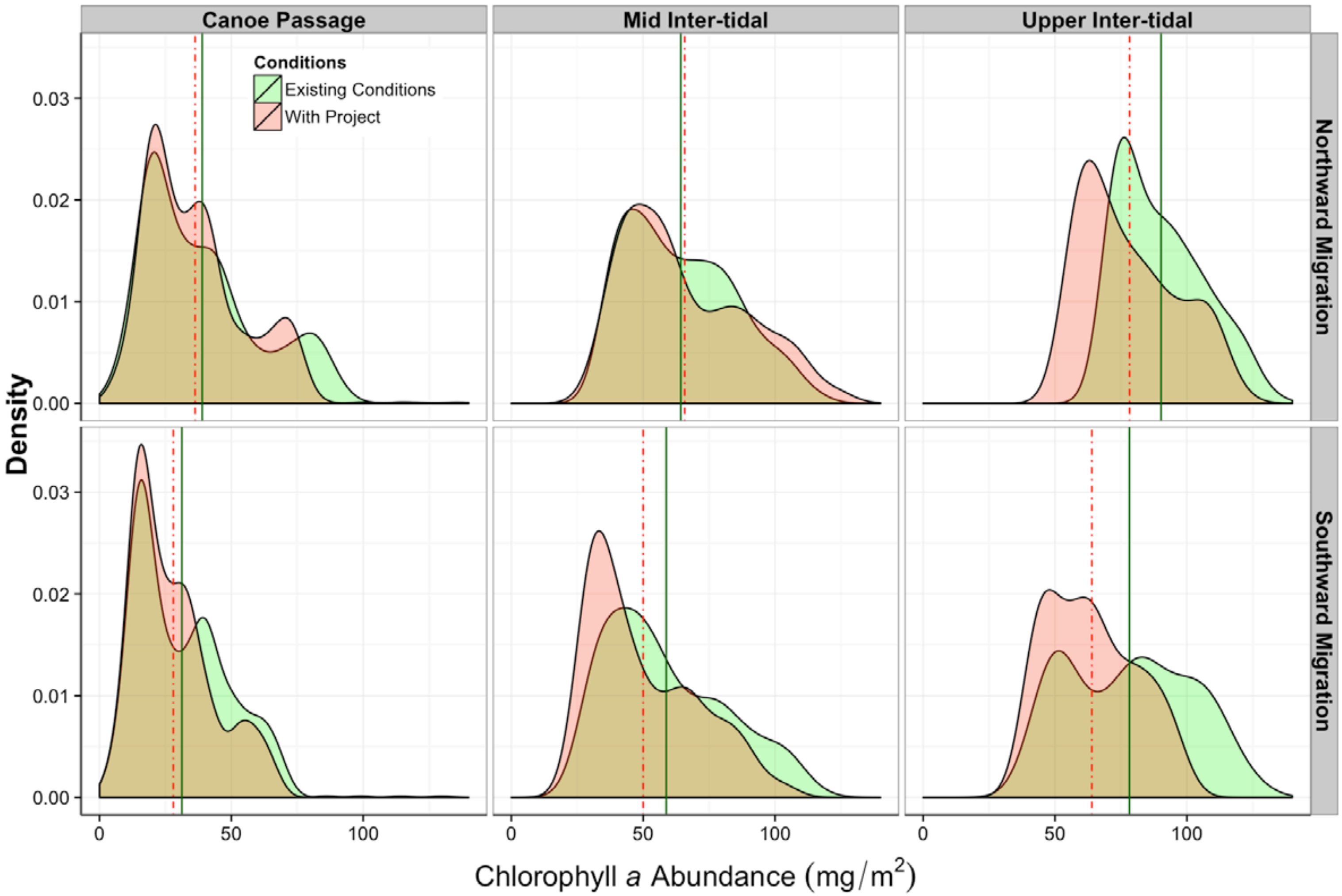
Consistent to all areas and zones was a predicted shift towards lower density chlorophyll *a* abundances under With Project Conditions; however, the nature and size of the shift varied by zone and migration period. The largest shifts (as judged by changes to mean chlorophyll *a* abundances) appeared to occur in the Upper Intertidal zone during both the northward and southward migration periods, followed by the Mid Intertidal zone during the southward migration (**Figure 10**). Within the Intertidal Zones as a whole, under With Project conditions, the frequency of highest abundances levels were predicted to remain high during the northward migration, but not during the southward migration. During the northward migration, the peak in mid abundances shifted towards lower abundances, while during the southward migration, the peak in lower abundance sites shifted further towards lower abundances. Taken together, With Project shifts in the Intertidal Zones as a whole during the southward migration were predicted to be larger than during the northward migration, which showed relatively smaller shift in mean abundance (**Figure 9**). By contrast Canoe Passage showed the largest shift from the highest abundances during the northward migration, rather than the southward migration (**Figure 9**). Despite these differences, Canoe Passage showed overall smaller but consistent declines in average chlorophyll *a* abundances during both migration periods relative to the Intertidal Zones.

Figure 9 Distribution of Predicted Canoe Passage and Intertidal Zone Chlorophyll *a* Abundance (mg/m^2) under Existing and With Project Conditions during Northward and Southward Migration Periods



Note: Density curves show the relative frequency of abundance values over Canoe Passage and the Intertidal Zones under Existing and With Project conditions. The area under each curve is one. The area under the curve corresponding to a range of abundance values indicates the proportion of the landscape exhibiting those abundances. The green vertical solid line indicates mean abundance under Existing conditions and the red vertical dashed line mean abundance under the With Project conditions.

Figure 10 Distribution of Predicted Biofilm Abundance within Different Biofilm Zones during the Northward and Southward Migration Periods under Existing and With Project Conditions



Note: Density curves show the relative frequency of abundance values over Canoe Passage and the Individual Intertidal Zones included in the area of inference (see **Figure 4**) under Existing and With Project conditions. The area under each curve is one. The area under the curve corresponding to a range of abundance values indicates the proportion of the landscape exhibiting those abundances. The green vertical solid line indicates mean abundance under Existing conditions and the red vertical dashed line mean abundance under the With Project conditions.

4.1.1.4 Estimating Change in Biofilm Total Biomass and Total Available Biomass

The percent change in total chlorophyll *a* biomass (**Table 10**) and total available chlorophyll *a* biomass (**Table 11**) between Existing and With Project scenarios were estimated for each zone (i.e., Canoe Passage and the Intertidal Zones) and for each migration period.

The southward migration period exhibited the larger estimated declines in total biofilm biomass and total available biomass compared to the northward migration. Estimates of total biomass and total available biomass changes were similar, indicating that the location of biomass relative to periods of tidal exposure remained relatively constant. Estimated declines differed between Canoe Passage and the Intertidal Zones, and varied by migration period. Canoe Passage was estimated to have a larger relative decline compared to the Intertidal Zone during the northward migration, but the Intertidal Zones were estimated to have a higher relative decline during the southward migration. Nevertheless, the 95% confidence intervals on the change were wide and covered zero indicating that any differences may also be the result of random variation.

In all cases, the 95% confidence interval for the percent change contained zero, so the null hypothesis of no change cannot be ruled out; however, this interpretation needs to be viewed with some caution. The shortcoming of *p*-value based hypothesis tests has been well documented (Hung et al. 1997) and the interpretation of confidence intervals directly can be a preferable procedure. Confidence intervals suggest a lot of uncertainty surrounding the degree of change. For example, during the Northward migrations the confidence interval suggests that area wide change could be anywhere from 25% decline to a 23% increase in total biomass (**Table 10**) or for total available biomass a 28% decline to a 23% increase (**Table 11**). A conservative approach would be to consider the effect size associated with the lower confidence limit as representing the limit of knowledge. For example, if a decline does occur, there is little evidence for declines larger than 25% total biomass, or 28% total available biomass, during the northward migration.

Table 10 Estimated Percent Change in Chlorophyll *a* Biomass between Existing and With Project Conditions during the Northward and Southward Migration Periods

	Northern Migration			Southern Migration		
Area	**Estimate**	**Lower CI**	**Upper CI**	**Estimate**	**Lower CI**	**Upper CI**
Canoe Passage	-5.5%	-30.1%	23.2%	-9.2%	-36.6%	28.7%
Intertidal Zones	-1.5%	-26.4%	30.3%	-15.1%	-39.2%	17.6%
All Areas Combined	-3.6%	-24.6%	22.5%	-12.9%	-35.0%	16.0%

Table 11 Estimated Percent Change in Chlorophyll *a* Available Biomass between Existing and With Project Conditions during the Northward and Southward Migration Periods

	Northern Migration			Southern Migration		
	Estimate	**Lower CI**	**Upper CI**	**Estimate**	**Lower CI**	**Upper CI**
Canoe Passage	-8.3%	-31.2%	21.0%	-9.8%	-37.7%	26.9%
Intertidal Zones	-3.2%	-28.5%	29.9%	-15.7%	-41.2%	19.0%
All Areas Combined	-5.2%	-27.7%	23.2%	-14.1%	-36.9%	16.8%

Note: Total available biomass for each 1-ha grid cell was computed as the product of the area, abundance, and tidal cycle availability (see **Appendix A: Figure 41**).

4.1.1.5 Sensitivity Analysis

The effect of With Project geomorphology changes on chlorophyll *a* total biomass and total available biomass was investigated by selectively updating geomorphology modelling data while leaving other explanatory variables unchanged. Estimates of percent change in chlorophyll *a* biomass were recomputed using only changes to seasonal 90th percentile wave heights or changes to seasonal 50th percentile water column salinities under With Project conditions (**Appendix B: Table 28** and **Table 29** respectively). Estimates of percent change based only on changes to wave heights showed little change from Existing conditions with most point estimates of change being within a single percentage point of zero (**Appendix B: Table 28**). Estimates of percent change based only on salinity changes (**Appendix B: Table 29**) showed very similar estimated changes to modelling results obtained when including both factors (**Table 10**), suggesting that changes in salinity can be considered the primary driver for changes under With Project conditions.

Finally, estimates of biomass changes were based on geomorphology modelling data from the 2012 freshet event, a one in 25 year event. Such events will result in lower salinity across the LSA compared to more typical freshet events. Changes in biomass under different, more typical, freshet scenarios are considered in **Section 4.4**.

4.1.2 Estimating Foraging Opportunity

Biofilm foraging opportunity visualises the interplay between safety, abundance and available biomass (i.e., a proxy measurement for energy). Topologies were constructed for Canoe Passage and the Intertidal Zones during the northward (**Figure 11**) and southward (**Figure 12**) migrations and under Existing and With Project conditions based on predicted chlorophyll *a* abundances. Foraging topology height indicates available biomass (mg x hr) for a particular combination of safety and food (i.e., abundance).

4.1.2.1 Northward Migration Foraging Opportunity

During the northward migration (**Figure 11**), foraging opportunity under Existing conditions showed a peak in the Intertidal Zones at about 100 mg/m^2 and in an area of relatively low safety (<500 m from shore). In Canoe Passage, highest opportunity occurred at approximately three-quarters the abundance (around 75 mg/m^2), but in much safer areas (around 1,500 m from shore). In general, the Intertidal Zones possessed higher available biomass for most safety and abundance combinations than Canoe Passage, with Canoe Passage showing about 70% of the total available biomass as the Intertidal Zones during the northward migration (see **Appendix B: Table 30** for ratios).

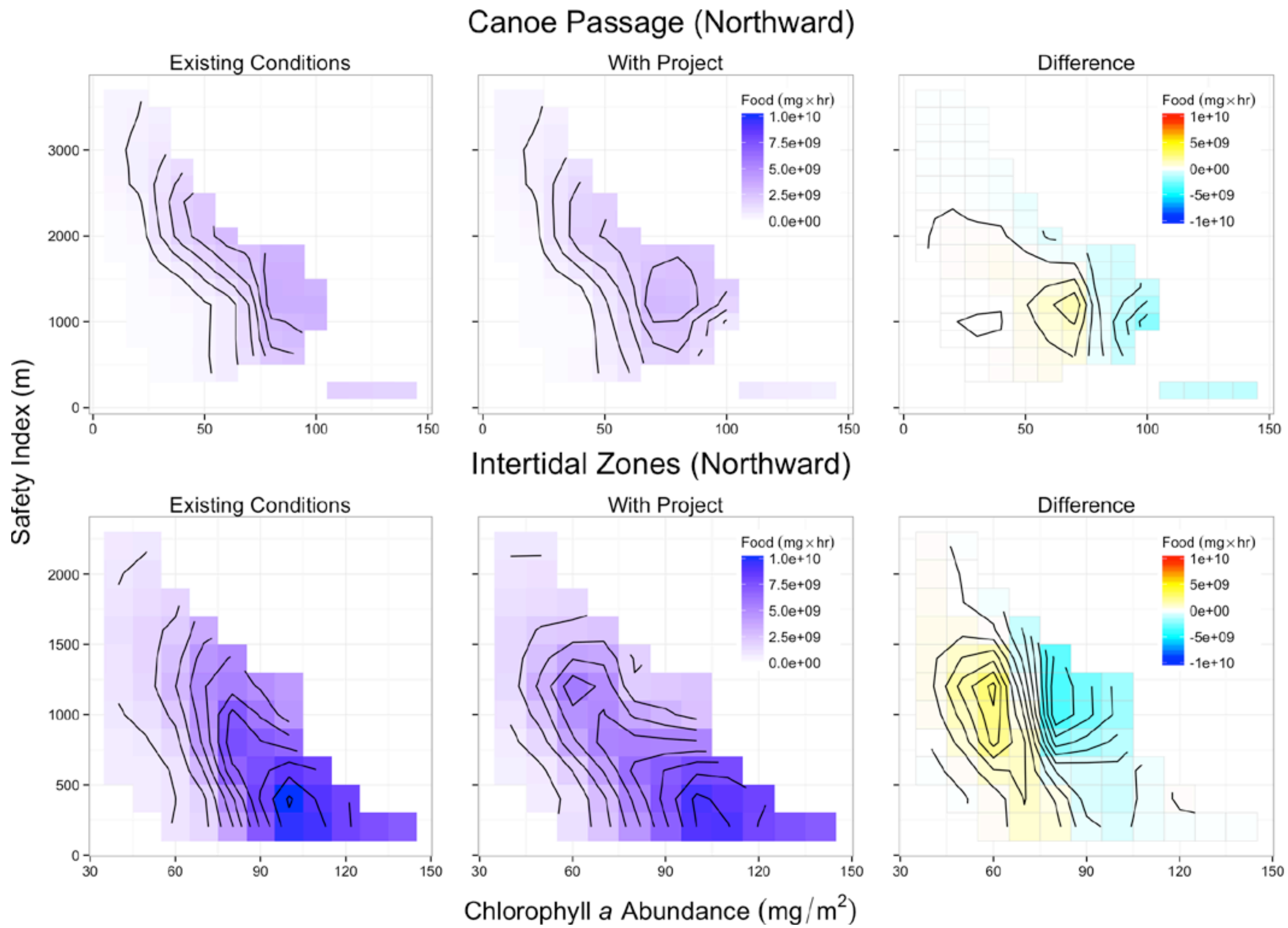
Under With Project conditions, peak opportunity in the Intertidal Zones was still in relatively unsafe areas (<500 m from shore), but with the foraging topology peak remaining largely unchanged with respect to chlorophyll *a* abundance. Within Canoe Passage, the position of peak foraging opportunity remained constant with respect to abundance and safety with a second peak at slightly lower abundances (ca. 45 mg/m^2) and higher safety (ca. 2,000 m from shore). For both Canoe Passage and the Intertidal Zones, opportunity showed a general trend of decreasing in higher abundances and increasing at lower abundances, with the Intertidal Zones showing larger changes. This pattern is also consistent with a general shift towards lower chlorophyll *a* abundances under With Project conditions. The shift also appears to be predominately in safer areas, with fewer changes predicted in more dangerous areas.

4.1.2.2 Southward Migration Foraging Opportunity

During the southward migration (**Figure 12**), foraging opportunity under Existing conditions exhibited patterns similar to the northward migration. For the Intertidal Zones' peak, foraging opportunity occurred at an abundance of around 100 mg/m^2 and a safety index ranging from 0 to 750 m. Within Canoe Passage, similar to the northward migration, peak foraging opportunity occurred at a lower abundance (around 70 mg/m^2), but in safer areas (ca. 1,250 m from shore). In general, the Intertidal Zones also had higher available biomass than Canoe Passage, with Canoe Passage showing about 70% of the total available biomass in the Intertidal Zones during the southward migration (see **Appendix B: Table 30** for ratios).

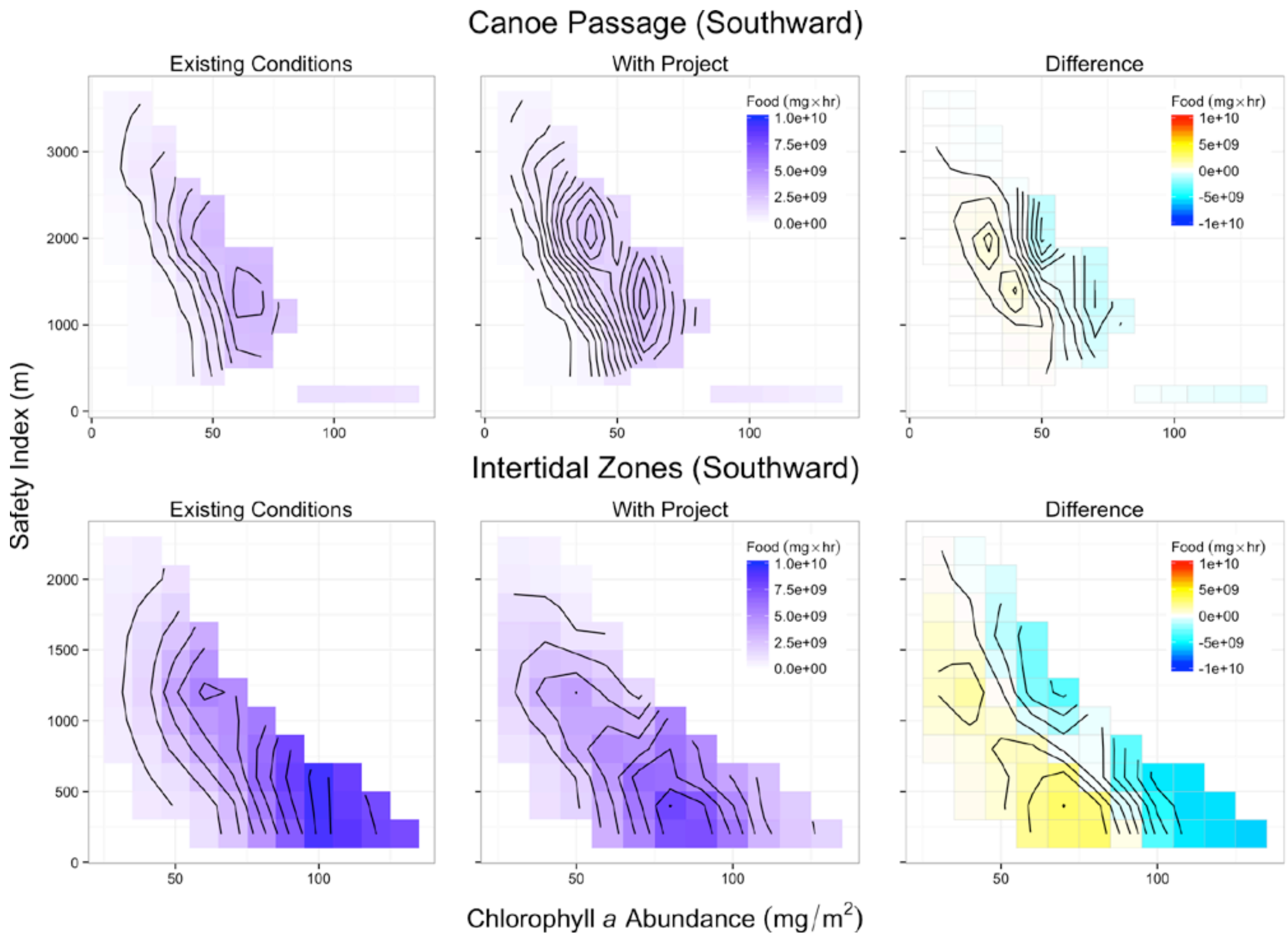
Under With Project conditions, foraging opportunity showed similar changes as during the northward migration. The Intertidal Zones had a shift in peak foraging opportunity at lower abundances (ca. 80 mg/m^2) and a shift towards less safe areas (<500 m from shore). Within Canoe Passage, the position of peak foraging opportunity remained constant with respect to abundance and safety with a second peak at slightly lower abundances (ca. 45 mg/m^2) and higher safety (ca. 2,000 m from shore). Similar to the northward migration, both Canoe Passage and the Intertidal Zones showed a general trend of decreasing opportunity in higher abundances and increasing opportunity at lower abundances, with the Intertidal Zones showing the largest change. This pattern is also consistent with a general shift towards lower chlorophyll *a* abundances under With Project conditions during the southward migration.

Figure 11 Biofilm Foraging Opportunity Topologies under Existing and With Project Conditions during the Northward Migration



Note: Chlorophyll *a* (mg/m^2) abundance was used as a proxy for biofilm abundance. Foraging opportunity is represented as a topology, where the height represents available food (available biomass) (mg x hr) for a given combination of food density (mg/m^2) and safety index (metres to shore). Safety Index was measured as distance to either the natural shoreline or the Roberts Bank causeway. Contour lines represent a curve along which the available biomass is constant. The difference topology simply highlights the differences between the Existing and With Project topologies. Separate topologies were created for Canoe Passage and the Intertidal Zones (**Figure 2**).

Figure 12 Biofilm Foraging Opportunity Topologies under Existing and With Project Conditions during the Southward Migration



Note: Chlorophyll *a* (mg/m^2) abundance was used as a proxy for biofilm abundance. Foraging opportunity is represented as a topology, where the height represents available food (available biomass) (mg x hr) for a given combination of food density (mg/m^2) and safety index (metres to shore). Safety Index was measured as distance to either the natural shoreline or the Roberts Bank causeway. Contour lines represent a curve along which the available biomass is constant. The difference topology simply highlights the differences between the Existing and With Project topologies. Separate topologies were created for Canoe Passage and the Intertidal Zones (**Figure 2).**

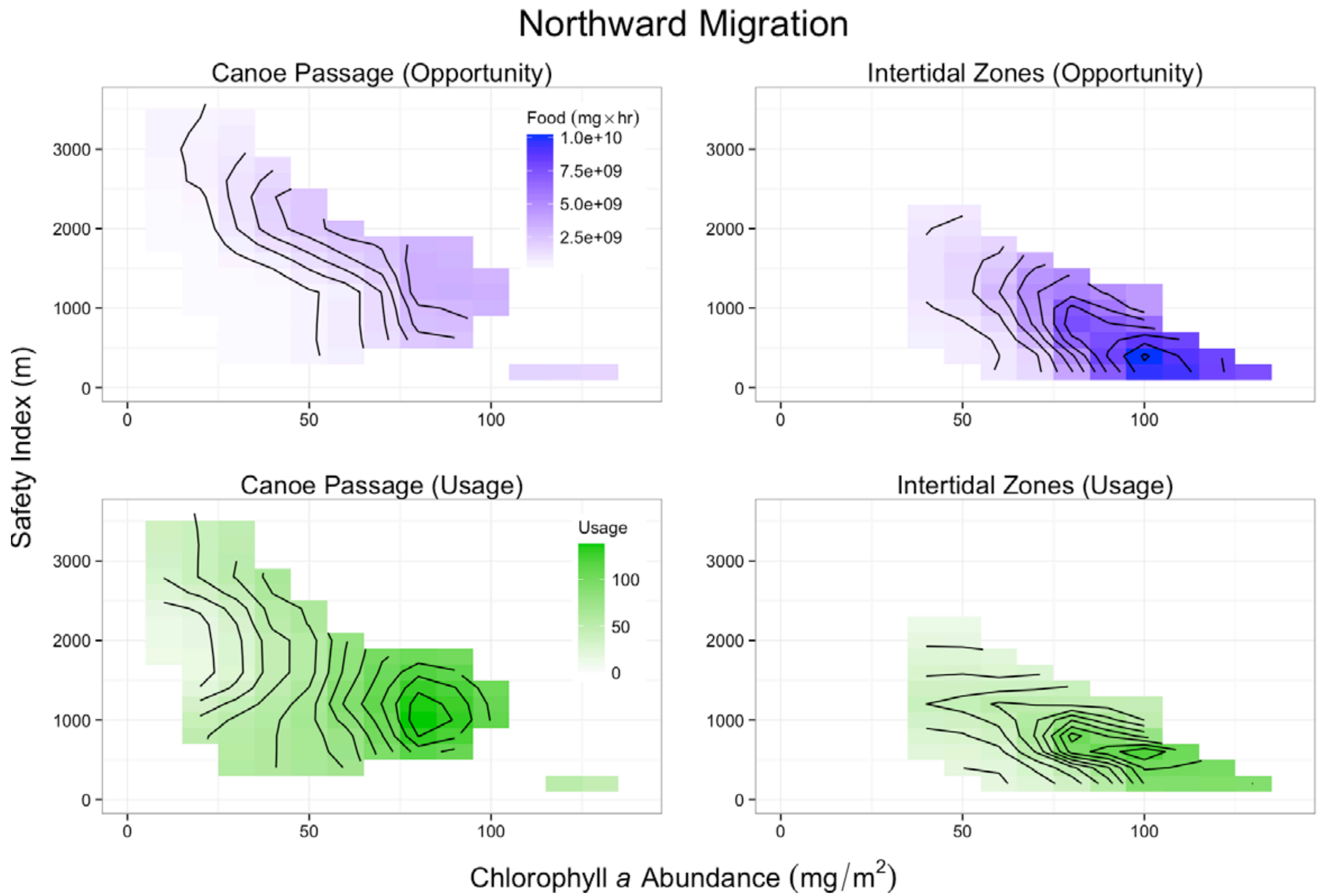
4.1.3 Comparing Foraging Opportunity and Usage

Biofilm foraging opportunity was compared to total usage during the 2012 northward migration (**Figure 13**) and the 2012 southward migration (**Figure 14**). The same two-dimensional bin criteria were used for all surfaces. Estimates of total usage were based on an IDW spatial interpolation of shorebird droppings data (**Figure 42**). Comparison between foraging opportunity and usage allows an assessment of how well estimated opportunity describes current usage.

In general, the pattern of total usage tracked foraging opportunity, with the tightest association occurring in the Intertidal Zones and during the northward migration. During the 2012 northward migration, the peak usage in Canoe Passage occurred in areas around 1,000 m from shore with chlorophyll *a* abundance around 80 mg/m^2. This peak also corresponds roughly with the peak foraging opportunity in Canoe Passage (i.e., >1,000 m from the nearest shoreline and chlorophyll *a* abundance around 80 to 90 mg/m^2). In the Intertidal Zones during the northward migration, the peak foraging opportunity was at a chlorophyll *a* abundance of around 100 mg/m^2 and a distance of around 500 m from the nearest shoreline, with a second peak around 70 to 80 mg/m^2, but further from shore (around 800 m). Peak usage in this area mimicked this pattern with two peaks in roughly the same area, but with the first peak shifted slightly back from shore. Both usage patterns consistently follow foraging opportunity, with some evidence for risk aversion close to shore, which is consistent with known behaviour (Pomeroy 2006). Finally, although the highest foraging opportunity occurred in the Intertidal Zones, peak usage was roughly equal between the two areas, which may indicate unused resources.

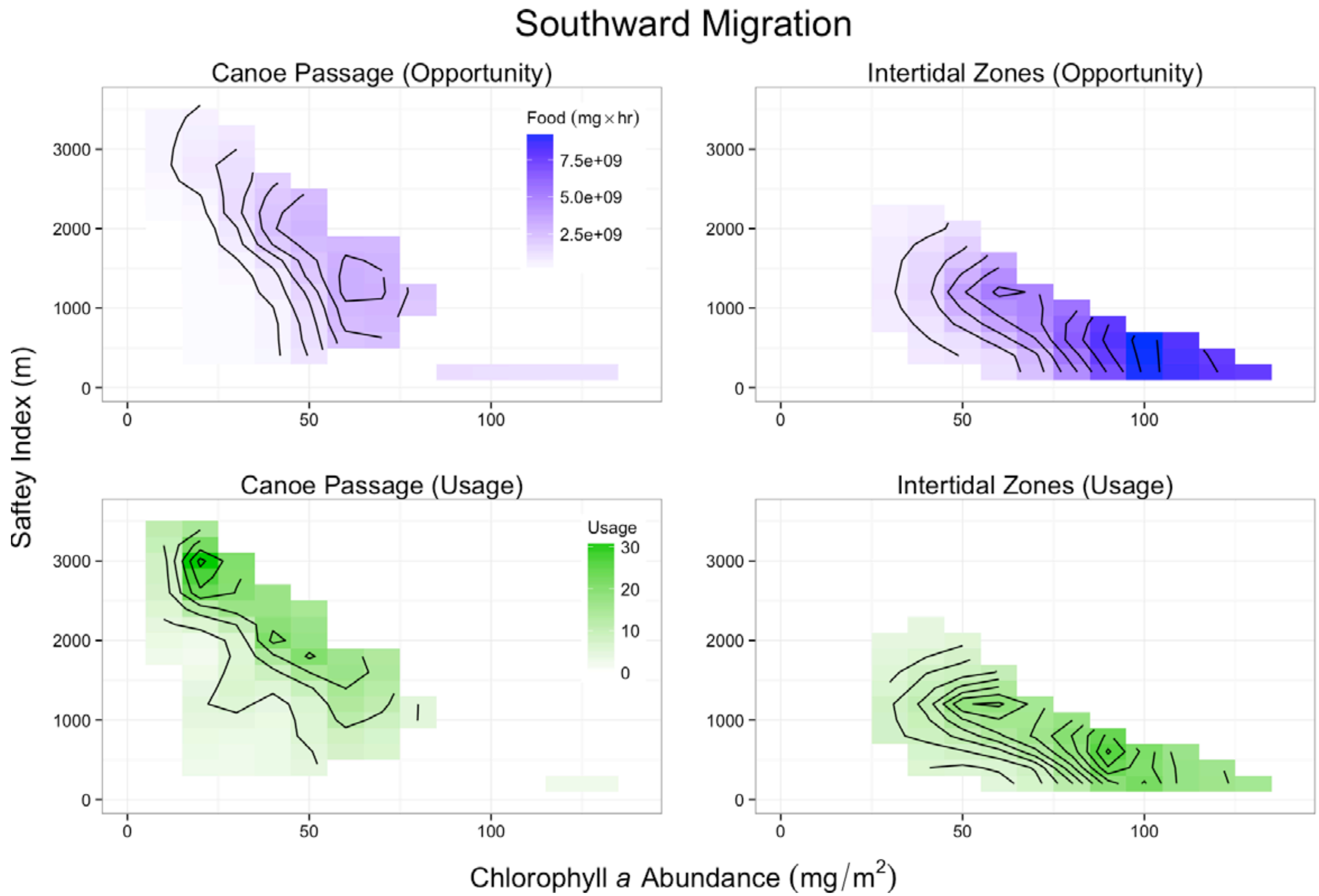
During the southern migration, usage patterns also tracked biofilm foraging opportunity in the Intertidal Zones, but less so in Canoe Passage (**Figure 14**). Although usage tracked opportunity in the Intertidal Zones, peak usage was again positioned slightly back from shore, which is consistent with avoidance of the highest risk areas (Pomeroy 2006, Pomeroy et al. 2008). In Canoe Passage, peak usage did not track biofilm foraging opportunity occurring in much safer habitat relative to usage in Canoe Passage during the northern migration; therefore, usage in Canoe passage during the southern migration may reflect other priorities, such as roosting or feeding on other food items. This pattern may also reflect lower biofilm demands as WESA densities are lower due to a more protracted migration period during the southern migration (Butler 1994).

Figure 13 Comparison of Biofilm Foraging Opportunity and Total Usage Topologies during the Northward Migration



Note: Opportunity topologies were constructed by determining the total available energy and total usage based applying abundance and safety criteria bins to the abundance and usage surfaces. A local trend surface was fit to bin values and normalised. Safety index represents the minimum distance (m) to either the natural shoreline or the Roberts Bank causeway shoreline.

Figure 14 Comparison of Biofilm Foraging Opportunity and Total Usage Topologies during the Southward Migration



Note: Opportunity topologies were constructed by determining the total available energy and total usage based applying abundance and safety criteria bins to the abundance and usage surfaces. A local trend surface was fit to bin values and normalised. Safety index represents the minimum distance (m) to either the natural shoreline or the Roberts Bank causeway shoreline.

4.1.4 Biofilm Capacity to Support Migrating Shorebirds

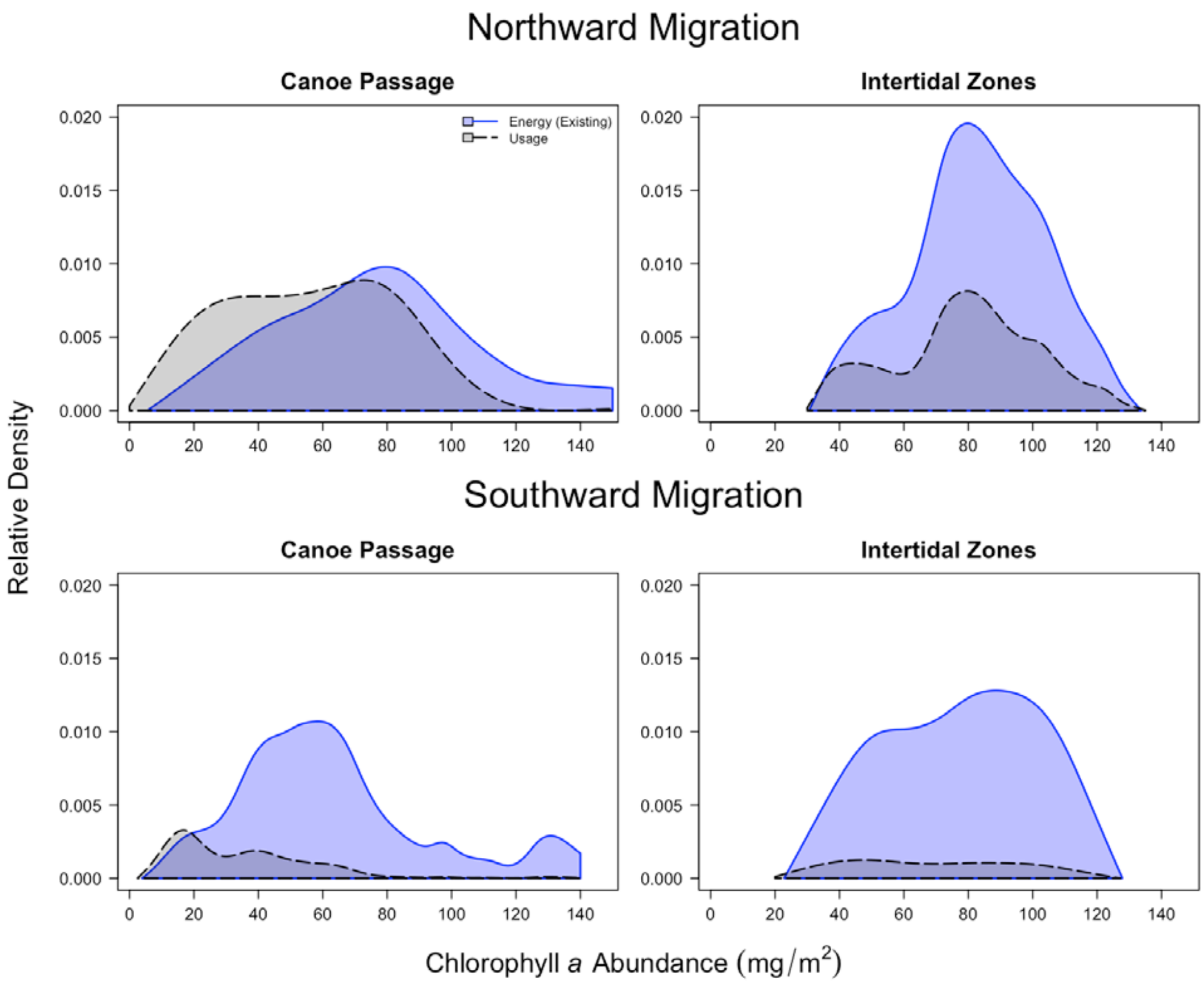
Biofilm capacity was estimated taking two different approaches. The first approach compared usage and total food availability during Existing conditions to provide an upper bound estimate of current biofilm usage. The second approach used known energetics and historic shorebird numbers during migration to estimate current biofilm utilization.

4.1.4.1 Capacity 1 - Availability Biofilm Biomass vs. Usage

The chlorophyll *a* available biomass curves were standardised against northward Intertidal Zone total available biomass, which showed the highest chlorophyll *a* total available biomass (**Appendix B: Table 30**). Total usage curves were first standardised against northward Canoe Passage usage, as this was the highest total usage (**Appendix B: Table 31**). All usage curves were then scaled by an additional factor of 0.75 in order to fit the usage curve peak within the available biomass curve during northward migration within Canoe Passage (**Figure 15**). The second usage-scaling step was done assuming that biofilm consumption could not exceed its availability; therefore, the overlap between the scaled usage and available biofilm density curves represents the upper bound of current usage and the non-overlapping area represents a lower bound of unused chlorophyll *a* capacity.

Estimates of the current chlorophyll *a* utilization along with remaining capacity were computed for Canoe Passage and the Intertidal Zones (**Table 12**).

Figure 15 Overlay of Chlorophyll *a* Available Biomass and Total Usage Densities by Zone during the Northward and Southward Migration Periods



Note: Energy densities have been scaled to represent the proportion of total energy relative to the maximum availability (Intertidal Zones; northward migration). Usage densities have been scaled relative to the maximum usage (Canoe Passage; southward migration), usage was then scaled further (by 0.75) in order for maximum northward Canoe Passage usage to fit within biofilm availability. Density plots without the further scaling are also available (**Appendix A: Figure 43**). A colour mixture indicates areas of overlap.

Table 12 Summary of Estimates of Chlorophyll *a* Available Capacity and Anticipated Change during the Northward and Southward Migration Periods

Season	Zone	Existing Capacity		With Project Changes		Total Availability Ratios
		Used	Free	Estimated	Lower CI	
Northward Migration	Canoe Passage	77%	23%	-3.2%	-28.5%	0.71
	Intertidal Zones	39%	61%	-8.3%	-31.2%	1.00
Southward Migration	Canoe Passage	18%	82%	-9.8%	-37.7%	0.61
	Intertidal Zones	10%	90%	-15.7%	-41.2%	0.90

Note: Estimates of capacity and change are restricted to the biofilm area of inference and are computed separately for Canoe Passage and the Intertidal Zones (**Figure 2**). Computation of total available biomass ratios can be found in **Appendix B: Table 30**.

Table 13 Estimates of Local Study Area Chlorophyll *a* Capacities under Existing and With Project Conditions during the Northward and Southward Migration Periods

Season	Existing Conditions		With Project (Estimated Change)		With Project (Worst Case)	
	Used	Free	Used	Free	Used	Free
Northward Migration	55%	45%	58%	42%	71%	29%
Southward Migration	13%	87%	15%	85%	18%	82%

Note: Capacity estimates for the LSA were based on combining zone-specific capacity estimates after adjusting for total available biomass differences.

4.1.4.2 Capacity 2 - Biofilm Availability vs. Shorebird Population Sizes

The second approach to investigating biofilm capacity to support migrating shorebirds in the LSA was based on the hyperspectral estimate of daily biofilm availability (termed the 'standing stock') (**Appendix A: Figure 46**), biofilm energetics, shorebird daily energetics demands, and daily population sizes. Only hyperspectral values over 30 mg/m^2 were considered to represent biofilm micro patches (ASL Environmental Sciences 2013). Because biofilm productivity can change by as much as 20% and the survey was conducted at a time of higher biofilm productivity (WorleyParsons 2014b), the standing stock was reduced by a further 10%. The biofilm standing stock was estimated to be sufficiently large to support 1.32 million WESA for a single day (i.e., based on an estimated daily consumption rate of 165.2 mg/day of chlorophyll *a* per individual; **Table 7**). This single day estimate is higher than the maximum of 1,125,000 shorebirds observed in the LSA during the northward migration (Drever et al. 2014) since 1991. While the estimated standing stock exceeds the largest recorded single day demand, this does not adequately assess how the biofilm standing stock may support the daily demand over the course of the migration, as daily population numbers follow a temporal trend and can be highly variable (Drever et al. 2014).

Daily biofilm surplus (see **Section 3.4.6.2** for methods) was summarised as energy ratios based on Existing conditions and With Project LSA declines of 4% and 25% (expected and worst case estimates respectively; see **Table 10**). Energy ratios between the three scenarios were then compared (**Figure 16**). In general, very few days experienced shortfalls and the population sizes resulting in shortfalls were larger than the largest observed population size to date, even for the worst-case scenario estimate (**Table 14**). These tended to represent very extreme population events, occurring < 0.2% percent of days for all scenarios. Under Existing conditions, around 2.4% of simulation runs had at least one day experiencing a limitation, however the actual number of total days showing a limitation was quite small (0.084%). Under With Project conditions these increased due to the reduction in standing stock. For the estimated decline of 4%, the number of runs that had at least one day experiencing a limitation increased slightly to 2.5%, with 0.087% of total days experiencing a limitation. Under the worst-case scenario of decline, the number of runs that had at least one day of limitation increased to 4.7%, with the total number of days showing a limitation increasing to (0.194%).

While limitation events were noted, these events represented very extreme population events with population sizes generally larger than the largest shorebird population size observed to date in the LSA were present (1,125,000; Drever et al. 2014). Under Existing conditions the smallest population that experienced a limitation was 1.33 million shorebirds, which is larger than the single largest single day population observed in the LSA during the northward migration (**Table 14**). For the estimated With Project decline of 4%, the smallest population experiencing a limitation was 1.29 million birds, which still exceeded the largest observed population size. The worst-case scenario was the only scenario where the minimum population size experiencing a limitation was smaller than the largest population observed to date. In this case the smallest population size that experienced a limitation was 1 million birds, which was smaller than the largest observed population size by about 123,000 birds, but was also the only recorded population size to exceed 1 million birds.

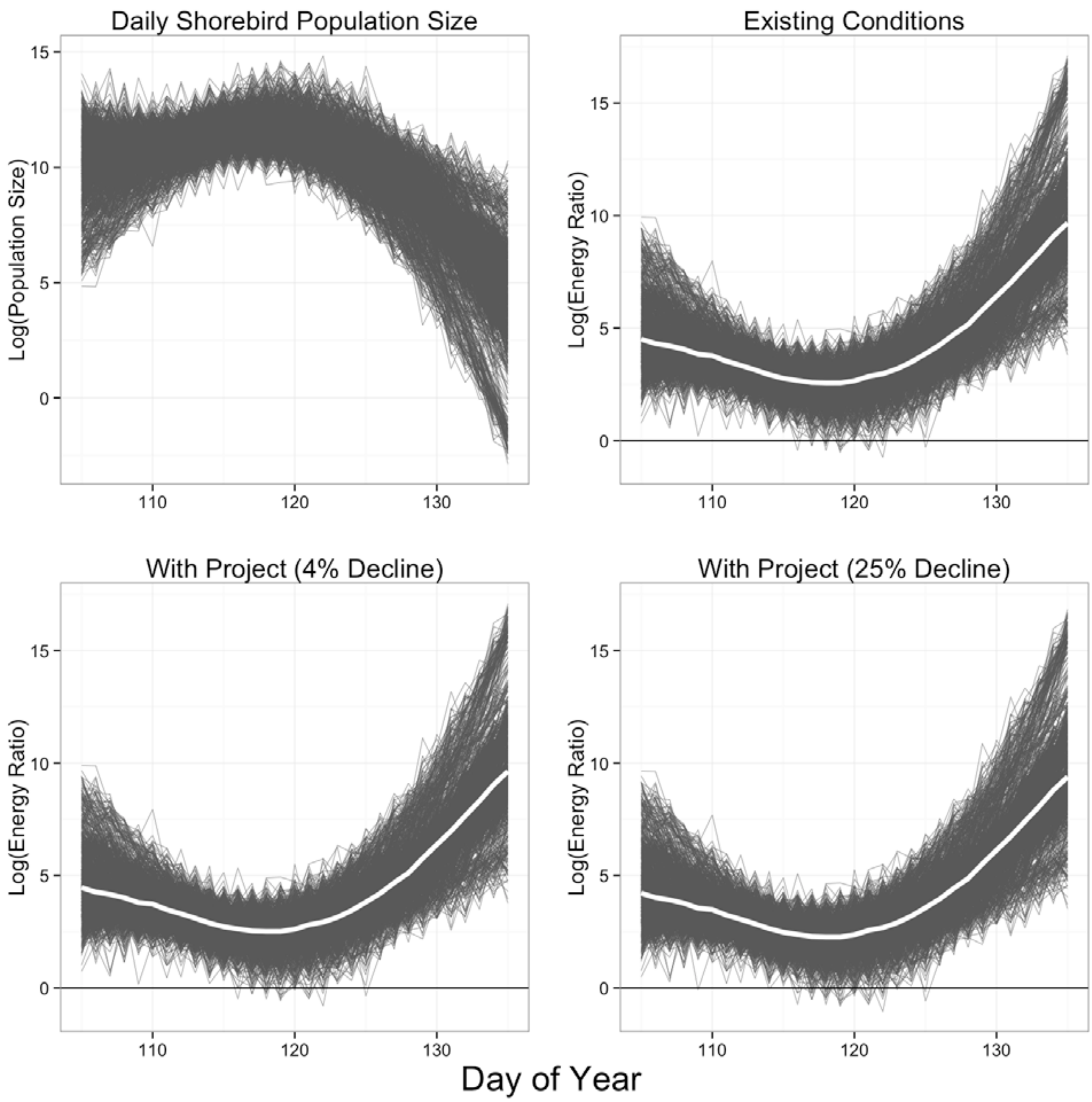
A comparison of more ‘average’ conditions can be considered by comparing the median energy ratio across each day-of-year between scenarios (**Figure 17**). The median energy ratio represents the most common standing stock surplus across simulation realizations. While biofilm declines under With Project conditions resulted in a lowering of the median energy ratio, it still remained around or above 10, suggesting that for the ‘average’ population event, large surpluses of biofilm will likely remain even under the worst-case scenario for biofilm decline.

Table 14 Summary of the Ability of Biofilm Standing Stock to Support Migrating Shorebirds under Existing and With Project Conditions

Scenario	Percentage of Simulation Runs where Biofilm was Limiting	Percentage of "Days" where Biofilm was Limiting	Minimum Daily Population Size where Biofilm was Insufficient to Support Migrating Shorebirds
Existing Conditions	2.4%	0.084%	1,334,000
With Project (4% decline; estimated)	2.5%	0.087%	1,292,000
With Project (25% decline; worse-case)	4.7%	0.194%	1,002,000

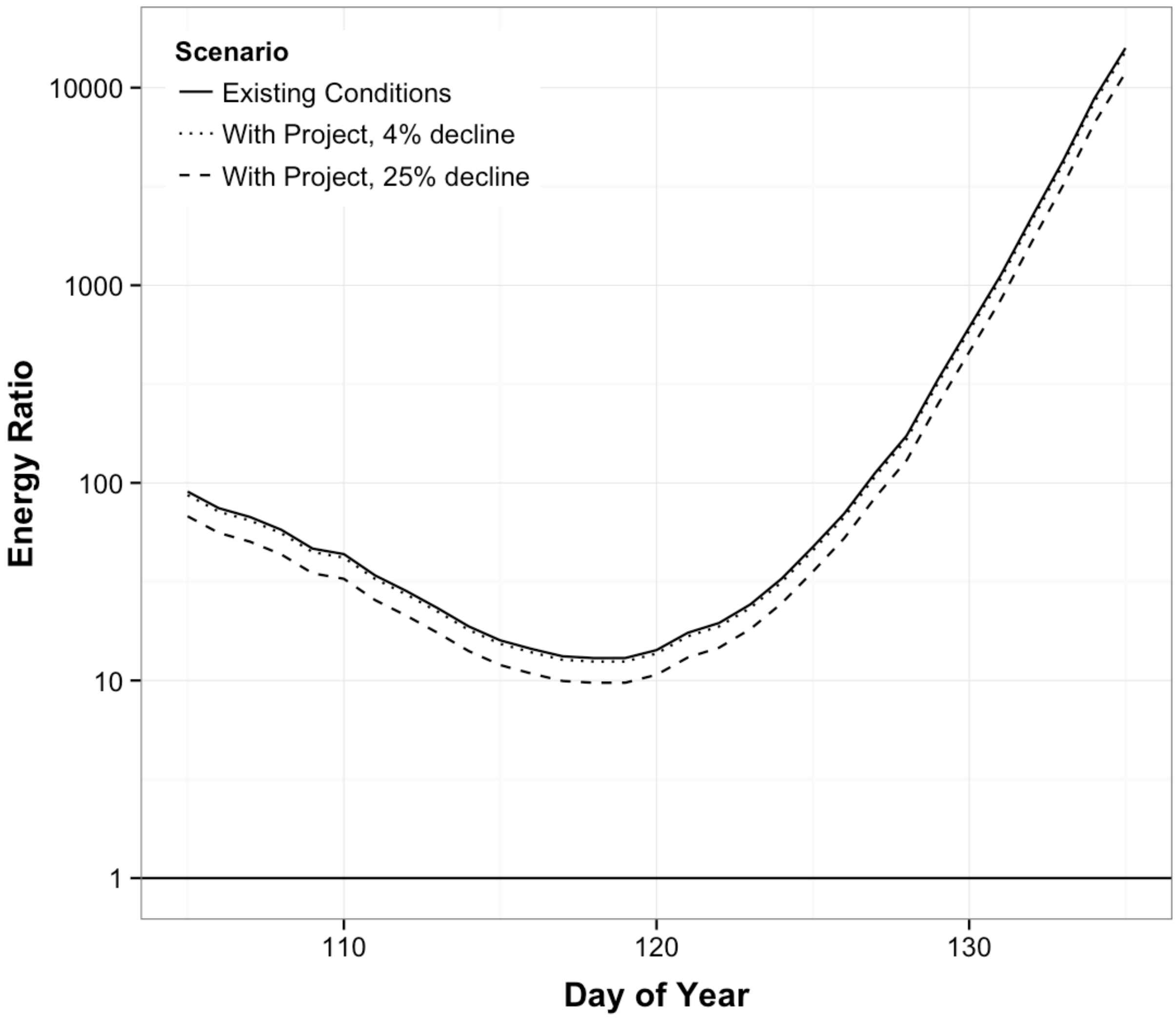
Note: 1,000 Monte Carlo simulations and biofilm standing stock levels were compared to the demand represented by daily population sizes, while also allowing for biofilm recovery (**Appendix A: Figure 47**). Any day where the demand exceeded the supply was considered limiting. The largest single day population size documented at Brunswick Point since 1991 was 1,125,000 birds.

Figure 16 Simulated Daily Shorebird Populations and Biofilm Energy Surplus from the Monte Carlo Simulations under Existing Conditions and Expected and Worst Case with Project Conditions



Note: 1,000 Monte Carlo simulations and biofilm standing stock levels were compared to the demand represented by daily shorebird population sizes, while also allowing for biofilm recovery (**Appendix A: Figure 47**). Any day where the demand exceeded the supply (horizontal zero line) was considered limiting. The median energy ratio is indicated as a solid white line.

Figure 17 Daily Median Biofilm Energy Ratios from the Monte Carlo Experiment



Note: Biofilm surplus was represented as a ratio between available standing stock and demand on a given day. Energy ratio values are displayed on the log scale and represent the standing stock (relative to expected shorebird consumption) for a given day-of-year. Horizontal line at an energy ratio of one indicates the point where supply equals demand.

4.2 Meiofauna Foraging Opportunity in the Local Study Area

4.2.1 Predicting Abundance of Meiofauna

4.2.1.1 Regression Model

The final regression model used to predict the meiofauna abundance was of the form:

Log Meiofauna ~ Year + Season + Seasonal Wave Height + Seasonal Salinity

Variance inflation factors were computed for each of the centered and scaled explanatory variables in the model. All values were within acceptable limits (i.e., <10) indicating that multicollinearity was not a substantial problem. The response variable was log transformed in order to meet statistical assumptions of the regression-kriging approach. The definition of each model parameter is outlined in **Table 15**.

The *Seasonal Wave Height* term represents the geomorphology modelling wave height predictions based on 90^{th} percentile computed over either May (northward migration) or July (southward migration). This represents the impact of wave energy on meiofauna abundance. The *Seasonal Salinity* terms represent the geomorphology modelling water column salinity values (psu) based on 50^{th} percentiles computed over either May (northward migration) or July (southward migration).

Table 15 Meiofauna Regression Model Parameters, Role, and Applied Transformations

Model Parameter	Type	Transformation	Description / Interpretation
Log Meiofauna	Response	Natural Log	Natural log transformed meiofauna abundance values (g/m^2). Regression model predicts orders of magnitude changes in meiofauna abundance.
Year	Explanatory	None	Categorical variable allowing differences between years
Season	Explanatory	None	Categorical variable allowing differences northward and southward migration periods
Seasonal Wave Height	Explanatory	None	Seasonal 90^{th} percentile of the geomorphology wave height modelling value. A May percentile was used for the northward migration and a July percentile for the southward migration. Extreme wave events predict log meiofauna abundance in a linear manner
Seasonal Salinity	Explanatory	None	Seasonal 50^{th} percentile of the geomorphology water column salinity modelling value. A May percentile was used for the northward migration and a July percentile for the southward migration. Median salinity predicts log meiofauna abundance in a linear fashion.

Note: All explanatory variables were standardized and scaled prior to fitting the regression model. Variance inflation factor analysis was used to assess multicollinearity of centered and scaled explanatory variables. In all cases multicollinearly was found to be within acceptable levels.

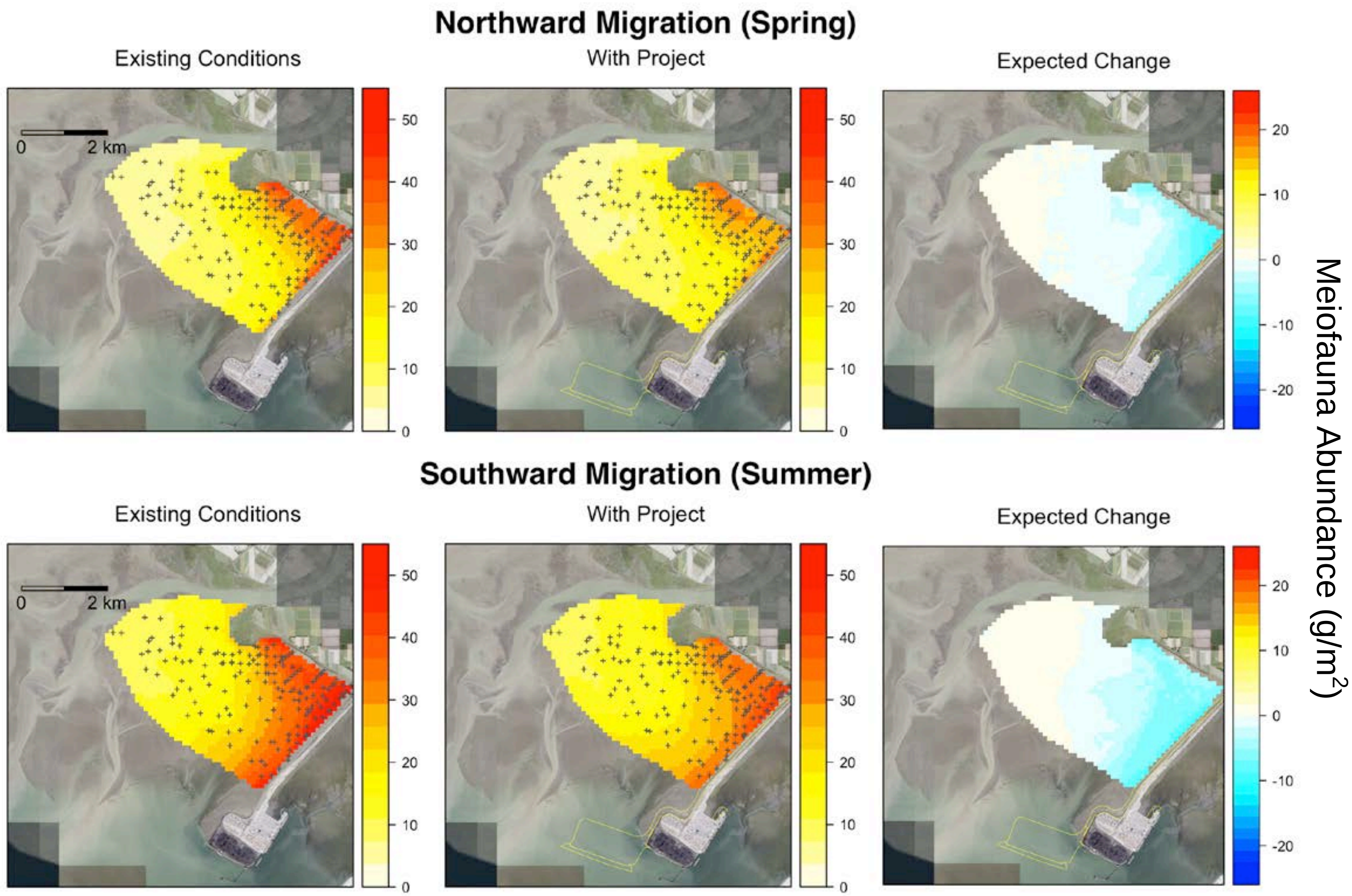
4.2.1.2 Spatial Predictions

Using the top supported regression model, a regression-kriging surface of meiofaunal abundances was created for the northward and southward migration periods under both Existing and With Project conditions (**Figure 18**). Changes between Existing and With Project surfaces are also indicated. The regression model was trained using both 2012 and 2013 years; however, because geomorphology modelling data was only available for the 2012 study year, spatial abundance predictions are for 2012.

Leave-one-out cross-validation was used to assess the model. Each data point was left out once, and predictions created based on the remaining samples. Predicted values were then compared to the sediment sample left out. The procedure indicated that the model explained roughly 43% of the variation in observed log meiofauna abundances, which is satisfactory. Investigation of model residuals from leave-one-out cross-validation indicated well-behaved residuals, with a slight skew towards lower residuals than expected under a strict Gaussian model. There were no strong indications of a lack-of-fit.

Under Existing conditions the highest meiofauna abundances were found towards the shore (both the natural shoreline and the Inter-causeway shoreline) and away from Canoe Passage (**Figure 18**). Northward migration also showed generally higher biofilm abundances than during southward migration period, which also coincides with the peak of the spring freshet.

Figure 18 Estimated Meiofauna Abundance (g/m^2) under Existing and With Project Conditions during the Northward and Southward Migration Periods

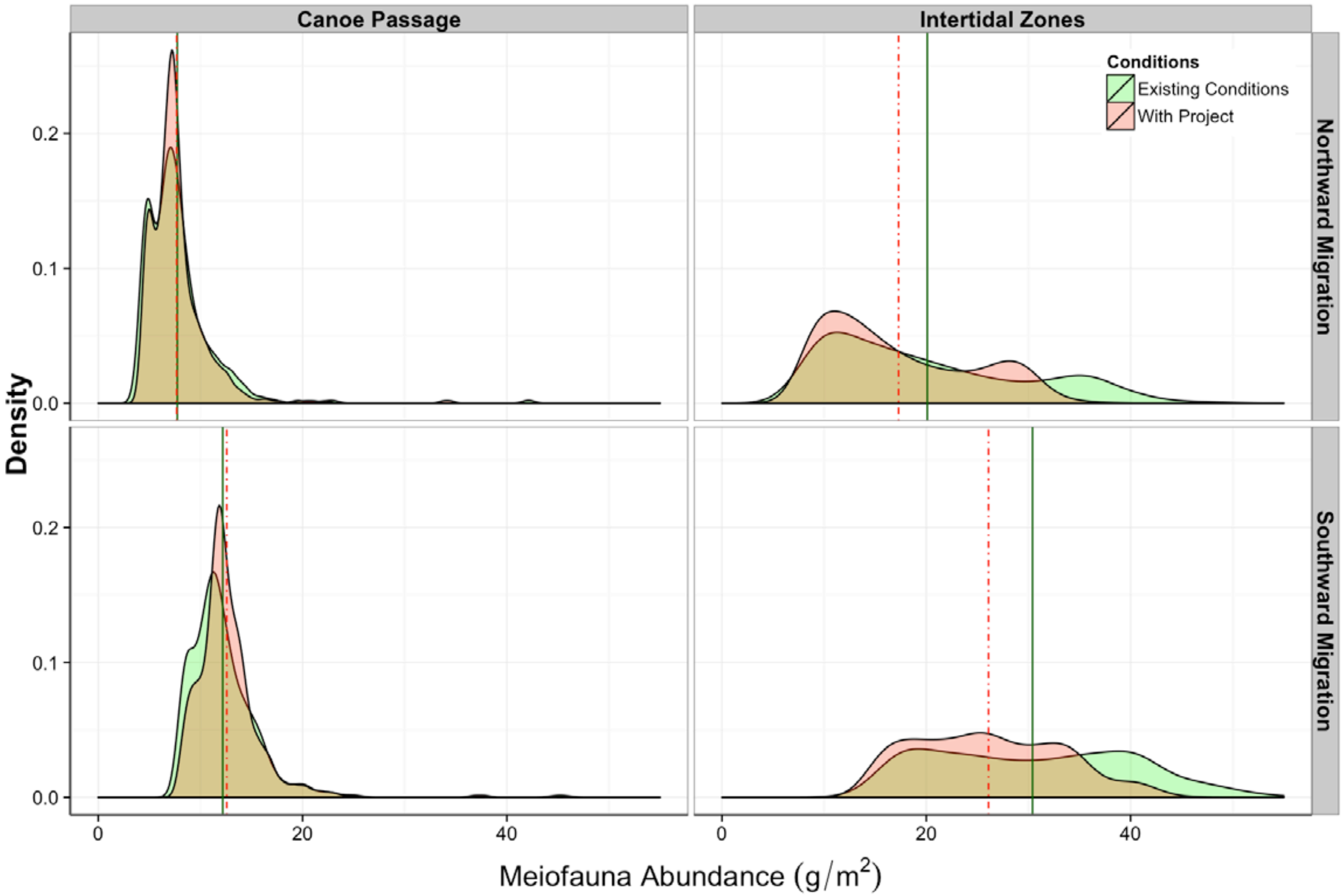


Note: Meiofauna abundance (g/m^2) was estimated for each 1-ha grid using a regression-kriging based on the 2012 coastal geomorphology modelling data. Each row shows abundance estimates under Existing and With Project conditions for either the northward or southward migration periods. Coastal geomorphology modelling data used were specific to that period. The final column indicates predicted changes in abundance. Sediment sampling locations used to train the regression-kriging model are indicated on the figure.

4.2.1.3 Distributional Changes in Abundance

While spatial plots of abundance can be useful, assessing what proportion of the landscape supports a particular level of abundance can be difficult. As such, the spatial dimension was removed and the distribution of estimated abundance was investigated by zone (i.e., Canoe Passage and Intertidal Zones; see **Figure 2** for definitions). The abundance distribution was summarised by a density plot, which represents the relative frequency of different meiofauna abundance values across the LSA (**Figure 19**). Overall, the distribution of predicted mieofauna abundance showed little change in Canoe Passage, and a shift towards lower abundances in the Intertidal Zones (**Figure 19**). For the northward and southward migration periods under With Project conditions, predictions were for loss of higher meiofauna abundances and increased frequency of lower meiofauna abundances.

Figure 19 Distribution of Predicted Canoe Passage and Intertidal Zone Meiofauna Abundance (g/m^2) under Existing and With Project Conditions during Northward and Southward Migration Periods



Note: Density curves show the relative frequency of abundance values over Canoe Passage and the Intertidal Zones under Existing and With Project conditions. The area under each curve is one. The area under the curve corresponds to a range of abundance values and indicates the proportion of the landscape exhibiting those abundances. The green vertical solid line indicates mean abundance under Existing conditions and the red vertical dashed line indicates mean abundance under the With Project conditions.

4.2.1.4 Change in Meiofauna Total Biomass and Total Available Biomass

The percent change in total meiofauna biomass (**Table 16**) and total available meiofauna biomass (**Table 17**) between Existing and With Project scenarios were estimated for each zone (i.e., Canoe Passage and the Intertidal Zones) and for each migration period.

Overall, declines in total biomass and total available meiofauna biomass were predicted for the Intertidal Zones during both the northward and southward migrations under With Project conditions. Estimates of total biomass and total available biomass changes were similar, indicating that the location of biomass relative to periods of tidal exposure remained relatively constant. Total biomass in Canoe Passage was estimated to increase during northward and southward migrations, but total available biomass was estimated to decrease slightly during the northward migration. Total available biomass during the southward migration was estimated to increase, similar to estimates of total biomass.

In all cases, the 95% confidence interval for the percent change contained zero so the null hypothesis of no change cannot be ruled out; however, this interpretation needs to be viewed with some caution. The shortcoming of *p*-value based hypothesis tests has been well documented (Hung et al. 1997) and the direct interpretation of confidence intervals can be preferred. As a conservative approach, the effect size associated with the lower confidence limit was interpreted as representing the limit of knowledge. For example, if a decline does occur during the northward migration, there is little evidence for declines larger than 37% of total biomass, or 37% in total available biomass.

Table 16 Estimated Percent Change in Meiofauna Total Biomass between Existing and With Project Conditions during the Northward and Southward Migration Periods

Area	Northern Migration			Southern Migration		
	Estimate	Lower CI	Upper CI	Estimate	Lower CI	Upper CI
Canoe Passage	1.3%	-34.8%	51.4%	6.0%	-32.1%	53.6%
Intertidal Zones	-13.9%	-41.2%	21.2%	-13.8%	-39.1%	17.6%
All Areas Combined	-10.6%	-36.8%	23.4%	-9.2%	-33.1%	18.7%

Table 17 Estimated Percent Change in Meiofauna Total Available Biomass between Existing and With Project Conditions during the Northward and Southward Migration Periods

Area	Northern Migration			Southern Migration		
	Estimate	Lower CI	Upper CI	Estimate	Lower CI	Upper CI
Canoe Passage	-2.0%	-36.9%	46.6%	3.9%	-36.6%	54.7%
Intertidal Zones	-15.0%	-40.0%	16.8%	-14.4%	-39.5%	16.0%
All Areas Combined	-13.0%	-36.9%	17.1%	-11.0%	-36.2%	19.2%

Note: Total available biomass for each 1-ha grid cell was computed as the product of the area, abundance, and tidal cycle availability (see **Appendix A: Figure**).

4.2.1.5 Sensitivity Analyses

The effect of different geomorphology modelling parameters on estimated meiofana biomass changes was investigated by selectively updating geomorphology data, while leaving other explanatory variables unchanged. Estimates of percent change in meiofauna total biomass were recomputed using only changes to seasonal 90th percentile wave heights or changes to seasonal 50th water column salinities under With Project conditions (**Appendix B: Table 32** and **Table 33,** respectively). With Project estimates of percent change based only on changes to wave heights showed increases relative to Existing conditions (**Appendix B: Table 32**), while percent change based only on salinity changes showed larger estimated decreases (**Appendix B: Table 33**). Taken together, these findings suggest that salinity is predicted to be the primary driving factor behind estimated With Project decreases.

Finally, estimates of biomass change were derived from geomorphology modelling data based on the 2012 freshet event, a one in 25 year event. Such events will result in lower LSA salinity than smaller freshet events. Changes in biomass under different freshet scenarios were considered in **Section 4.4**.

4.2.2 Estimating Foraging Opportunity

Meiofauna foraging opportunity visualises the interplay between safety, meiofauna abundances and available biomass (i.e., a proxy measurement for energy). Topologies were constructed for both Canoe Passage and the Intertidal Zones and during the northward (**Figure 20**) and southward (**Figure 21**) migrations and under Existing and With Project conditions based on predicted meiofauna abundances. Foraging topology height indicates available biomass (g x hr) for a particular combination of safety and food (i.e., abundance).

4.2.2.1 Northward Migration Foraging Opportunity

During the northward migration (**Figure 20**), foraging opportunity under Existing conditions showed that peak opportunity in the Intertidal Zones occurred at an abundance of around 40 g/m^2 and in an area of relatively low safety (250 m from shore), while in Canoe Passage, highest opportunity peaked at approximately one-third the abundance (around 10 g/m^2), but in much safer areas (around 2,000 m from shore). In general, the Intertidal Zones had nearly three times the total available biomass relative to Canoe Passage during the northward and southward migrations (see **Appendix B: Table 34** for ratios).

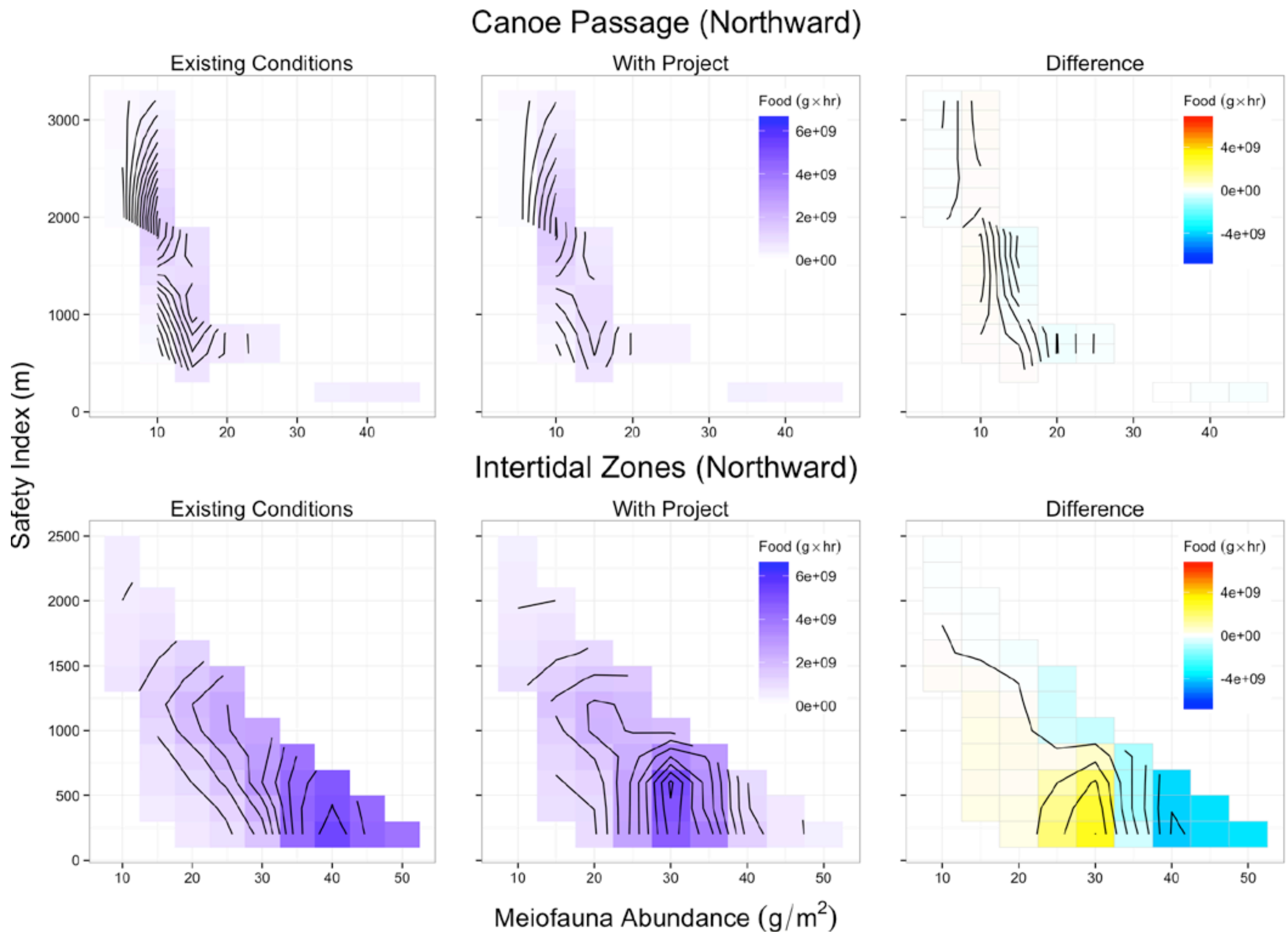
Under With Project conditions, peak opportunity in the Intertidal Zone remained in relatively unsafe areas (500 to 700 m from shore), with the largest opportunity shifting from 40 g/m^2 to 30 g/m^2. There was also a loss of higher abundance foraging opportunity. Within Canoe Passage there was relatively little change, with the position of peak foraging opportunity remaining constant in terms of location relative to abundance and safety. For both Canoe Passage and the Intertidal Zones, **foraging opportunity topology** showed a general trend of decreased opportunity in higher meiofaunal abundances and an increased opportunity at lower abundances, with the Intertidal Zones showing the largest changes (**Figure 19**).

4.2.2.2 Southward Migration Foraging Opportunity

During the southern migration (**Figure 21**), foraging opportunity under Existing conditions exhibited similar patterns as the northward migration. Peak foraging opportunity in the Intertidal Zones occurred in relatively dangerous areas (<500 m from shore), but slightly higher abundances (ca. 45 g/m^2) than in the northward migration. Canoe Passage peak opportunity again occurred in safer areas (around 2,000 m from shore), although at slightly higher abundances and was consistent with the higher total available biomass estimated during the southern migration period (**Appendix B: Table 34**).

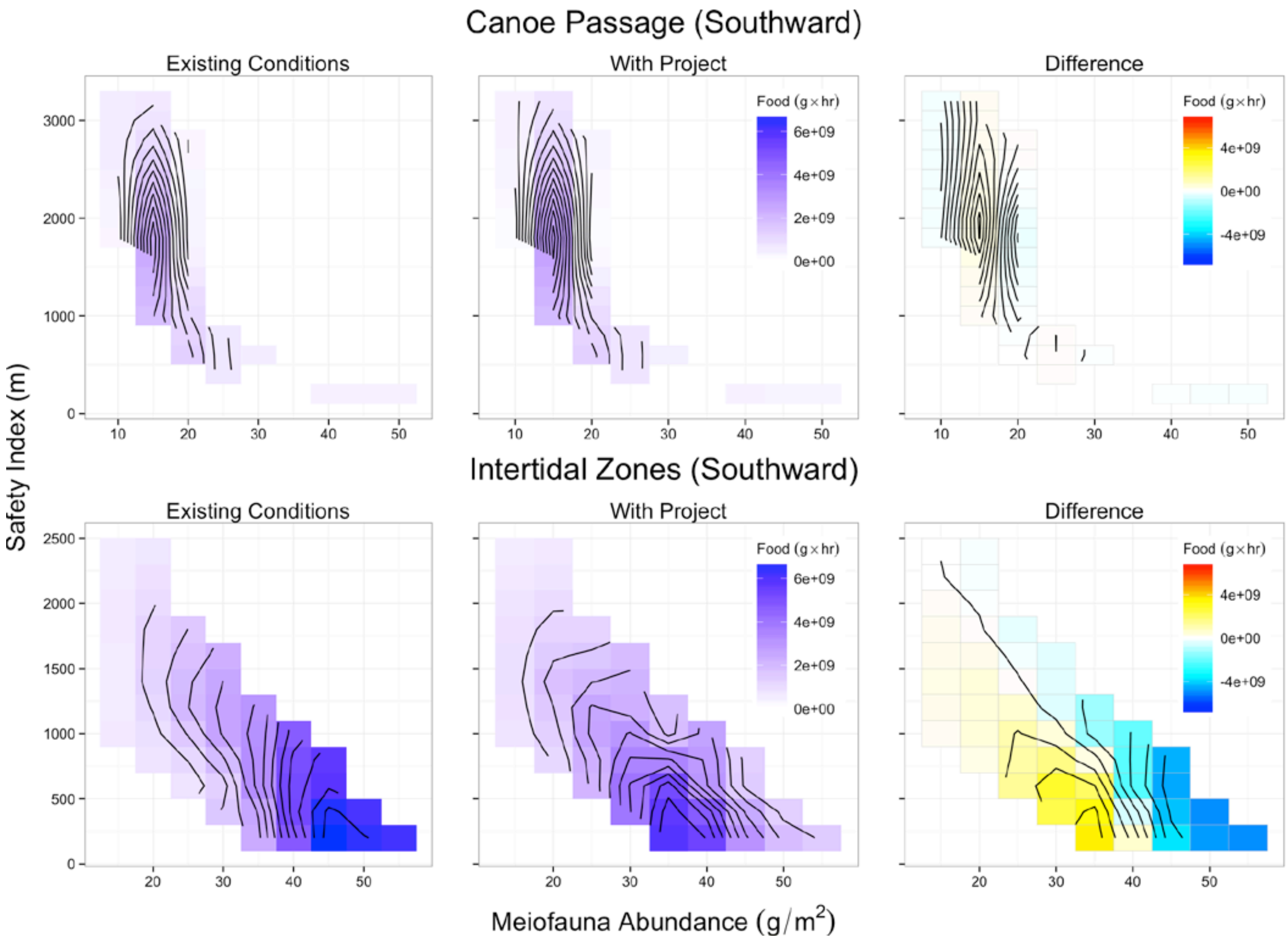
Under With Project conditions, foraging opportunity in Canoe Passage remained largely unchanged with a small increase in the height of the opportunity peak. For the Intertidal Zones, there was a general shift towards lower abundances with peak foraging opportunity occurring at a lower abundance value (35 g/m^2), but also a shift to safer conditions (500 to 700 m from shore) relative to Existing conditions (ca. 250 m).

Figure 20 Estimated Meiofauna Foraging Opportunity under Existing and With Project Conditions during the Northward Migration



Note: Foraging opportunity is represented as a topology, where the height represents available food (available biomass) (g x hr) for a given combination of food density (mg/m^2) and safety index (metres to shore). Safety Index was measured as distance to either the natural shoreline or the Roberts Bank causeway. Contour lines represent a curve along which the available biomass is constant. The difference topology simply highlights the differences between the Existing and With Project topologies. Separate topologies were created for Canoe Passage and the Intertidal Zones (**Figure 2**).

Figure 21 Meiofauna Foraging Opportunity under Existing and With Project Conditions during the Southward Migration



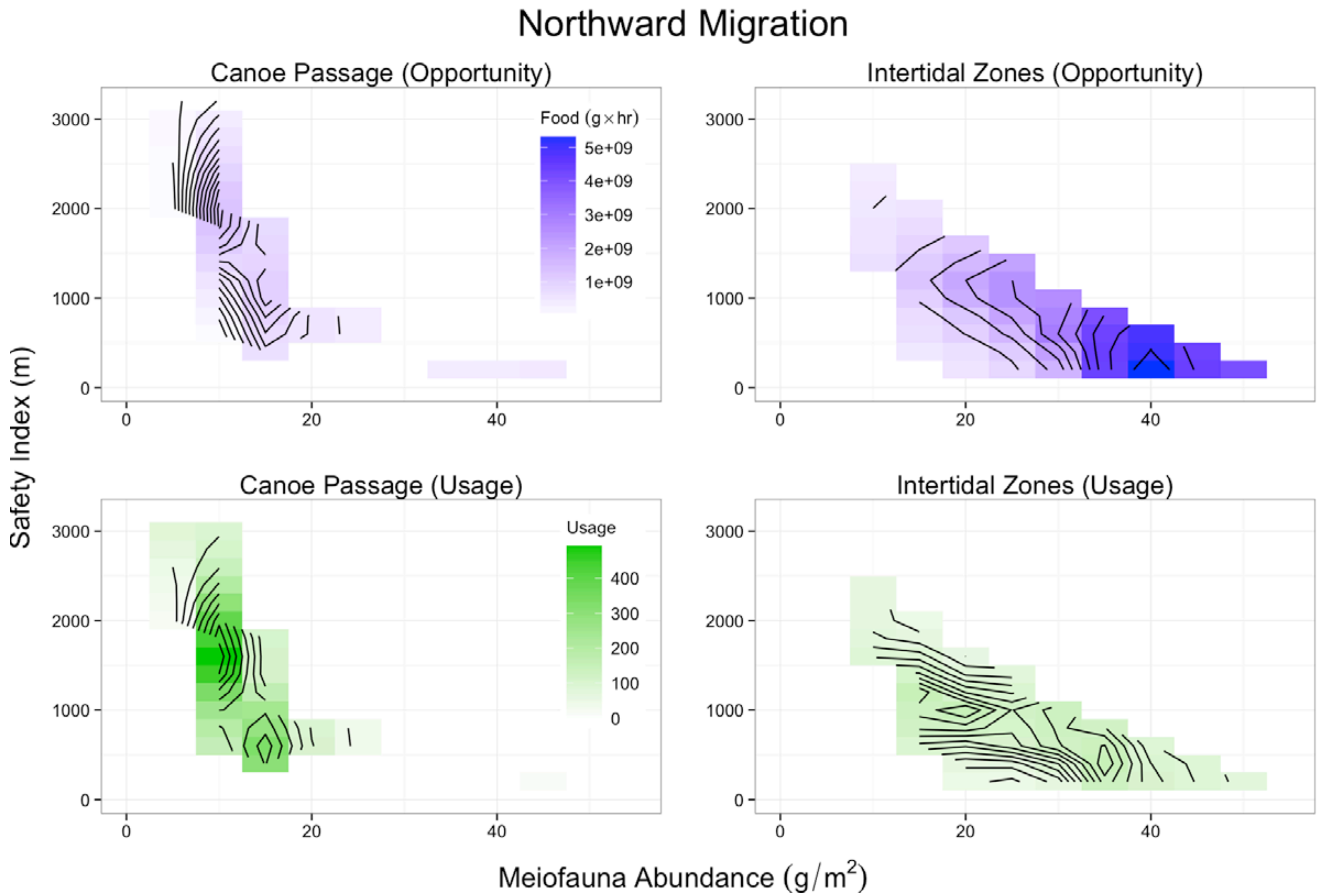
Note: Foraging opportunity is represented as a topology, where the height represents available food (available biomass) (g x hr) for a given combination of food density (mg/m^2) and safety index (metres to shore). Safety Index was measured as distance to either the natural shoreline or the Roberts Bank causeway. Contour lines represent a curve along which the available biomass is constant. The difference topology simply highlights the differences between the Existing and With Project topologies. Separate topologies were created for Canoe Passage and the Intertidal Zones (**Figure 2**).

4.2.3 Comparing Foraging Opportunity and Usage

Meiofauna foraging opportunity was compared to total usage during the 2012 northward migration (**Figure 29**) and the 2012 southward migration (**Figure 30**). The same two-dimensional bin criteria was used for all surfaces as foraging opportunity. Estimates of total usage were based on an IDW spatial interpolation of shorebird droppings data (**Figure 42**). Comparison of the two allows an assessment of how well estimated opportunity describes current usage.

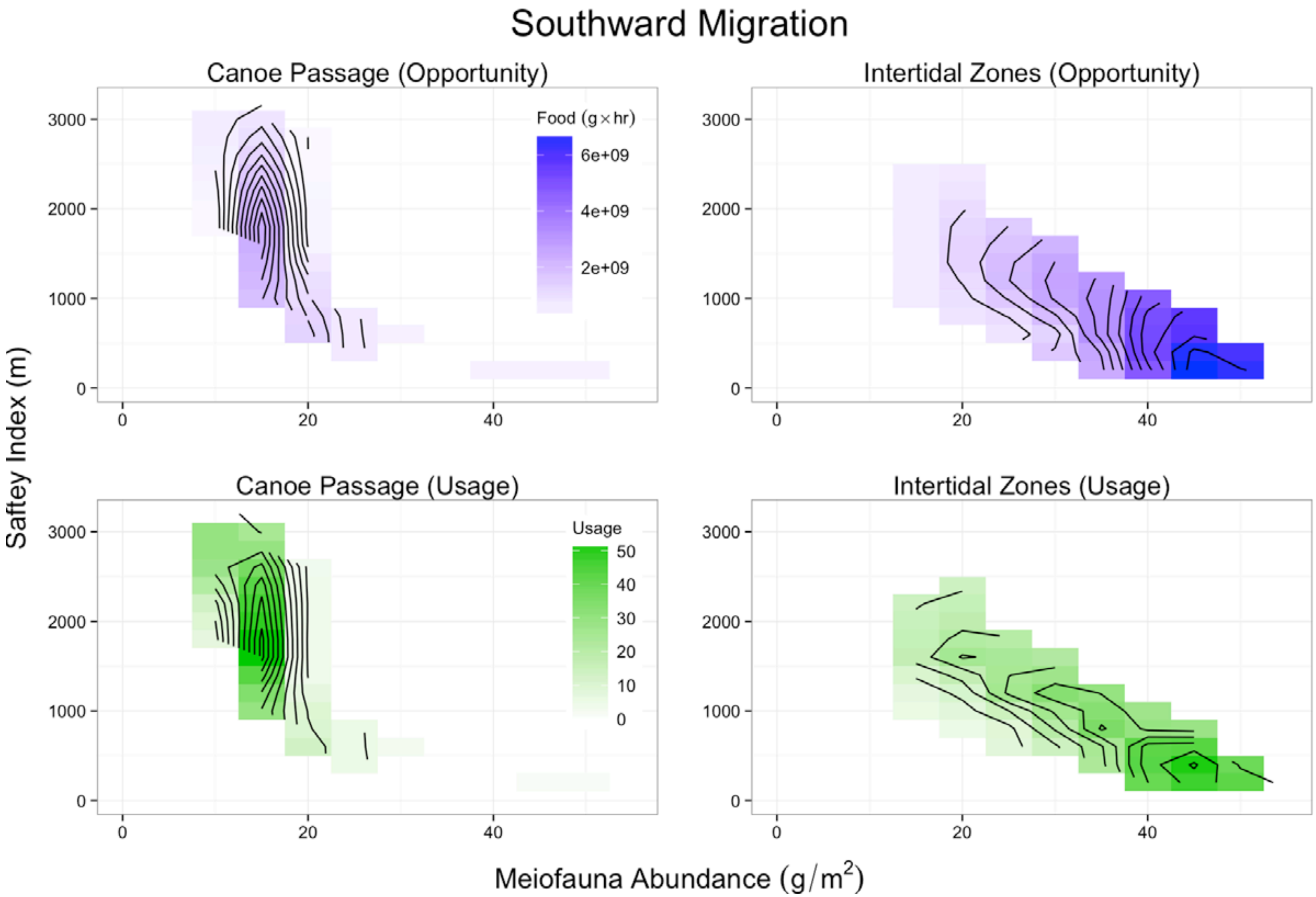
In general, total usage topology tracked meiofauna foraging opportunity topology well during both migration periods. Peak Intertidal Zones usage and opportunity aligned, both occurring in relatively unsafe areas (i.e., around 500 m from shore) and at similar meiofauna abundance levels. Canoe Passage usage and meiofauna foraging opportunity also occurred at similar positions in the opportunity space with the usage peak.

Figure 22 Comparison of Meiofauna Foraging Opportunity and Total Usage Topologies during the Northward Migration



Note: Opportunity topologies were constructed by determining the total available energy and total usage based applying abundance and safety criteria bins to the abundance and usage surfaces. A local trend surface was fit to bin values and normalised. Safety index represents the minimum distance (m) to either the natural shoreline or the Roberts Bank causeway shoreline.

Figure 23 Comparison of Meiofauna Foraging Opportunity and Total Usage Topologies during the Northward Migration



Note: Opportunity topologies were constructed by determining the total available energy and total usage based applying abundance and safety criteria bins to the abundance and usage surfaces. A local trend surface was fit to bin values and normalised. Safety index represents the minimum distance (m) to either the natural shoreline or the Roberts Bank causeway shoreline.

4.2.4 Estimating Meiofauna Capacity

Meiofauna capacity was estimated by comparing the distribution of available biomass and total usage, relative to abundance. Distributional curves for available meiofauna biomass and total usage in Canoe Passage and the Intertidal Zones for the northward and southward migrations were constructed. Meiofuna available biomass curves were standardised against northward migration Intertidal Zones total available biomass (**Appendix A: Figure 44**), which showed the highest levels of all areas by migration period comparisons (**Appendix B: Table 34**). Total usage curves were first standardised against northward Canoe Passage usage, as this usage was the highest total usage (**Appendix B: Table 35**). Comparison of availability and usage curves showed the two tracked well in both Canoe Passage and the Intertidal Zones during the northward migration. The distributions did not track one another strongly during the southern migration.

Usage curves were then scaled by an additional factor of 0.15 in order to have peak northward Canoe Passage usage fall within peak meiofauna availability biomass in Canoe Passage (**Figure 24**). The second usage-scaling step was done under the assumption that if meiofauna intake made up the majority of WESA diets then usage could not exceed availability. By this logic, total realised utilization must be either equal to or less than the scaled usage density curve as it is not possible to use more of a resource than currently exists; therefore, the overlap between the scaled usage and availability density curves will represent the upper bound of current usage. The area of the availability density curve not covered by the usage curve will represent a lower bound of unused meiofauna capacity.

Estimates of the current meiofauna utilization along with remaining capacity were computed for Canoe Passage and the Intertidal Zones by computing the areas availability/usage overlap and area where no overlap occurred (**Table 18**). The mean and lower bound estimates of percent change in available meiofauna (see **Table 17**) were also included for comparison purposes. The lower bound was used to represent a worst-case scenario. For all zones and migration periods the estimated capacity exceeded the expected changed; however, this was not true for the worst-case estimate of change, which exceeded Canoe Passage the capacity. Capacity of the LSA as a whole on the other hand was larger than 50% during northward migration and in excess of 90% during the southward migration, even under the worst-case scenario for change (**Table 19**). This indicates that Intertidal Zones has a large pool of meiofauna capacity that can compensate for potential changes within Canoe Passage.

Table 18 Summary of Zone-specific Estimates of Meiofauna Available Capacity and Anticipated Change during the Northward and Southward Migration Periods

Season	Zone	Existing Capacity		With Project Changes		Total Availability Ratios
		Used	Free	Estimated	Lower CI	
Northward Migration	Canoe Passage	83%	17%	0.8%	-47.1%	0.17
	Intertidal Zones	17%	83%	-17.8%	-45.4%	0.73
Southward Migration	Canoe Passage	9%	91%	4.5%	-42.8%	0.26
	Intertidal Zones	4%	96%	-16.2%	-46.1%	1.00

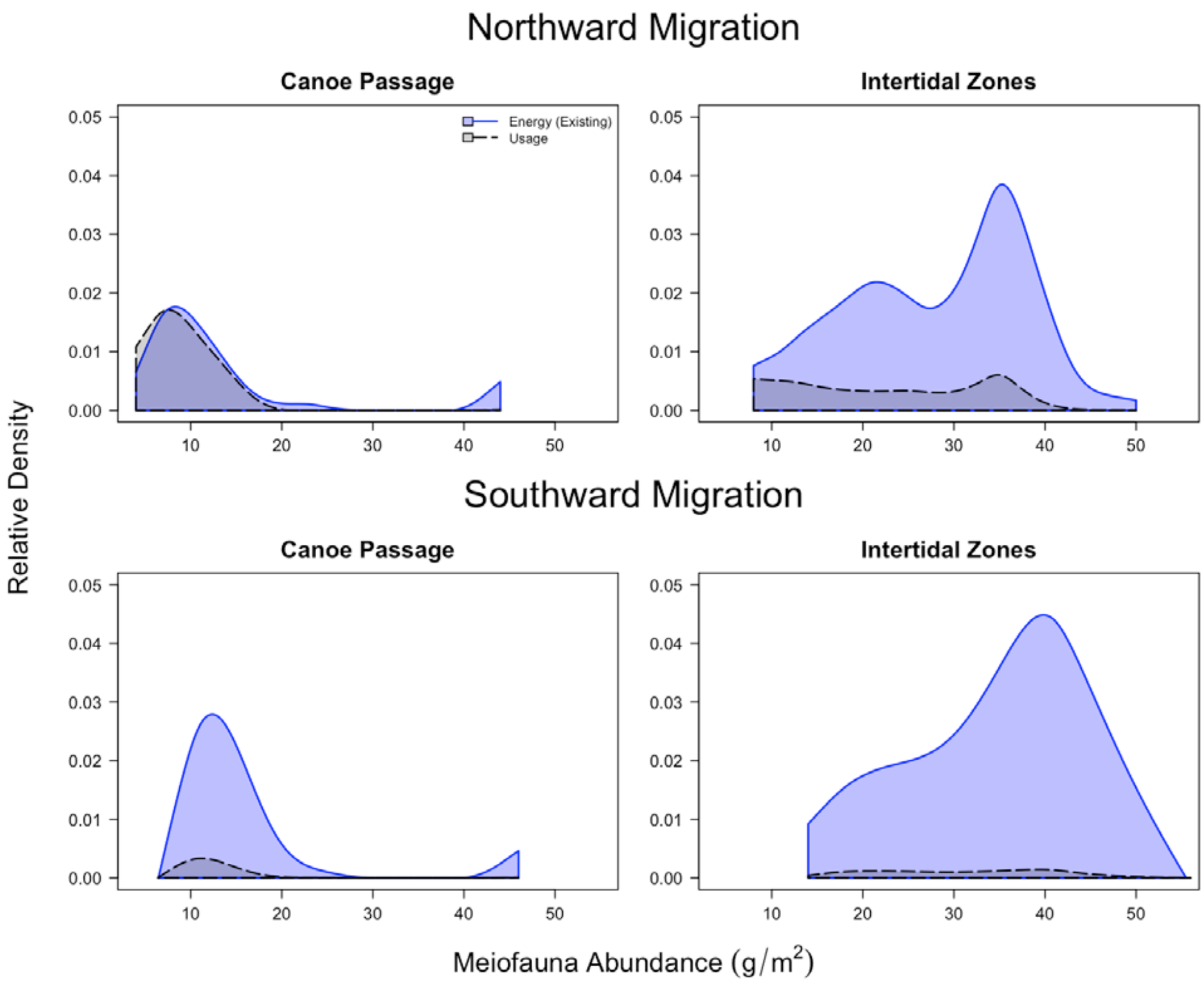
Note: Estimates of capacity and change are restricted to the infauna area of inference and computed separately for Canoe Passage and the Intertidal Zones (**Figure 2**). Computation of total available biomass ratios can be found in **Appendix B: Table 34**.

Table 19 Estimates of Local Study Area Meiofauna Capacities under Existing and With Project Conditions during the Northward and Southward Migration Periods

Season	Existing Conditions		With Project (Estimated Change)		With Project (Worst Case)	
	Used	Free	Used	Free	Used	Free
Northward Migration	29%	71%	34%	66%	43%	57%
Southward Migration	5%	95%	6%	94%	7%	93%

Note: Capacity estimates for the LSA were based on combining zone-specific capacity estimates after adjusting for total available biomass differences.

Figure 24 Overlay of Meiofauna Available Biomass and Total Usage Distributions by Zone During the Northward and Southward Migration Periods



Note: Energy densities have been scaled to represent the proportion of total energy relative to the maximum availability (Intertidal Zones; northward migration). Usage densities have been scaled relative to the maximum usage (Canoe Passage; southward migration), usage was then scaled a further (by 0.15) in order for maximum northward Canoe Passage usage to fit within biofilm availability. Densities plots without the further scaling are also available (**Appendix A: Figure 44**). A colour mixture indicates areas of overlap.

4.3 MACROFAUNA FORAGING OPPORTUNITY IN THE LOCAL STUDY AREA

4.3.1 Predicting Abundance of Macrofauna

4.3.1.1 Regression Model

The final regression model used to predict the macrofauna abundance was of the form:

Log Macrofauna ~ Year + Seasonal Wave Height + Seasonal Salinity

Variance inflation factors were computed for each the centered and scaled explanatory variables in the model. All values were within acceptable limits (i.e., <10) indicating that multicollinearity was not a substantial problem. The response variable was log transformed in order to meet statistical assumptions of the regression-kriging approach. The definition of each model parameter is outlined in **Table 20**.

The *Seasonal Wave Height* term represents the geomorphology modelling wave height predictions based on 90th percentile computed over either May (northward migration) or July (southward migration). This represents the impact of wave energy on macrofaunal abundance.

The *Seasonal Salinity* terms represent the geomorphology modelling water column salinity values (psu) based on 50th percentiles computed over either May (northward migration) or July (southward migration). There was no support for a second-degree polynomial term.

Table 20 Macrofauna Regression Model Parameters, Role, and Applied Transformations

Model Parameter	Type	Transformation	Description / Interpretation
Log Macrofauna	Response	Natural Log	Natural log transformed macrofauna abundance values (g/m^2). Regression model predicts orders of magnitude changes in in macrofauna abundance.
Year	Explanatory	None	Categorical variable allowing differences between years.
Seasonal Wave Height	Explanatory	None	Monthly 90th percentile of the geomorphology wave height modelling data. A May percentile was used for the northward migration and a July percentile for the southward migration. Extreme wave events predict log macrofauna abundance in a linear manner.
Seasonal Salinity	Explanatory	None	Seasonal 50th percentile of the geomorphology water column salinity modelling value. A May percentile was used for the northward migration and a July percentile for the southward migration. Median water column salinity predicts log macrofauna abundance in a simple linear fashion.

Note: All explanatory variables were standardised and scaled prior to fitting the regression model. Variance inflation factor analysis was used to assess multicollinearity of centered and scaled explanatory variables. In all cases multicollinearly was found to be within acceptable levels.

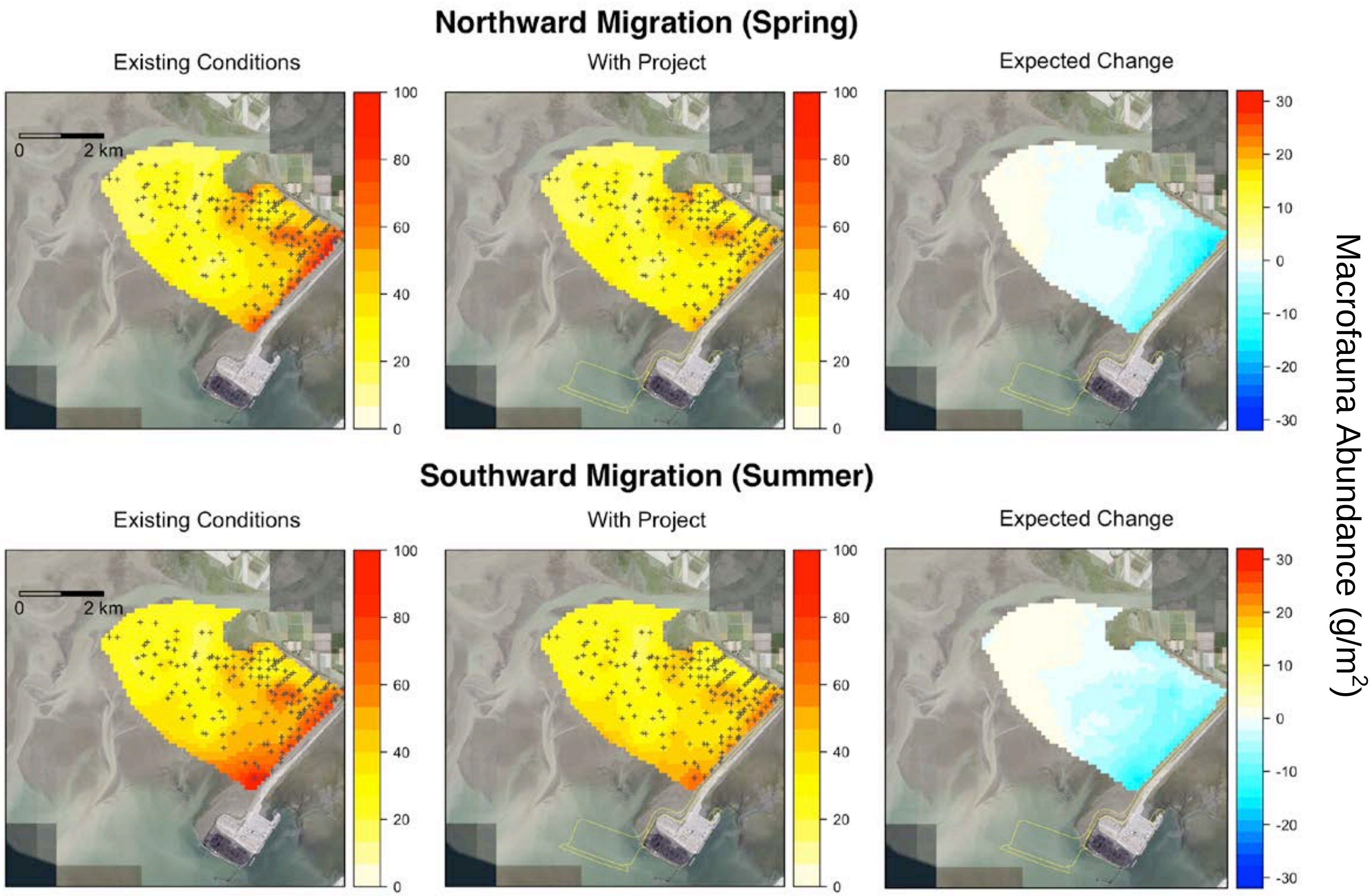
4.3.1.2 Spatial Predictions

Using the top supported regression model, a regression-kriging surface of macrofaunal abundances was created for the northward and southward migration periods under both Existing and With Project conditions (**Figure 25**). Changes between Existing and With Project surfaces are also indicated. The regression model was trained using both 2012 and 2013 years; however, because geomorphology modelling data were only available for the 2012 study year, spatial abundance predictions are for 2012.

Leave-one-out cross-validation was used to assess the model. Each data point was left out once, and predictions created based on the remaining samples. Predicted values were then compared to the sediment sample left out. The procedure indicated that the model explained roughly 10% of the variation in observed log macrofauna abundances, which indicates poor descriptive power. Investigation of model residuals from leave-one-out cross-validation indicated well-behaved residuals. There were no strong indications of a lack-of-fit, despite the poor predictive powers.

Under Existing conditions, the highest macrofauna abundances were found towards the shore (both the natural shoreline and the Inter-causeway shoreline) and away from Canoe Passage (**Figure 25**). With Project predictions showed some decreases in the Intertidal Zones and increases in Canoe Passage. Some seasonal differences were also visible, with higher predicted abundances along the Roberts Bank causeway during the southward migration period.

Figure 25 Estimated Macrofauna Abundance (g/m^2) under Existing and With Project Conditions during the Northward and Southward Migration Periods

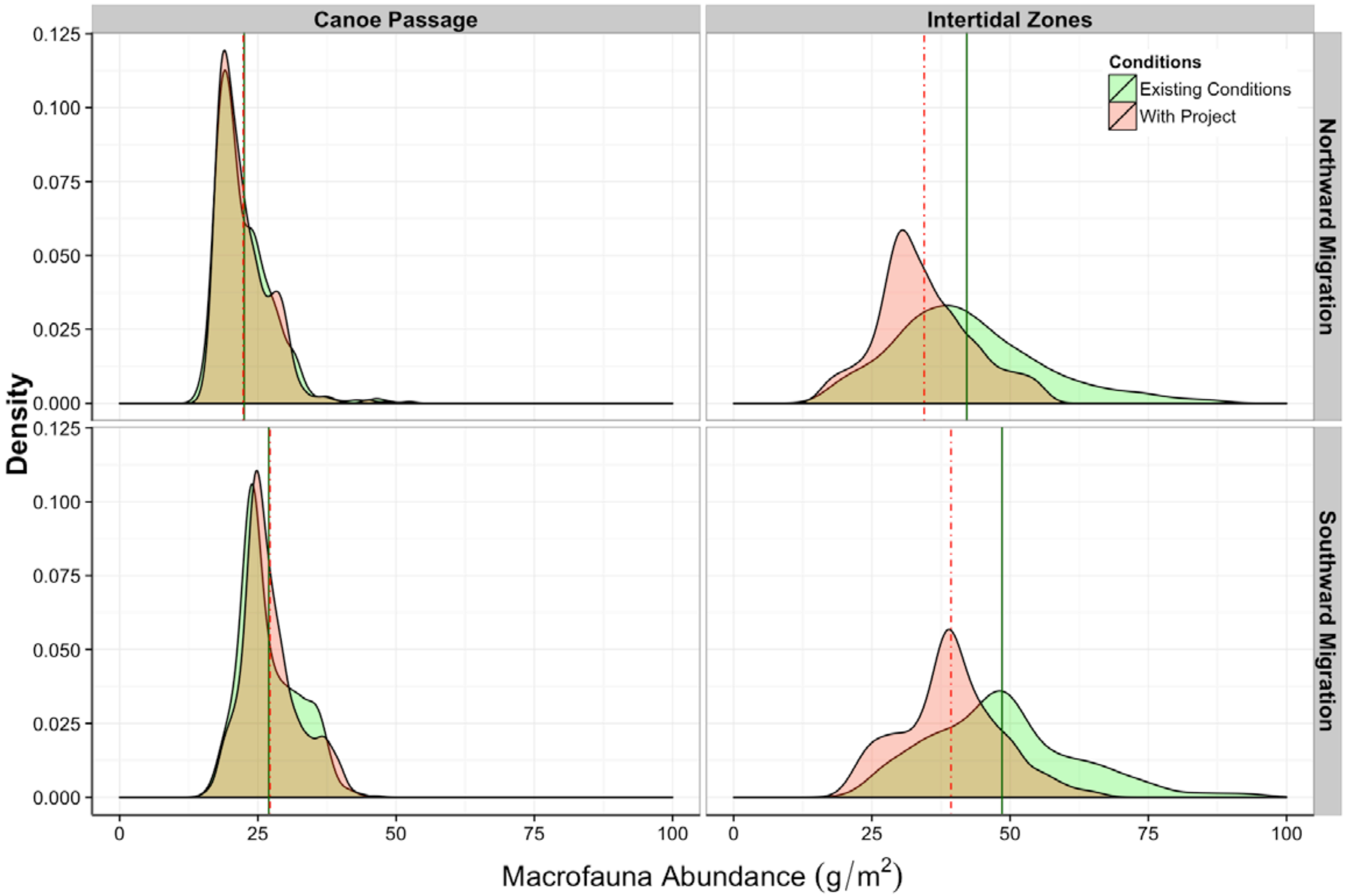


Note: Macrofauna abundance (g/m^2) was estimated for each 1-ha grid using a regression-kriging based on the 2012 coastal geomorphology modelling data. Each row shows abundance estimates under Existing and With Project conditions for either the northward or southward migration periods. Coastal geomorphology modelling data used were specific to that period. The final column indicates predicted changes in abundance. Sediment sampling locations used to train the regression-kriging model are indicated on the figure.

4.3.1.3 Distributional Changes in Abundance

While spatial plots of abundance can be useful, assessing what proportion of the landscape supports a particular level of abundance can be difficult. As such, the spatial dimension was removed and the distribution of estimated abundance was investigated by zone (i.e., Canoe Passage and Intertidal Zones; see **Figure 2** for definitions). The abundance distribution was summarised by a density plot, which represents the relative frequency of different macrofauna abundance values across the LSA (**Figure 26**). Overall, the distribution of predicted macrofauna abundance showed little change in Canoe Passage, and a shift towards lower abundances in the Intertidal Zones (**Figure 26**). For both the northward and southward migration periods under With Project conditions, predictions were for loss of higher macrofauna abundances and increased frequency of lower macrofauna abundances.

Figure 26 Distribution of Predicted Canoe Passage and Intertidal Zone Macrofauna Abundance (g/m^2) under Existing and With Project Conditions during Northward and Southward Migration Periods



Note: Density curves show the relative frequency of abundance values over Canoe Passage and the Intertidal Zones under Existing and With Project conditions. The area under each curve is one. The area under the curve corresponds to a range of abundance values and indicates the proportion of the landscape exhibiting those abundances. The green vertical solid line indicates mean abundance under Existing conditions and the red vertical dashed line indicates mean abundance under the With Project conditions.

4.3.1.4 Estimating Change in Total Biomass and Total Available Biomass

The percent change in total macrofauna biomass (**Table 21**) and total available macrofauna biomass (**Table 22**) between Existing and With Project scenarios were estimated for each zone (i.e., Canoe Passage and the Intertidal Zones) and for each migration period.

Overall, With Project declines in total biomass and total available macrofauna biomass were predicted for the Intertidal Zones during both the northward and southward migrations; however, total biomass and total available biomass were estimated to increase in Canoe Passage during both the northward and southward migrations, but total available biomass was closer to zero during the northward migration. Total available abundance during the southward migration was closer to estimates of total biomass changes than during the northward migration.

In all cases, the 95% confidence interval for the percent change contained zero so the null hypothesis of no change cannot be ruled out; however, this interpretation needs to be viewed with some caution. The shortcoming of *p*-value based hypothesis tests has been well documented (Hung et al. 1997) and the direct interpretation of confidence intervals directly can be preferred. As a conservative approach, the effect size associated with the lower confidence limit was interpreted as representing the limit of knowledge. For example, if a decline does occur, there is little evidence for declines larger than 47% total biomass, or 42% in total available biomass, during the northward migration.

Table 21 Estimated Percent Change in Macrofauna Total Biomass between Existing and With Project Conditions during the Northward and Southward Migration Periods

Area	Northern Migration			Southern Migration		
	Estimate	Lower CI	Upper CI	Estimate	Lower CI	Upper CI
Canoe Passage	4.1%	-48.2%	94.5%	5.6%	-41.5%	74.2%
Intertidal Zones	-16.6%	-48.9%	27.8%	-16.7%	-45.7%	25.1%
All Areas Combined	-11.1%	-46.5%	36.9%	-10.5%	-39.9%	31.2%

Note: Total biomass for each 1-ha grid cell was computed by taking the product of the area and abundance. Total biomass for an area under Existing and With Project conditions was then computed for 1,000 Monte Carlo simulations and percent change computed. The Monte Carlo distribution was then used to approximate the distribution of the percent change statistic providing the point estimate and 95% confidence intervals.

Table 22 Estimated Percent Change in Macrofauna Total Available Biomass between Existing and With Project Conditions during the Northward and Southward Migration Periods

Area	Northern Migration			Southern Migration		
	Estimate	Lower CI	Upper CI	Estimate	Lower CI	Upper CI
Canoe Passage	0.8%	-47.1%	76.0%	4.5%	-42.8%	74.5%
Intertidal Zones	-17.8%	-45.4%	17.7%	-16.2%	-46.1%	27.9%
All Areas Combined	-14.2%	-42.0%	20.7%	-11.5%	-42.4%	33.9%

Note: Total available biomass for each 1-ha grid cell was computed as the product of the area, abundance, and tidal cycle availability (see **Appendix A: Figure 41**).

4.3.1.5 Sensitivity Analyses

The effect of With Project geomorphology changes on macrofauna biomass was investigated by selectively updating geomorphology data, while leaving other explanatory variables unchanged. Estimates of percent change in macrofauna biomass were recomputed using only changes to seasonal 90th percentile wave heights or changes to seasonal 50th percentile water column salinities under With Project conditions (**Appendix B: Table 36** and **Table 37**). With Project estimates of percent change based only on changes to wave heights, showed increases relative to Existing conditions (**Appendix B: Table 36**), while percent change based only on salinity changes showed larger estimated decreases (**Appendix B: Table 37**). Taken together, salinity is predicted to be the primary driving factor behind estimated With Project decreases.

Finally, estimates of biomass changes were based on geomorphology modelling data that were based on the 2012 freshet event, a one in 25 year event. Such events will result in lower LSA salinity than smaller freshet events. Changes in biomass under different freshet scenarios were as considered in **Section 4.4**.

4.3.2 Estimating Foraging Opportunity

Macrofauna foraging opportunity visualises the interplay between safety, macrofauna abundances and available biomass (i.e., a proxy measurement for energy). Topologies were constructed for both Canoe Passage and the Intertidal Zones and during the northward (**Figure 27**) and southward (**Figure 28**) migrations and under both Existing and With Project conditions based on predicted macrofauna abundances. Foraging topology height indicates available biomass (g x hr) for a particular combination of safety and food (i.e., abundance).

4.3.2.1 Northward Migration Foraging Opportunity

During the northward migration (**Figure 27**), foraging opportunity under Existing conditions showed that peak opportunity in the Intertidal Zones occurred at an abundance of around 50 g/m^2 and in an area of moderate to low safety (0 to 700 m), while in Canoe Passage highest opportunity peak occurred at approximately half the abundance (around 25 g/m^2), but in much safer areas (around 2,000 m from shore). The available biomass (i.e., g x hr) represented by the topology height was also generally higher in the Intertidal Zones compared to Canoe Passage. Comparing both areas as a whole, the Intertidal Zones had nearly three times the total available biomass relative to Canoe Passage during both the northward and southward migration (see **Appendix B: Table 38** for ratios).

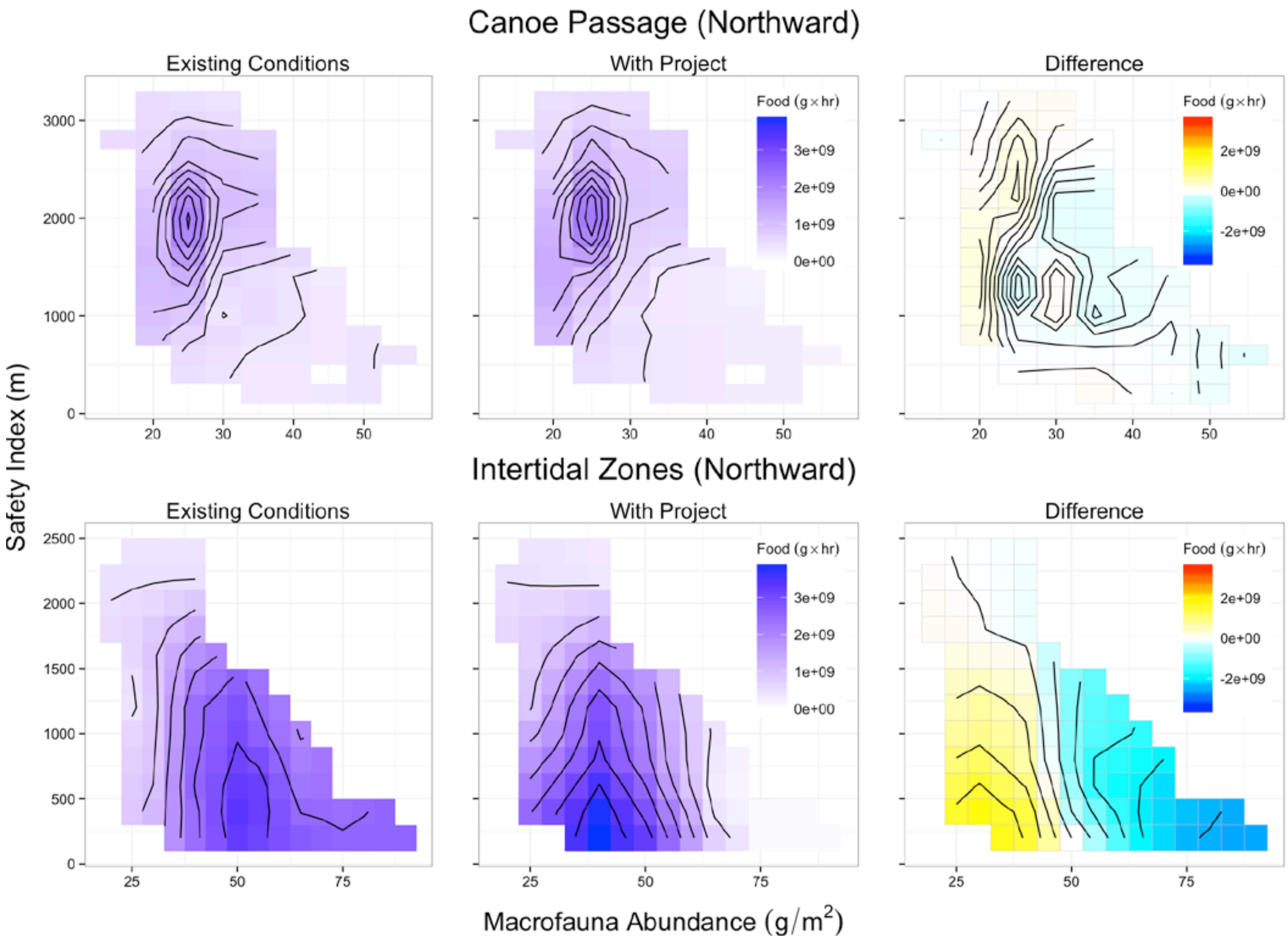
Under With Project conditions, peak opportunity in the Intertidal Zones was still in relatively unsafe areas (0 to 500 m), but with the foraging topology peak shifting to an abundance of around 30 g/m^2, instead of 50 g/m^2. Within Canoe Passage, the position of peak foraging opportunity remained constant with respect to abundance and safety. For both Canoe Passage and the Intertidal zones, opportunity showed a general trend of decreasing opportunity in higher abundances and increasing opportunity at lower abundances, with the Intertidal Zones showing the largest change. This pattern is also consistent with a general shift towards lower macrofauna abundances under With Project conditions. The shift also resulted in a small increase in the height of the Canoe Passage foraging opportunity topology peak, as a result of its location in lower abundance areas.

4.3.2.2 Southward Migration Foraging Opportunity

During the southern migration (**Figure 28**), foraging opportunity under Existing conditions exhibited different patterns relative to the northward migration. While peak foraging opportunity in the Intertidal Zones occurred in relatively dangerous areas during the northward migration, during the southward migration, the peak was located in less dangerous areas (around 1,000m). Peak foraging opportunity in Canoe Passage covered a larger area of the opportunity space than in the northward migration; however, the trade-off between abundance and safety remained similar to the northward migration conditions, with peak total biomass availability occurring in relatively safe areas. The With Project opportunity peaks remained largely unchanged for both Canoe Passage and the Intertidal Zones, with a higher Canoe Passage peak.

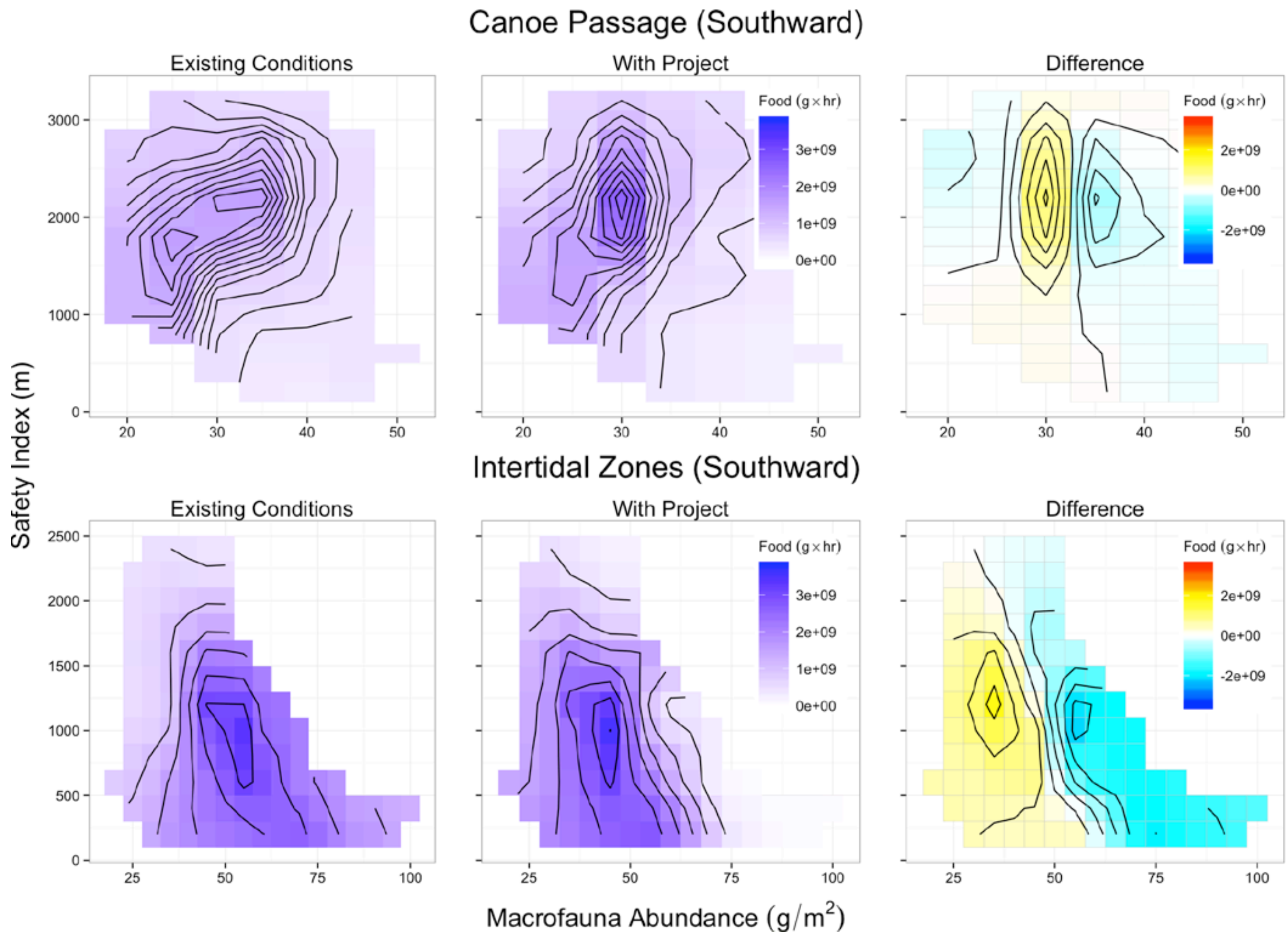
Under With Project conditions, foraging opportunity during the southward migration showed different changes compared to the northward migration. Again there was the general trend of loss of higher abundance opportunity and a gain of lower abundance opportunity (**Figure 28**). Within Canoe Passage, the shift resulted in a more focused peak in the foraging opportunity topology and a higher peak in total available biomass. Peak foraging opportunity in the Intertidal Zones also did not shift in position within the opportunity space, despite the loss of higher abundance opportunity.

Figure 27 Estimated Macrofauna Foraging Opportunity Under Existing and With Project Conditions during the Northward Migration



Note: Foraging opportunity is represented as a topology, where the height represents available food (available biomass) (g x hr) for a given combination of food density (mg/m^2) and safety index (metres to shore). Safety Index was measured as distance to either the natural shoreline or the Roberts Bank causeway. Contour lines represent a curve along which the available biomass is constant. The difference topology simply highlights the differences between the Existing and With Project topologies. Separate topologies were created for Canoe Passage and the Intertidal Zones (**Figure 2**).

Figure 28 Estimated Macrofauna Foraging Opportunity under Existing and With Project Conditions during the Southward Migration



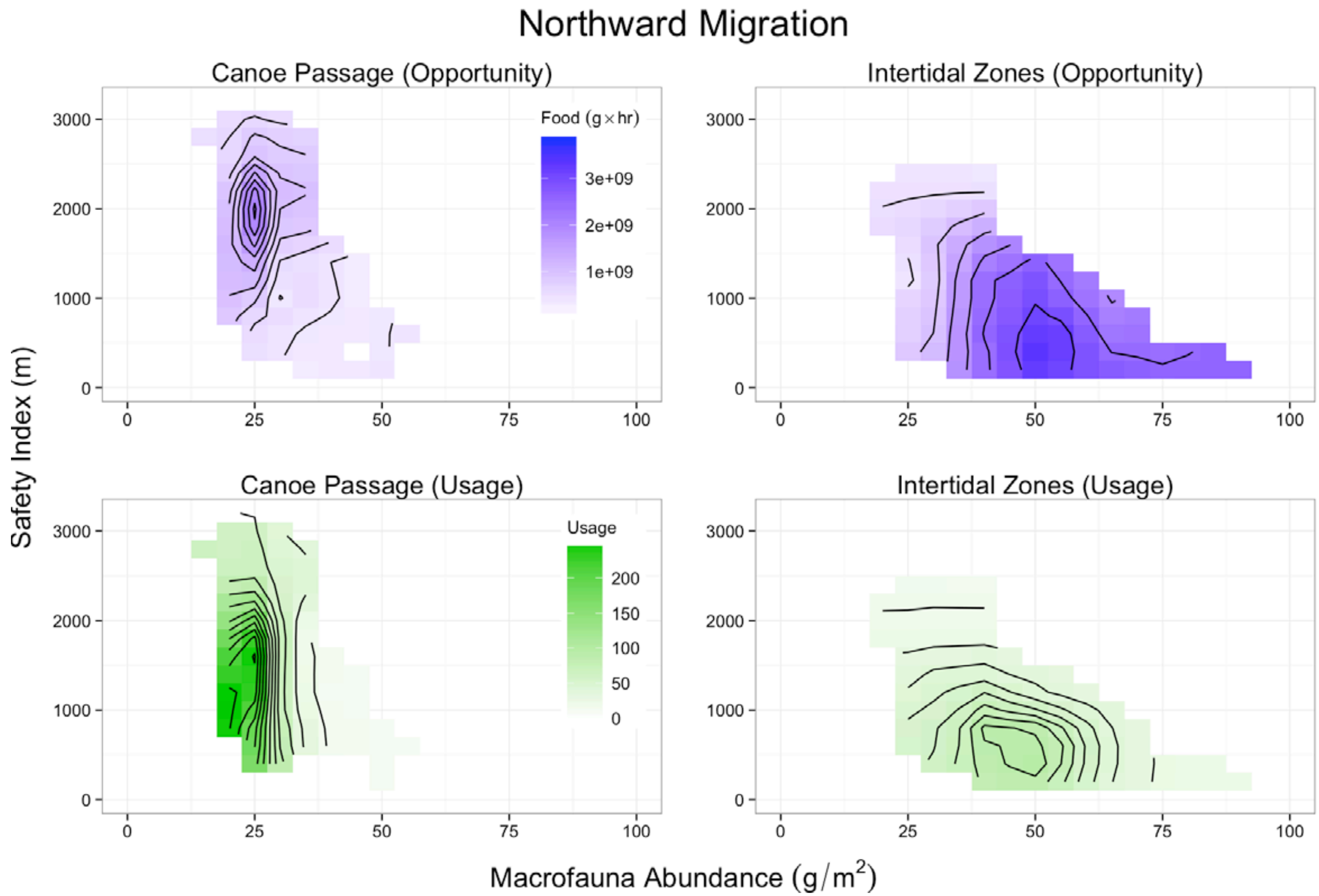
Note: Foraging opportunity is represented as a topology, where the height represents available food (available biomass) (g x hr) for a given combination of food density (mg/m^2) and safety index (metres to shore). Safety Index was measured as distance (m) to either the natural shoreline or the Roberts Bank causeway. Contour lines represent a curve along which the available biomass is constant. The difference topology simply highlights the differences between the Existing and With Project topologies. Separate topologies were created for Canoe Passage and the Intertidal Zones (**Figure 2**).

4.3.3 Comparing Foraging Opportunity and Usage

Macrofauna foraging opportunity was compared to total usage during the 2012 northward migration (**Figure 29**) and the 2012 southward migration (**Figure 30**). The same two-dimensional bin criteria was used for all surfaces. Estimates of total usage were based on an IDW spatial interpolation of shorebird droppings data (**Appendix A: Figure 42**). Comparison of the two allows an assessment of how well estimated opportunity describes current usage.

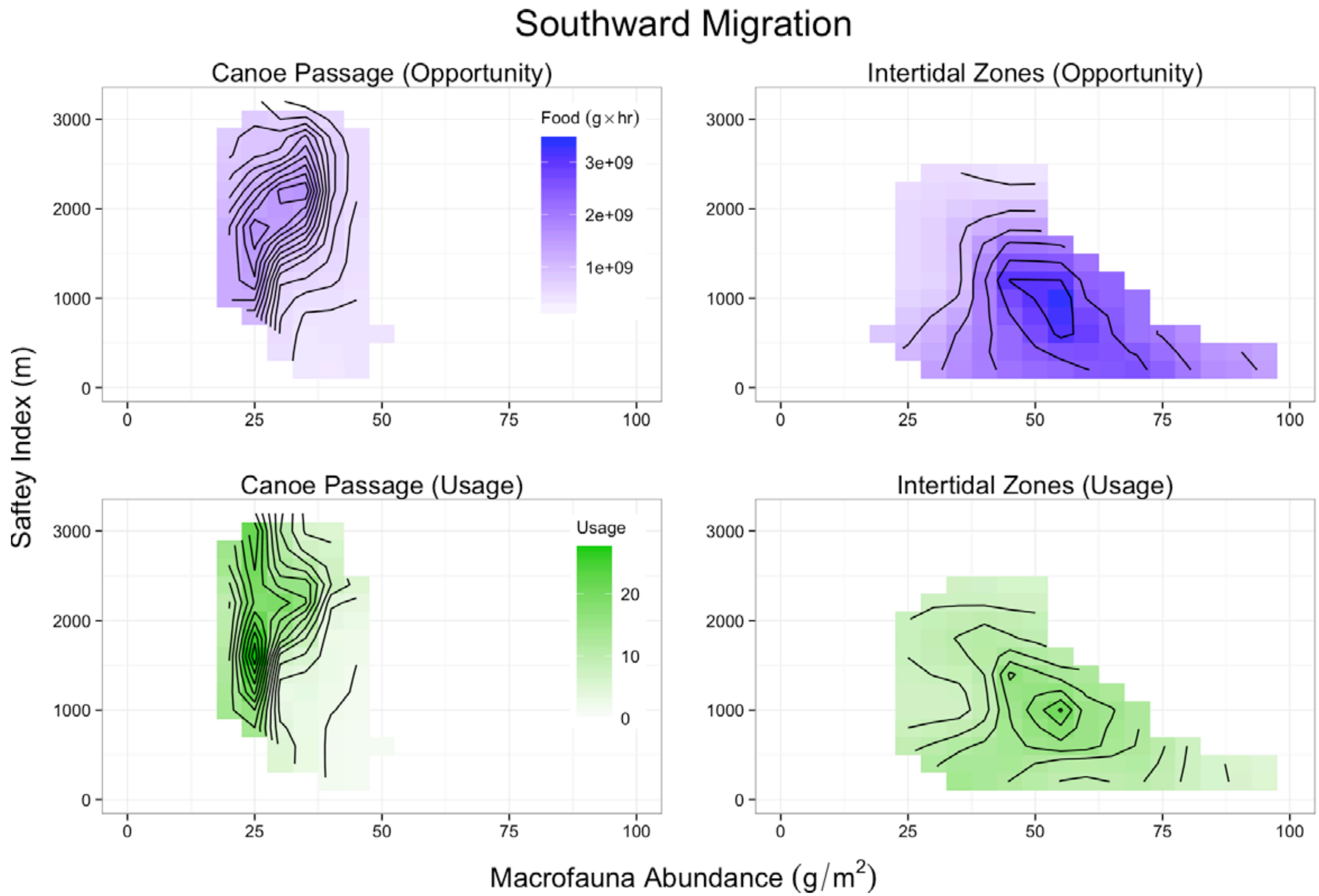
In general, the total usage topology tracked macrofauna foraging opportunity topology well during both migration periods. Peak Intertidal Zones usage and opportunity aligned, both occurring in relatively unsafe areas (i.e., around 500 m) and at similar macrofauna abundance levels. Canoe Passage usage and macrofauna foraging opportunity also occurred at similar positions in the opportunity space with the usage peak shifted slightly towards less safe areas than the estimated peak macrofauna opportunity.

Figure 29 Comparison of Macrofauna Foraging Opportunity and Total Usage Topologies during the Northward Migration



Note: Opportunity topologies were constructed by determining the total available energy and total usage based applying abundance and safety criteria bins to the abundance and usage surfaces. A local trend surface was fit to bin values and normalised. Safety index represents the minimum distance (m) to either the natural shoreline or the Roberts Bank causeway shoreline.

Figure 30 Comparison of Macrofauna Foraging Opportunity and Total Usage Topologies during the Southward Migration



Note: Opportunity topologies were constructed by determining the total available energy and total usage based applying abundance and safety criteria bins to the abundance and usage surfaces. A local trend surface was fit to bin values and normalised. Safety index represents the minimum distance (m) to either the natural shoreline or the Roberts Bank causeway shoreline.

4.3.4 Estimating Macrofauna Capacity

Macrofauna capacity was estimated by comparing the distribution of available biomass and total usage, relative to abundance. Separate distribution density curves were created for total available macrofauna biomass and total usage by zone (i.e., Canoe Passage and the Intertidal Zones) and by migration period. Total available biomass density curves were then standardised against southward Intertidal Zone total biomass (**Appendix A: Figure 45**), which showed the highest available macrofauna biomass (**Appendix B: Table 38**). Total usage curves were first standardised against total northward Canoe Passage usage in the infauna inference area (**Figure 2**), as this usage was the highest total usage (**Appendix B: Table 35**). All usage curves were then scaled by an additional factor of 0.2 to have peak northward Canoe Passage usage fall within macrofauna availability curve for Canoe Passage (**Figure 31**).

The second usage-scaling step was made under the assumption that macrofauna consumption cannot exceed availability, as it should not be possible to consume more resources that currently exist. An estimate of current utilization was computed based on the proportion of the total availability curve that overlapped with the usage curve, while capacity was the remaining area under the availability curve after accounting for potential usage (**Table 23**). These estimates represent an upper limit to utilization.

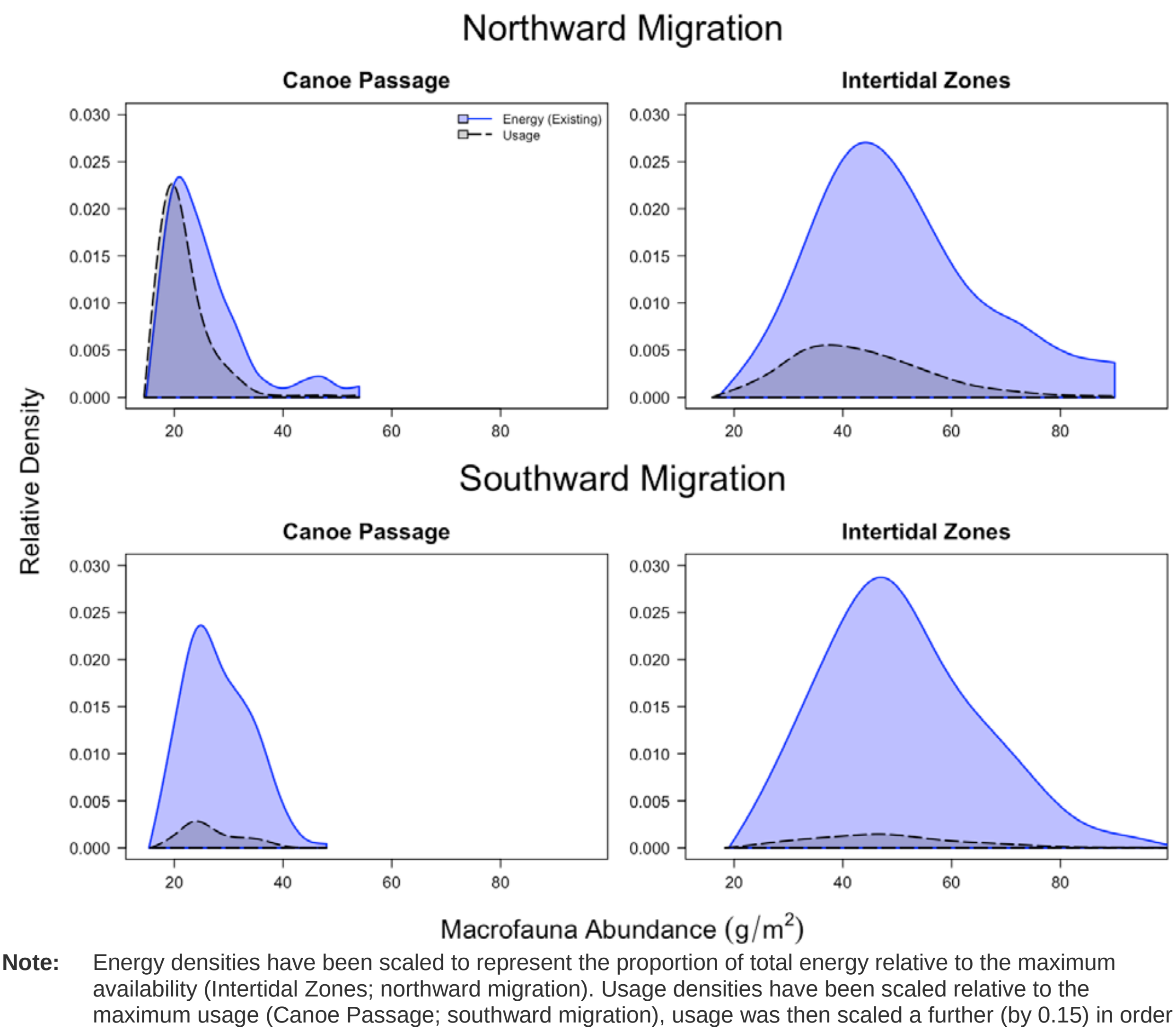
The largest estimates of capacity (e.g., greater than 90%) were estimated to occur during the southern migration for both Canoe Passage and the Intertidal Zones (**Table 23**). During the northern migration, Canoe Passage was estimated as having 38% capacity remaining, while the Intertidal Zones were estimated to have 82% of total available biomass unused. In addition to having a larger capacity, the Intertidal Zones was also estimated to have about 3 times higher total available biomass than Canoe Passage (**Appendix B: Table 38**).

Estimates of LSA utilization and capacity were then generated (**Table 24**) based on combining the zone-specific estimates of utilization and total biomass availabilities (**Table 23**). Estimates were generated for Existing conditions and with zone-specific estimates With Project changes. With Project changes included estimated change and a ‘worse case’ scenario based on the lower 95% confidence interval. Estimates also assumed that total consumption can be distributed between zones in the LSA and remained constant, and showed capacities in the LSA remained above 50% even under the worst-case scenario for With Project decline.

For the northward migration, this surplus is largely driven by the large Intertidal Zone capacities, which have optimal foraging opportunity in more dangerous areas (**Figure 27**). For the southward migration, large capacities remain in both zones, where Canoe Passage peak foraging opportunity occurs in safer areas (**Figure 28**).

Finally, the availability usage distributions ignore considerations of safety and may provide insight into shorebird foraging macrofauna habitats with respect to safety. Overall, the usage distribution curves strongly tracked availability distribution curves in Canoe Passage. Given that peak macrofauna foraging opportunity in Canoe Passage (**Figure 27**) occurred in relatively safe areas, this is not surprising as there would be a lower risk of predation. The strong association between usage and macrofauna availability may represent an explanation for mismatch between usage and biofilm availability curves, which was suggested to potentially represent time spent foraging on other food items (**Figure 15**).

Figure 31 Overlay of Macrofauna Available Biomass (g x hr) and Total Usage Distributions by Zone During the Northward and Southward Migration Periods



Note: Energy densities have been scaled to represent the proportion of total energy relative to the maximum availability (Intertidal Zones; northward migration). Usage densities have been scaled relative to the maximum usage (Canoe Passage; southward migration), usage was then scaled a further (by 0.15) in order for maximum northward Canoe Passage usage to fit within biofilm availability. Density plots without the further scaling are also available (**Appendix A: Figure 45**). A colour mixture indicates areas of overlap.

Table 23 Estimates of Macrofauna Capacity and Anticipated Change by Zone during the Northward and Southward Migration Periods

Season	Zone	Existing Capacity		With Project Changes		Total Availability Biomass Ratios
		Used	Free	Estimated	Lower CI	
Northward Migration	Canoe Passage	62%	38%	0.8%	-47.1%	0.30
	Intertidal Zones	18%	82%	-17.8%	-45.4%	0.93
Southward Migration	Canoe Passage	9%	91%	4.5%	-42.8%	0.37
	Intertidal Zones	5%	95%	-16.2%	-46.1%	1.00

Note: Estimates of capacity and change are restricted to the infauna area of inference and computed separately for Canoe Passage and the Intertidal Zones (**Figure 2**). Computation of total available biomass ratios can be found in **Appendix B: Table 38**.

Table 24 Estimates of Local Study Area Macrofauna Capacities under Existing and With Project Conditions during the Northward and Southward Migration Periods

Season	Existing Conditions		With Project (Estimated Change)		With Project (Worst Case)	
	Used	Free	Used	Free	Used	Free
Northward Migration	29%	71%	32%	68%	42%	58%
Southward Migration	6%	94%	7%	93%	9%	91%

Note: Capacity estimates for the LSA were based on combining zone-specific capacity estimates after adjusting for total available biomass differences.

4.4 FRESHET AND SALINITY SENSITIVITY ANALYSIS

The 2012 geomorphology modelling data were generated under a 1 in 25 year freshet event (**Figure 32**). Under these conditions, water in the LSA is less saline than years with a freshet size closer to the historical average. Due to the importance of salinity on With Project biofilm, meiofauna, and macrofauna abundance predictions, the impact of differing freshet sizes and salinity modelling assumptions were investigated for biofilm, meiofauna, and macrofauna in the LSA.

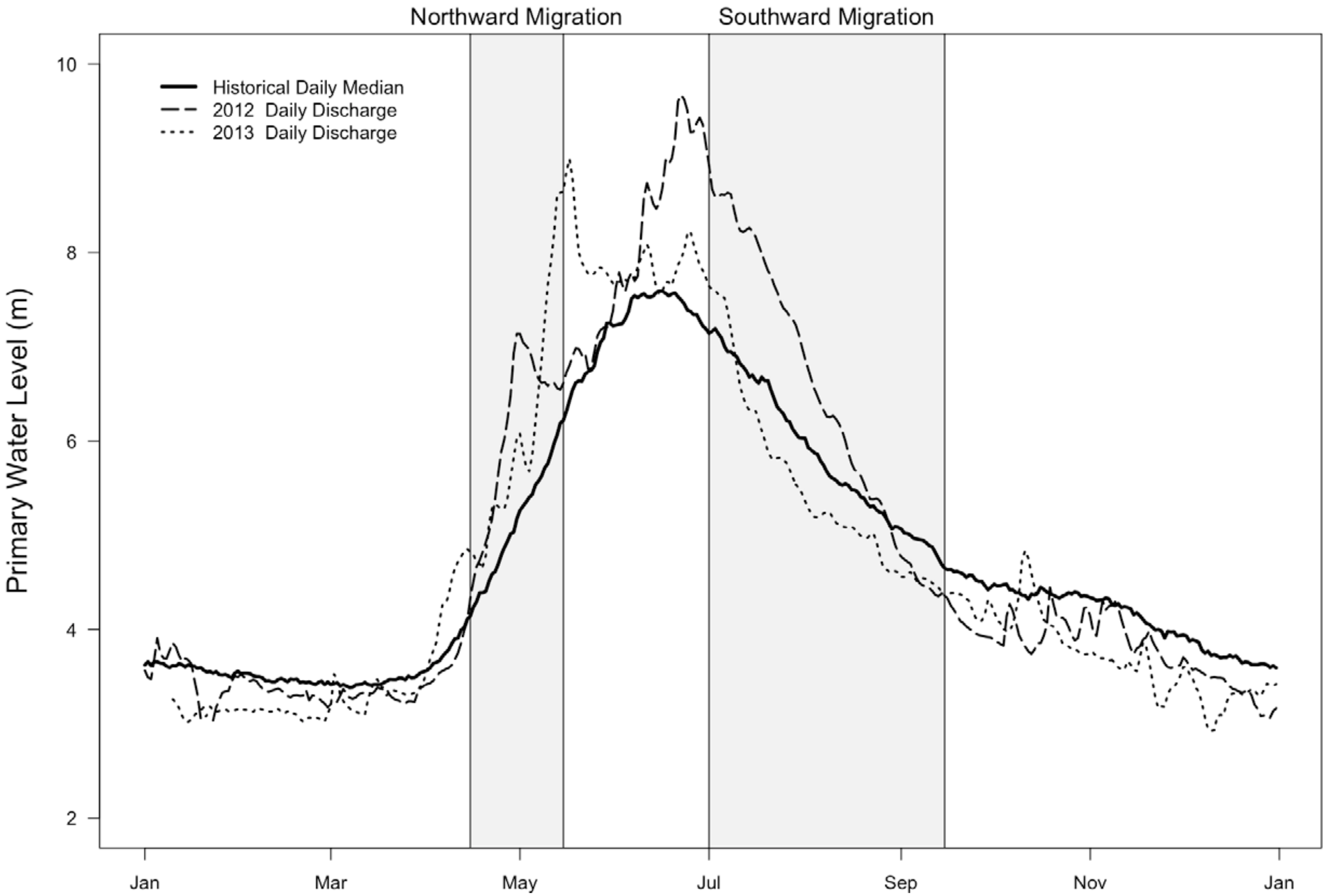
For the purpose of this analysis, the historical median daily flow (1914 - 2013) was used to represent more ‘typical’ conditions (**Figure 32**). Because only the 2012 geomorphology modelling data (generated under the 1 in 25 year freshet event) were available to replicate more ‘typical’ conditions, different 2012 geomorphology monthly percentiles were selected based on matching 2012 flow rates to the median flow rates seen in the northward and southward migration periods (**Figure 32**). For the northward migration, which spans April and May, the 2012 50th percentile September geomorphology water column salinity data were used (**Figure 33**). For the southward migration, which spans from July to mid-September, the 2012 50th percentile August geomorphology salinity data were used (**Figure 34**). At the time of the analysis, wave height monthly percentiles for August and September were not available and were not considered as part of this analysis. Because biofilm (chlorophyll *a*) regression models included a polynomial salinity term (see **Table 9**), changes under different freshet conditions were also considered with and without a polynomial salinity term. Estimates of total biomass percent change between Existing and With Project conditions were then generated for chlorophyll *a* (**Table 25**), meiofauna (**Table 26**), and macrofauna (**Table 27**) using the revised salinity values and the same methods as for the initial estimates.

In all cases, estimates of percent change under a ‘typical’ freshet resulted in either smaller declines or, in some cases, increased total biomass (e.g., northward migration biofilm, and northward and southward macrofauna) compared to With Project changes estimates generated under the 2012 freshet salinity values. This was also true for chlorophyll *a* models with a regression structure that included either linear salinity terms or polynomial salinity terms. None of these differences can be considered statistically significant due to the large confidence intervals (not shown) on the percent change statistic, but do suggest that abundance related changes associated with With Project salinity changes may not be easily generalised to a single set of conditions (e.g., 2012 freshet).

The difficultly in generalizing With Project salinity changes is further highlighted when the degree and nature of salinity changes are compared between differing freshet scenarios on a monthly basis. In general, under the ‘typical’ freshet scenario the LSA has higher salinity values (rightmost column; **Figure 33** and **Figure 34**); however, the patterns of With Project salinity changes were not identical between the 2012 and ‘typical’ freshet scenarios. Under the ‘typical’ freshet, within a given season (i.e., northward or southward migration), the patterns of With Project salinity changes showed larger areas of salinity increase relative to the 2012 freshet (bottom row; **Figure 33** and **Figure 34**). These increases start in the lower Canoe Passage zone and ingress farther into the Intertidal Zones when the freshet event is smaller. Under the ‘typical’ freshet scenario, there are some salinity increases in the Intertidal Zones in addition to most of Canoe Passage. Under the 2012 freshet, With Project salinity increases were mostly relegated to the Canoe Passage zone, which showed lower estimates of total biomass for chlorophyll *a*, mieofauna, and macrofauna (see **Appendix B: Table 30**, **Table 34**, and **Table 38**, respectively).

Further complicating summarizing With Project changes, is the salinity polynomial relationship used in the chlorophyll *a* predictive models (**Figure 35**). Generally, higher salinity resulted in higher predicted abundance (and biomass by extension), but at a value of 16.2 psu there is an inflection point, suggesting an optimal salinity for chlorophyll *a* abundance. Beyond this point of water column salinity value, chlorophyll *a* abundance is predicted to decline (assuming all other variables are held constant). As a result, predicting With Project changes in LSA total chlorophyll *a* biomass becomes more complicated because there are multiple competing patterns. Patterns of With Project salinity changes across the LSA are dependent on the size of the freshet event, and chlorophyll *a* abundance follows an inverse parabolic relationship. As a result, areas of optimal salinity for chlorophyll *a* abundance can be expected to vary between migration periods and by the size of freshet event (**Figure 36** and **Figure 37**). Under a more typical freshet scenario, the northward migration showed the largest area of optimal salinity occurring within the Intertidal Zones and under With Project conditions (September percentiles; **Figure 36**); however, during larger freshet events, the area of optimal salinity occupies a smaller proportion of the biofilm zone, which should result in lower biofilm production (top row; **Figure 36** and **Figure 37**). Taken together, this suggests it is not possible to represent With Project changes in biofilm as a singular process, but rather as an alteration of a highly dynamic process.

Figure 32 Historical Median Discharge and Observed Fraser River Discharge Levels during the Study Period



Note: Water level was measured at the Hope station (49° 22' 50" N, 121° 27' 05"). Historical median daily flow was computed over the period from 1912 to 2013. Sediment samples were collected in 2012 and 2013. Northward and southward migration windows are indicated on the figure.

Figure 33 Monthly 2012 Geomorphology Model Water Column Salinity Values for the Northward Migration Freshet Analysis

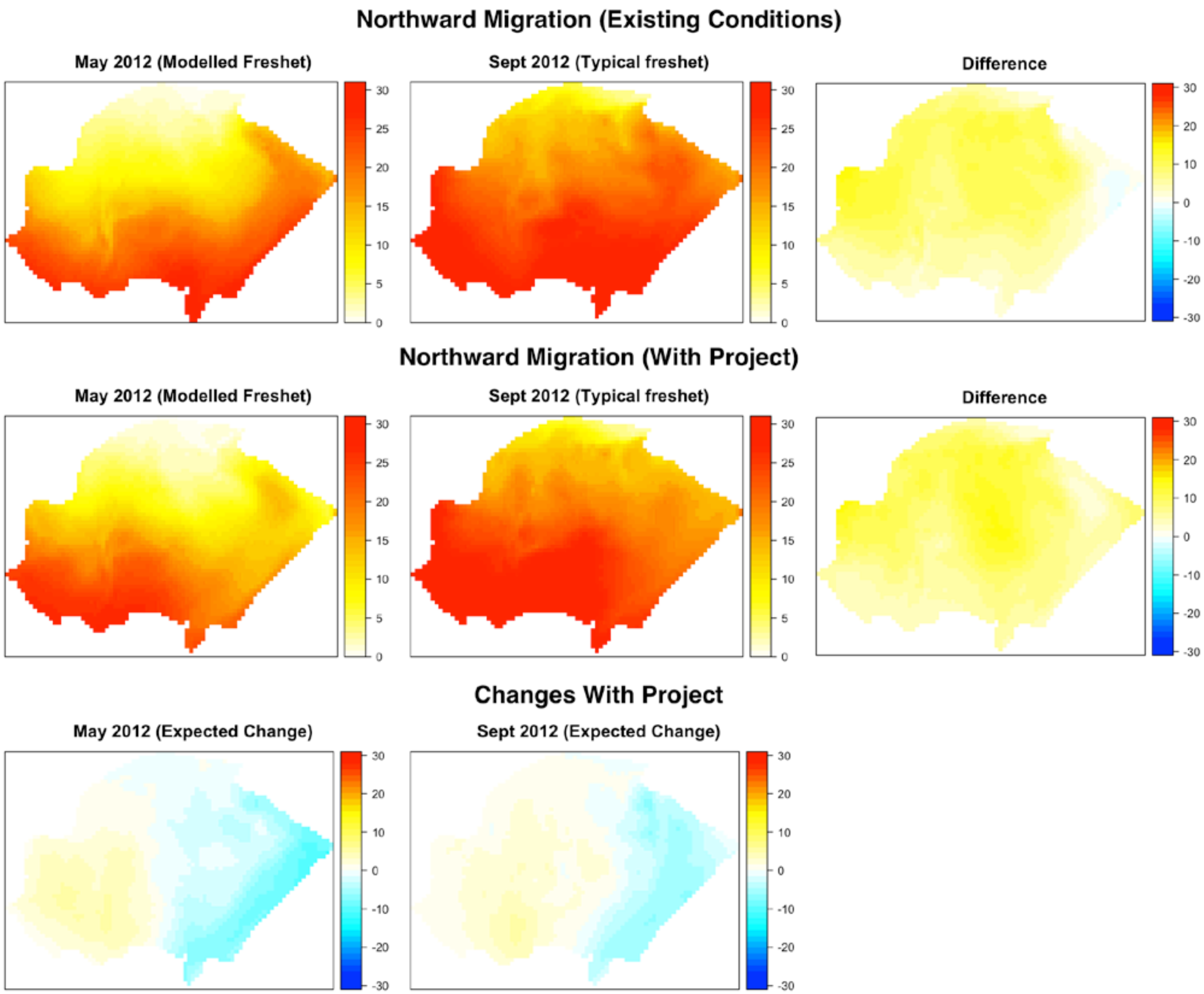


Figure 34 Monthly 2012 Geomorphology Model Water Column Salinity Values for the Southward Migration Freshet Analysis

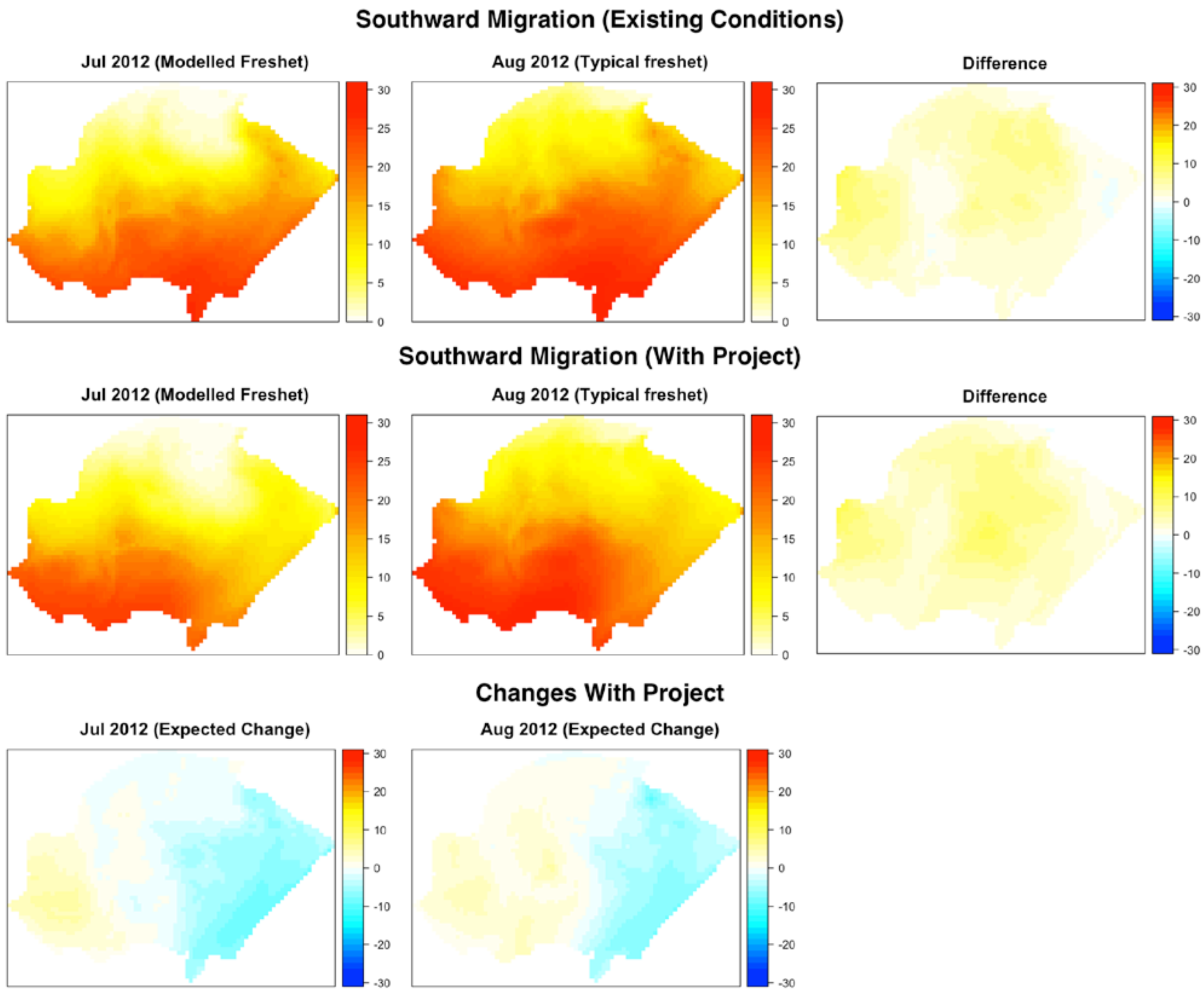


Table 25 Chlorophyll *a* Biomass Percent Change Estimates from the Freshet and Salinity Sensitivity Analysis

Season	Area	2012 Freshet		'Typical' Freshet	
		Top Model	Linear Salinity	Top Model	Linear Salinity
Northward Migration	Canoe Passage	-5%	-1%	2%	2%
	Intertidal Zones	-2%	-8%	18%	-6%
	All Zones Combined	-4%	-5%	8%	-2%
Southward Migration	Canoe Passage	-9%	-3%	-1%	-1%
	Intertidal Zones	-15%	-7%	-5%	-7%
	All Zones Combined	-13%	-6%	-4%	-5%

Note: Summary of point estimates of change using either the 50th percentiles for May (northward) and July (southward) 2012 geomorphology modelling data (2012 freshet) or 50th percentiles for September (northward) and August (southward) to represent more 'typical' conditions. Top supported model included a polynomial salinity term.

Table 26 Meiofauna Biomass Percent Change Estimates from the Freshet and Salinity Sensitivity Analysis

Season	Area	2012 Freshet	'Typical' Freshet
		Top Model	Top Model
Northward Migration	Canoe Passage	1%	11%
	Intertidal Zones	-14%	-8%
	All Zones Combined	-11%	-4%
Southward Migration	Canoe Passage	6%	12%
	Intertidal Zones	-14%	-11%
	All Zones Combined	-9%	-6%

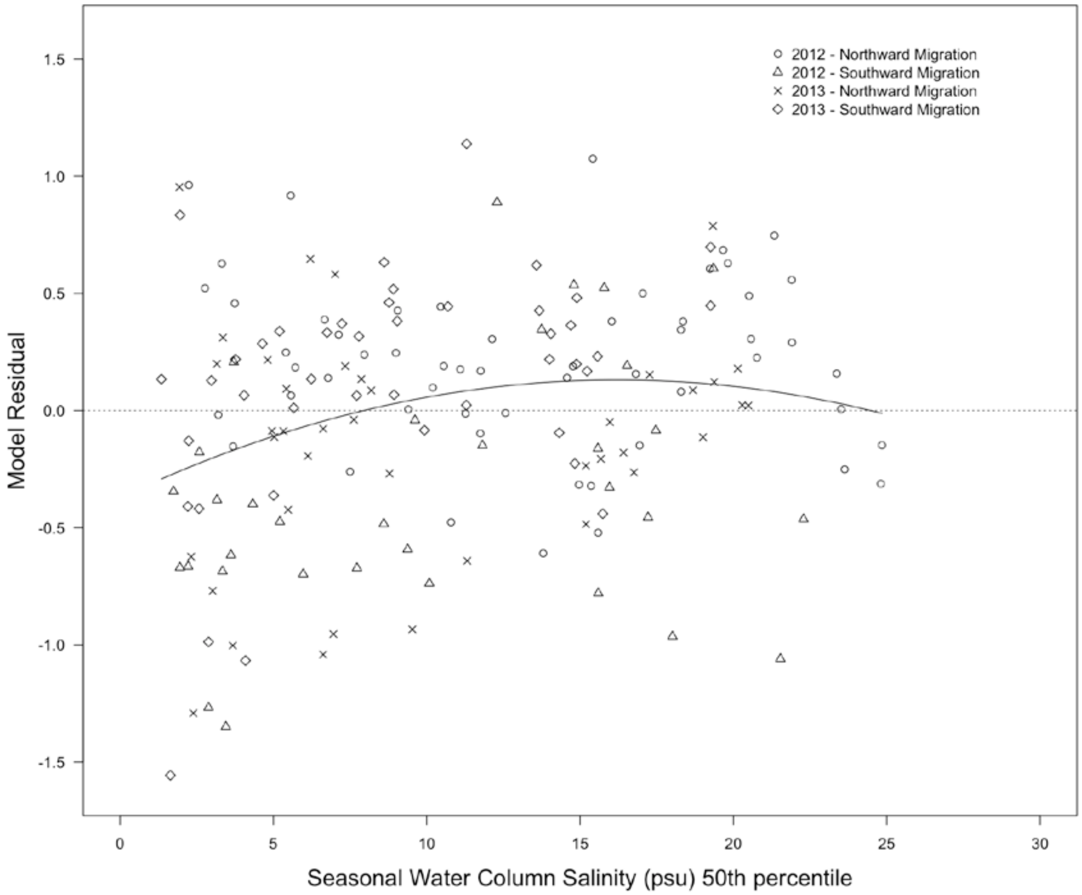
Note: Summary of point estimates of change using either the 50th percentiles for May (northward) and July (southward) 2012 geomorphology modelling data (2012 freshet) or 50th percentiles for September (northward) and August (southward) to represent more 'typical' conditions.

Table 27 Macrofauna Biomass Percent Change Estimates from the Freshet Analysis

Season	Area	2012 Freshet	'Typical' Freshet
Northward Migration	Canoe Passage	4%	7%
	Intertidal Zones	-17%	7%
	All Zones Combined	-11%	7%
Southward Migration	Canoe Passage	6%	10%
	Intertidal Zones	-17%	5%
	All Zones Combined	-10%	6%

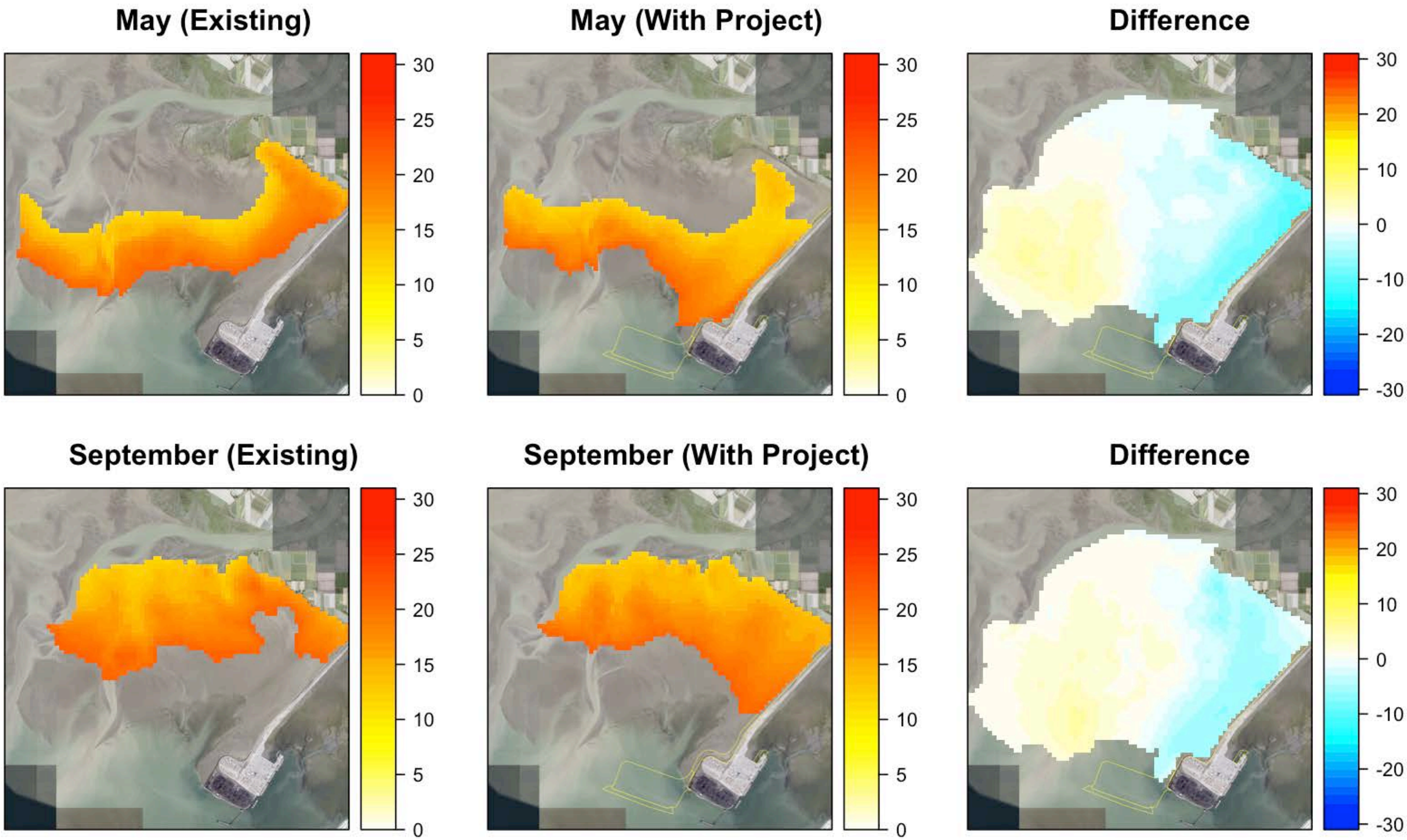
Note: Summary of point estimates of change using either the 50th percentiles for May (northward) and July (southward) 2012 geomorphology modelling data (2012 freshet) or 50th percentiles for September (northward) and August (southward) to represent more 'typical' conditions.

Figure 35 Chlorophyll *a* Abundance Model Second Order Polynomial Relationship with Geomorphology Water Salinity



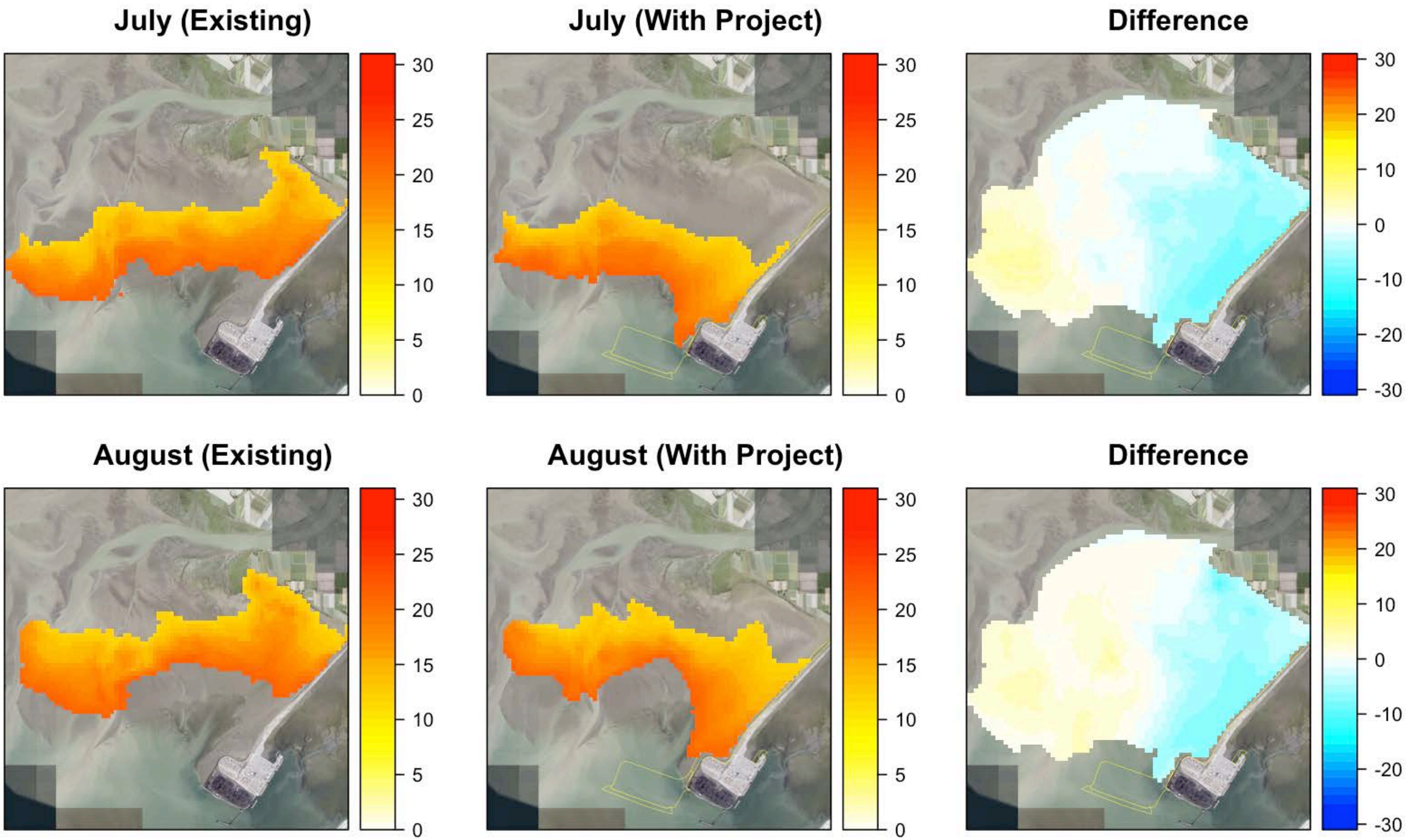
Note: The best estimate of the second order salinity polynomial term is regressed against log chlorophyll *a* model residuals from the regression model fitted without the polynomial salinity term. The inflection point of the curve occurs at a salinity value 16.2 psu. The season of the sampling points is indicated by symbol.

Figure 36 Zones of Optimal Biofilm Salinity under Different Freshet Event Sizes during the Northward Migration



Note: Displayed values are monthly 50th percentiles from water column salinity from the 2012 geomorphology data within 5 psu of the estimated optimal biofilm salinity. May monthly percentiles represent northward water column salinities during the 2012 freshet, while September monthly percentile represents northward water column salinities during more typical freshet events. The rightmost column indicates the change between Existing and With Project conditions for a given month.

Figure 37 Zones of Optimal Biofilm Salinity under Different Freshet Event Sizes during the Southward Migration



Note: Displayed values are monthly 50th percentiles from water column salinity from the 2012 geomorphology data within 5 psu of the estimated optimal biofilm salinity. May monthly percentiles represent northward water column salinities during the 2012 freshet, while September monthly percentile represents northward water column salinities during more typical freshet events. The rightmost column indicates the change between Existing and With Project conditions for a given month.

4.5 TOTAL BIOMASS ACROSS THE REGIONAL STUDY AREA AND ROBERTS BANK

Estimates of total biomass for the three food sources (i.e., biofilm, meiofauna, and macrofauna) were computed across the RSA by stratum (**Figure 3**) in order to compare the usage and resources of the LSA (**Figure 2**) relative to surrounding areas where shorebirds may also forage. First, estimates of total biomass and total usage were compared within Roberts Bank (i.e., Westham Island, Brunswick Point, and the Inter-causeway, see **Figure 3**), as these areas are in close proximity of the LSA, and then compared across the RSA. For the latter comparison, Roberts Bank is then compared to Sturgeon Bank and then Boundary Bay.

4.5.1 Regression Models and Spatial Distribution of Abundances

In order to generate estimates of RSA biomass, a slightly different approach was required in order to formulate regression-kriging models. Modelled geomorphology data of sufficient special resolution were only available in the LSA. Outside of the LSA, the geomorphology modelling data were averaged at too large of a spatial scale and were not sufficiently correlated with abundance measurements in the sediment samples in order to build predictive models. As such, a different set of explanatory variables was used to predict abundance in areas outside of the LSA. These variables include adjusted sediment chloride, percent sand, and total organic carbon, which were used in place of coastal geomorphology modelling data. As values for these variables were not completely known across the landscape, separate regression-kriging surfaces were built for these variables first using all available data at the time (see **Appendix A: Figure 49**, **Figure 50**, and **Figure 51** for sediment chloride, percent sand, and total organic carbon, respectively).

Abundance predictions for biofilm, meiofauna, and macrofauna at each 1-ha grid cell across the RSA were made based on regression-kriging surfaces using model structures indicated in Appendix B (**Appendix B: Table 39**, **Table 40**, and **Table 41**, respectively). For biofilm (chlorophyll *a*), abundance predictions (**Appendix A: Figure 52**) indicated large areas of very low chlorophyll *a* values (e.g., less than 20 mg/m^2). These areas are unlikely to represent biofilm and are likely a result of the model predicting a proxy for biofilm, without any cut-offs present in the model. These low levels of chlorophyll *a* are unlikely to represent biofilm and could bias estimates of total biomass due to the large areas involved. As a result, a cut-off of 30 mg/m^2 was used resulting in a reduced spatial distribution of biofilm (**Appendix A: Figure** 53). The cut-off was based on the cut-off used for the hyperspectral definition of biofilm (see ASL Environmental Sciences 2013). While there is no empirical evidence to date for using this cut-off for sediment sample measurements of chlorophyll *a*, this likely represents a better starting point than a completely arbitrary chosen cut-off point. Estimates of meiofauna (**Appendix A: Figure 54**) and macrofauna (**Appendix A: Figure 55**) were used without further modification. Total usage was estimated from the IDW of log dropping densities (**Appendix A: Figure 56**) by expanding stratum-specific averages to generate stratum-specific averages of total usage (see **Section 3.4.4.2**).

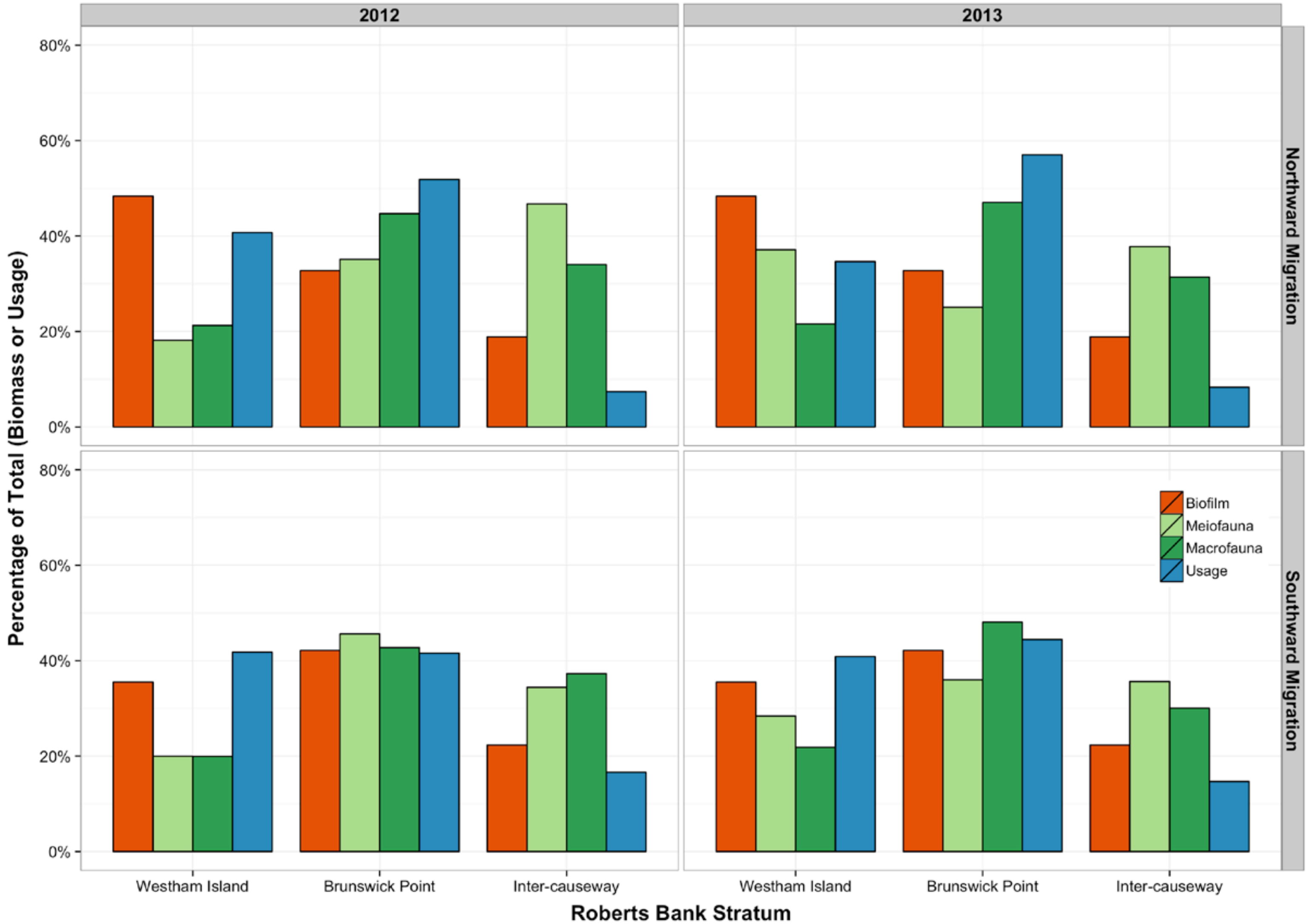
4.5.2 Comparison of Total Biomass in Roberts Bank

Within each stratum, estimates of chloropyll *a*, meiofauna, and macrofauna total biomass was computed along with estimates of total usage (see **Section 3.4.4.2** for details). Total biomass was then computed across all of Roberts Bank and the biomass of individual stratum was converted to a proportion (**Figure 38**).

Similar levels of chlorophyll *a* total biomass were found in Westham Island and Brunswick Point, with the Inter-causeway showing the lowest total biomass (**Figure 38**). This same trend is shown for both 2012 and 2013; however, this may be an artefact of sampling technique being confounded with year (see **Section 3.4.2.3** for more details). Meiofauna and macrofauna total biomass was estimated to be highest in the Inter-causeway and Brunswick Point stratum (**Figure 38**).

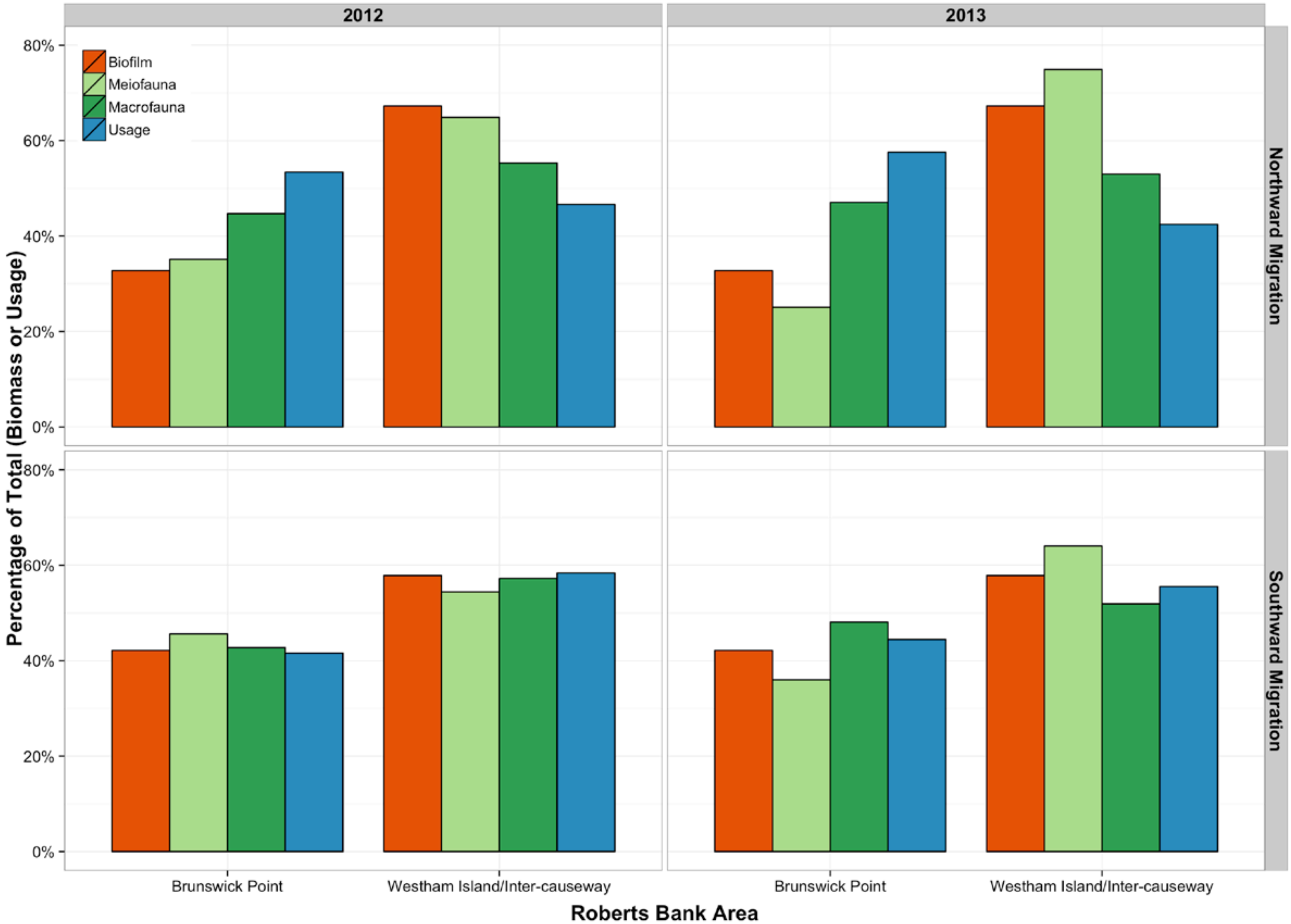
One consistent trend across all years and migration periods was the high availability of all three food sources in the Brunswick Point stratum, infauna food sources in the Inter-causeway, and chlorophyll *a* levels in Westham Island. During the same period, shorebird usage was consistently higher in Brunswick Point, followed by Westham Island. From this perspective Brunswick Point is unique as it provides high levels of all food sources in one place; however, Westham Island and the Inter-causeway complement each other in that the food source lacking in one predominates in the other. Taken together, these two stratum present higher levels of all three food sources than Brunswick Point (**Figure 39**); however, the drawback for shorebird foraging is the transit costs between sites in order to consume all three food sources.

Figure 38 Summaries of Roberts Bank Total Biomass and Total Usage by Stratum



Note: Total biomass within each stratum was first determined then converted to a percentage of the total biomass found in Roberts Bank. Total usage for each stratum was also determined (see **Section 3.4.4.2**. for methods on total usage determination).

Figure 39 Summaries of Roberts Bank Total Biomass and Total Usage by Area by Year



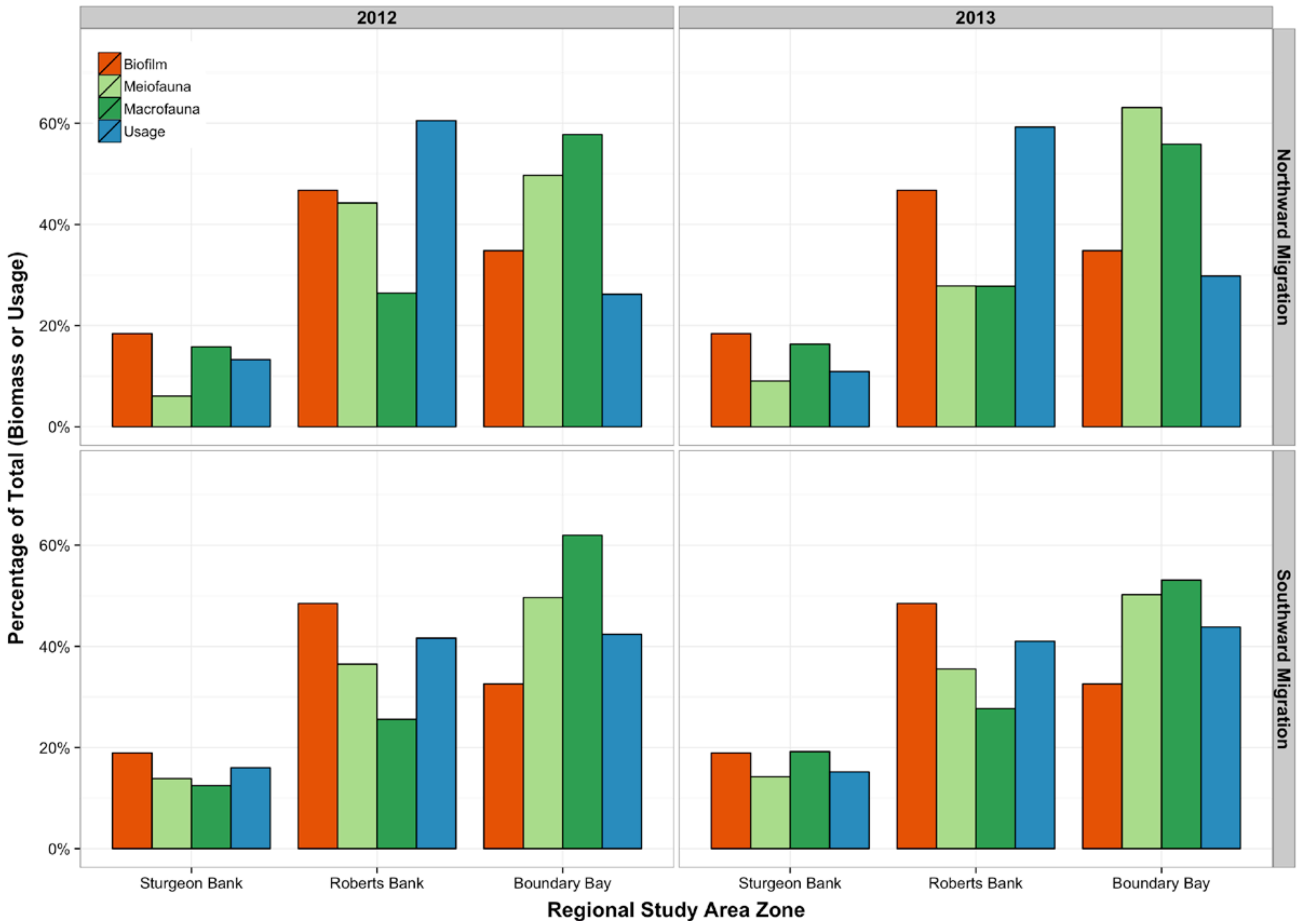
Note: Total biomass within each area was first determined then converted to a percentage of the total biomass found in Roberts Bank. Total usage for each area was also determined (see **Section 3.4.4.2**. for methods on total usage determination).

4.5.3 Comparison of Total Biomass across the Regional Study Area

Total biomass and total usage (see **Section 3.4.4.2** for methods) were also determined for the Roberts Bank area relative to the remainder of the RSA (**Figure 40**).

The highest total chlorophyll *a* biomass and highest usage were found in Roberts Bank, followed by Boundary Bay, with Sturgeon Bank showing the lowest total biomass. The highest total infauna biomass was found in Boundary Bay, followed by Brunswick Point, then Sturgeon Bank. During the northward migration, total usage was highest in the Roberts Bank area, followed by Boundary Bay and Sturgeon Bank. During the southward migration, total usage was more evenly split between the Roberts Bank area and Boundary Bay. Finally, the lower total biomass and usage seen in Sturgeon Bank is not unexpected as it also represents a smaller total area, about 12% of the total area in the RSA.

Figure 40 Summary of Total Biomass and Total Usage in Regional Study Area



Note: Total biomass within each stratum was first determined then converted to a percentage of the total biomass found in the RSA (**Figure 3**). Total usage was also determined for each area was also determined (see **Section 3.4.4.2**. for methods).

5.0 DISCUSSION

A discussion of the major results arising from the Shorebird Foraging Opportunity study and data gaps are provided below.

5.1 DISCUSSION OF KEY FINDINGS

Across all food sources investigated (i.e., biofilm (chlorophyll *a*), meiofauna, and macrofauna), total biomass and total available biomass was predicted to decline during shorebird migration. Estimated changes were generally small, but larger changes cannot be ruled out due to large confidence intervals associated with the high natural variability in the system. In all cases the changes in biomass were largely driven by predicted hydrodynamics changes in salinity in the LSA. Estimates of foraging opportunity showed some changes related to changes in biomass, but remained largely unchanged. Finally, using conservative assumptions and a worst-case scenario, there appears to be enough system capacity for shorebirds for typical population sizes.

Predicted changes food abundances (i.e., biofilm (chlorophyll *a*), meiofauna, and macrofauna) under With Project consistently showed in modelled water column salinity as the strongest driver of change relative to changes of wave energy (wave height) in the LSA. Estimates of With Project changes based on the 2012 geomorphology modelling data generally showed consistent declines for all three food sources during both the northward and southward migration periods. Estimates of foraging opportunity, which is a measure available biomass by food abundance and safety co-ordinates, showed shifts related to biomass declines, but there were no observed alterations in the available biomass to safety and abundance relationship after accounting for changes in biomass. For example, areas of high opportunity remained at similar safety and abundance co-ordinates.

Based on usage data taken at the same time as biomass sampling programs, individual shorebirds appear to be prioritizing safety. The highest usage was consistently seen in Canoe Passage, even though Canoe Passage had lower total available biomass than the Intertidal Zones (about 30 to 40% for infauna and about 70% for chlorophyll *a*). While lower in total available biomass, the foraging opportunity topology for Canoe Passage show a peak in areas considered relatively safe, while the foraging opportunity topology peak in the Intertidal Zones tended to occur in areas considered relatively dangerous (Pomeroy 2006).

All three food sources were found to have excess capacities, with capacities remaining after adjusting for the 'worst-case' estimate of With Project related biomass declines. The lowest capacity estimated was for biofilm (chlorophyll *a*) during the northward migration, which should also naturally see the largest demand (Butler et al. 1987, Kuwae et al. 2008, Drever et al. 2014). Under Existing conditions, this capacity was estimated at 45%. Under With Project conditions this capacity was estimated at 42%, with the 'worst-case' estimate showing a capacity of 29% remaining. Because these capacity estimates were based on an upper bound estimate for utilization, true utilization may be lower and capacities may be higher than estimated. These estimates were also based on 2012 usage data, which was a fairly typical year in terms of shorebird abundances within Roberts Bank (Drever et al. 2014), but atypical in changes to the biomass of food resources due to the occurrence of a 25-year freshet event. Abnormally larger population sizes would be expected to result in higher rates of consumption and lower capacities.

A second approach to assessing the capacity of the LSA to support migrating shorebirds focused on estimating biofilm capacity during the northward migration, based on hyperspectral determination of biofilm standing stock, known biofilm regeneration times, and historical shorebird population sizes (i.e., variable demand). Because this approach relied on independent datasets, it can be used to verify the first biofilm capacity estimate. Larger biofilm capacities were also estimated (typically 15x the required biomass during peak within-year demand, a capacity of roughly 93% during peak demand) during typical population sizes. Only under extreme population sizes were biofilm capacities found to be become depleted. Even under the ‘worst-case’ scenario of With Project biofilm biomass decline, population pressures required to deplete the biofilm standing stock were still larger than what has been observed in the last 23 years (Drever et al. 2014).

All estimates of With Project changes were also based on 2012 geomorphology modelling data, which were based on a large freshet event (a 1 in 25 year event). Because both the northward and southward migration periods occur within the freshet period, water column salinity may vary greatly from year-to-year during the migration period. Based on matching 2012 Fraser River flow rates to historical median flow rates, With Project abundance changes were also estimated under salinity conditions more consistent with historical medial flow. Under these conditions, estimates of With Project change showed either smaller declines or gains in biofilm, meiofauna, and macrofauna biomasses. This result suggests the difficulty of representing With Project changes in abundance, and by extension biomass, as a singular process, but rather as an alteration of a series of highly dynamic processes. Further discussion of this topic is presented below in the extended discussion (**Section 5.2**).

Finally, changes in LSA biomass were also placed in context of the RSA, which is not expected to undergo changes due to the RBT2 construction. The LSA, which consisted of the Brunswick Point stratum, showed a unique characteristic of having a more even mixture of the three food sources, compared to areas directly adjacent (i.e., Westham Island and the Inter-causeway). As such, Brunswick Point could represent more efficient feeding habitat, which may explain the higher proportional usage, especially during the northward migration when demand will be the highest. That said, the adjacent areas combined provide a similar balance of the three food sources, but may represent less efficient foraging habitat due to the need to transit between areas. While transiting between areas could be less efficient (both in terms of energy expenditure and risk exposure), the lower usage within Westham Island and the Inter-causeway could represent additional foraging capacity within Roberts Bank as a whole (i.e., Westham Island, Brunswick Point, and Inter-causeway). This hypothesis would be true if shorebirds (e.g., WESA and DUNL) were not constrained by food supply within Brunswick Point during 2012 and 2013 northward migration periods. Currently there is no evidence that such a supply constraint existed.

Finally, comparing Roberts Bank to the remainder of the RSA shows both the importance of the Roberts Bank and the productive nature of the RSA as a whole. Biofilm (as measured by chlorophyll *a*) was estimated to occur within Boundary Bay and Sturgeon Bank, although at lower levels, despite Brunswick Point stratum considered to be the primary location of biofilm. Boundary Bay also had higher total infauna biomasses. While current usage favours Roberts Bank (especially during the northward migration), this may again be the result of foraging efficiency rather than necessarily a reflection of total resource utilization.

5.2 EXPANDED DISCUSSION

5.2.1 Foraging Opportunity as a Topology

Foraging opportunity was visualised as a topology surface, with safety and abundance making up the axes with the topology height representing the amount of available biomass for a combination of safety and abundance. Safety was measured as the distance to the nearest shoreline (natural shoreline or the Roberts Bank causeway) and can be viewed as the inverse of predation risk, which is known to increase for shorebirds with proximity to shoreline vegetation (Dekker and Ydenberg 2004, Pomeroy 2006). Abundance was measured in terms of food density, which can represent a more efficient and profitable feeding environment. Because an area of higher abundance can produce more overall biomass than the same area with a low abundance, and the tidal cycle could impact the consumption of biomass, the topology height was a measure of the available biomass for a given safety and abundance co-ordinate. As such, an area with the highest safety, highest food abundance, and highest available biomass represented the highest foraging opportunity, while an area with the lowest safety, lowest abundance, and lowest available biomass represented the lowest foraging opportunity. The opportunity ranking of areas of intermediate abundance, safety, and available biomass were not as clear. This was the impetus behind viewing opportunity as a topology surface rather than a single summary value.

This approach deviates slightly from the Shorebird and Biofilm TAG interpretation of safety, which recommended using a weighting to represent safety. Safety is generally known to be an important modifier of shorebird behaviour during the migration period (Lank et al. 2003, Dekker and Ydenberg 2004, Pomeroy 2006, Pomeroy et al. 2008); however, using a weighting implies a quantitative assessment of predation risk exists, and is robust and uniform for all individuals, which is somewhat in contrast with current knowledge for shorebirds that views predation risk and individual risk tolerance to be variable and dependent on a variety of factors (Burns and Ydenberg 2002, Lank and Ydenberg 2003, Lank et al. 2003, Dekker and Ydenberg 2004, Pomeroy 2006, Pomeroy et al. 2008, van den Hout et al. 2010).

The visualization approach allowed the general relationship between food and safety to be explored without the difficulty of trying to create a single definable safety relationship. Also avoided is the requirement to explicitly define how food and safety interact to define foraging opportunity. These components will likely interact dynamically, likely based on to individual condition and risk tolerance, rather than a single constant and definable relationship. The only quantitative assessment made about foraging opportunity, was the location of the topology peak, which was simply defined as the combination of safety and abundance associated with the highest available biomass.

5.2.1.1 Existing Foraging Opportunity

Under both Existing and With Project conditions, some consistent patterns of foraging opportunity emerged. Overall the highest abundances and total available biomass levels were found in the Intertidal Zones, with peak foraging opportunity occurring in areas of lower safety. This was in contrast to Canoe Passage foraging opportunity, which had both lower overall total biomass and a lower height to the topology peak; however, the peak occurred in areas of much higher safety than in the Intertidal Zones. This general trend was observed consistently for all three food sources, although the exact size, shape, and position of the peaks differ subtly between food sources.

Intertidal Zones also showed consistently higher total available biomass compared to Canoe Passage, despite similar total areas (i.e., ranged from 40% higher total available biomass for chlorophyll *a* to nearly three times the total available biomass for both infauna types). This was in contrast with the highest total usage, which often occurred within Canoe Passage, despite a lower amount of available biomass.

5.2.2 Verification of Foraging Opportunity against Usage

Using the same topology visualization technique, comparisons of Existing usage and foraging opportunity showed a strong alignment. Peaks of usage and foraging opportunity tended occur in the same area within the opportunity space. While there is no way to confirm shorebirds judge the landscape in the exact same manner as described by the foraging opportunity topology, the association does lend credence to summarizing the landscape resources in this fashion.

The strongest alignment between Existing foraging opportunity and usage tended to occur in the Intertidal Zones, and appeared to be the strong during the northward migration for biofilm (chlorophyll *a*) and macrofauna. Within this zone, peak opportunity also tended to occur in less safe areas, suggesting that within the Intertidal Zones, WESA (the major contributor of dropping data in the areas under study) were willing to prioritise food intake over safety. The higher abundances estimated in the Intertidal Zones likely contributed to this apparent trade-off with risk.

Shorebird usage also aligned well with peak foraging opportunity for all three food sources in Canoe Passage during the northward migration and for both infauna food sources during the southward migration. Within Canoe Passage, peak foraging opportunity for all three food sources also occurred in relatively safe areas.

These differences, combined with the discrepancy between areas of highest available biomass and highest usage suggest that WESA may be employing a mix of strategies in terms of balancing food intake rates with safety considerations. Higher usage in Canoe Passage, despite lower total available biomass, suggests that WESA may be prioritizing safety; however, when feeding in the Intertidal Zones, individuals appear to be trading safety against the potential for higher intake rates. This potential mixture of strategies may depend on a variety of factors (e.g., body condition) and underlies the difficulty in assess how individuals may perceive risk (Burns and Ydenberg 2002, Lank and Ydenberg 2003, Lank et al. 2003, Dekker and Ydenberg 2004, Pomeroy 2006, Pomeroy et al. 2008, van den Hout et al. 2010). The overall higher usage and lower total available biomass in Canoe Passage implies that excess capacities may exist within the system, especially within the Intertidal Zones. This could potentially come at the cost of individual safety, but could represent an important system capacity to handle variations in supply (e.g., poor productivity years) or demand (e.g., large populations sizes). In years of high demand and lower supply, individuals would be expected to behave in a less risk adverse manner.

5.2.3 Estimates of Capacity

Based on the observed differences between total usage and total available biomass distributions of food sources, a novel approach was developed to provide a lower bound estimate of capacity by standardizing total usage distribution against total food availability distributions. The approach was based on the simplifying assumption that within an area, consumption cannot exceed availability and that individuals spend the majority of time foraging, which is supported from an energetics standpoint (e.g., Kuwae et al. 2008). This approach allowed the total usage distribution (a proxy for actual usage) to be converted into an upper bound estimate for consumption and, by extension, provided a lower bound estimate for capacity, which was defined as the total available biomass not consumed.

Under Existing conditions, capacity estimates showed that the largest capacities existed during the southward migration, which is more protracted with lower peak shorebird abundances and therefore lower demand (Butler et al. 1987, Ydenberg et al. 2004). During the southward migration, excesses in infauna capacity estimates are over 90% and biofilm (chlorophyll *a*) was estimated at 87%. During the northward migration, where the migration window is shorter and peak abundances and demands are higher, estimated capacities were slightly lower with estimates of 71% for infauna and 45% of biofilm (chlorophyll *a*). The lowest overall capacity was therefore for biofilm (chlorophyll *a*) during the northward migration, which is consistent with demands being higher during this period and with recent findings suggesting the importance of biofilm as a food source during this migration period (Butler et al. 1987, Elner et al. 2005, Kuwae et al. 2008, Butler and Lemon 2010, Kuwae et al. 2012).

Under With Project conditions, capacities were assessed based on the estimated decline and worst-case estimates of decline in food resources. In both assessments, capacities for the three food sources were estimated to remain, with infauna still showing the largest capacities and biofilm the smallest. The smallest capacities under With Project conditions occurred again during the northward migration, for biofilm (chlorophyll *a*) with estimates of 42 and 29% for the estimated With Project decline and the worst-case estimate of With Project decline, respectively. Relative to Existing conditions, this represented a 3 and 16 percentage point decrease, respectively.

These estimates of remaining capacities should be considered conservative. The worst-case scenario was based on the lower 95% confidence limit and represents the limit of knowledge in estimating biomass changes. It does not imply the change will be this large, only that there is little statistical evidence for a decline in biomass beyond the lower confidence bound. In fact, 95% confidence intervals also included positive gains in biomass, suggesting that there was not sufficient statistical power to resolve whether With Project increases or decrease will actually occur. Unless explicit assumptions are made about the estimated effect size being the *true* effect size, no firm comments can be made on how likely a particular percentage change will be. As such, the conservative approach employed was to use the lower bound estimate of change as part of the analysis. Doing so still resulted in estimates of positive capacities. Capacities were also conservative because they were based on upper bound estimates of consumption. True consumption will likely be equal or lower than the estimated consumption, resulting in capacities that are underestimates, which was supported with the second approach taken to estimate biofilm capacity based on the hyperspectral data, which showed an even larger capacity estimate.

The second biofilm capacity approach also considered the ability of the study area to support natural changes in demand associated with natural shorebird population fluctuations. The first approach to estimating capacity was based on 2012 available biomass and usage data, which was a fairly typical year in terms of shorebird abundances within Roberts Bank (Drever et al. 2014). The biofilm standing stock was based on the single day estimate provided by the hyperspectral survey (ASL Environmental Sciences 2013). Biofilm was drawn down based on knowledge of daily energy requirements (e.g., Kuwae et al. 2008, 2012) of simulated WESA and DUNL daily population sizes and allowed to recover based on estimated biofilm recovery rates (WorleyParsons 2014b). Similar to the estimates based on usage and availability, large capacities were predicted for the northward migration (e.g., typically 15x or more the required energy during peak within-year demand), except for extreme population sizes. Even under the worst-case scenario of With Project biofilm biomass decline, simulated population sizes resulting in limitations were still larger than what has been observed in the last 23 years (Drever et al. 2014). Because the northward migration also represents the highest demand and that two independent approaches point towards the existence of unused capacities post-construction, even under worst-case estimates of change, there should be sufficient flexibility within the system to accommodate change.

Finally, neither capacity analysis considered safety or predation risk. While safety is known to affect individual foraging decisions (e.g., Lank et al. 2003, Pomeroy 2006, Pomeroy et al. 2008), individuals may also change their risk tolerance in response to environmental conditions and food quality. The nature of future trade-offs cannot be known and, as such, investigations into capacity needed to exclude considerations of safety.

5.2.4 Environmental Variability

The width of the confidence intervals associated with percent change estimates reflect the difficulty in estimating change across the intertidal mudflat. A further contributing factor is that estimates are also associated with a narrow temporal window (northward and southward migration periods), which also experience large environmental changes. Both the northward and southward migrations occur during the Fraser River's freshet period, which can show substantial variation from year-to-year. Geomorphology modelling data were based on 2012 conditions, which was a 1-in-25 year event, and may represent salinity changes that differ from more typical freshet events. This is especially important considering sensitivity analyses indicated the importance of salinity on estimated biomass changes for all three food sources.

Predictions of With Project biomass changes based on smaller freshet events, showed consistently smaller With Project effects and in some cases positive gains in food source biomasses. For all three food sources a mostly positive relationship with salinity existed. Under smaller freshet events, larger areas of the LSA showed increased salinity relative to the 2012 freshet salinity. These larger areas of With Project salinity increases provided more offsetting relative to the salinity decreases that tended to occur within the Intertidal Zones. For biofilm (chlorophyll *a*), the top model also included a polynomial salinity term suggesting a zone of optimal salinity for biomass production. Under more typical freshet events (as judged by the median historical Fraser River flow rates), larger areas within the area of known biofilm production had salinity closer to the optimal salinity value estimated for biofilm. This area was also largest during the northward migration, a period of highest biofilm demand. Taken together, it is not possible to represent With Project changes in biofilm as a singular process, but rather as a highly dynamic process. Under high freshet events, biofilm under With Project conditions may decline relative to Existing conditions, but under a more typical freshet event, biofilm may increase relative to Existing conditions.

5.2.5 The Effect of Turnover Rates

The accuracy of both the main analysis and the freshet sensitivity are dependent on the ability of standing stock biomass to adapt to environmental changes. Estimates of With Project change for both sets of analysis are for periods of highly variable Fraser River output. If standing stock biomass is able to respond quickly to environmental conditions, then these estimates may be reasonably accurate; however, if standing stock biomass reacts slowly to changing conditions, then actual biomass changes may be more reflective of changes to conditions outside the freshet period, which were not investigated in the current analysis. Within the LSA, the regeneration time for biofilm was estimated at approximately nine days (WorleyParsons 2014b). As a result, biofilm standing stock could respond with the monthly time frame used for modelling With Project changes. For meiofauna and macrofauna, the turnover rate is slower with regeneration rates ranging from 3 to 10 generations per year, with macrofauna typically showing longer intergenerational times than meiofauna (Gerlach 1971, Chapman and Brinkhurst 1981). This suggests that for infauna abundance models, the monthly periods used for geomorphology salinity measurements may have been too short and that biologically relevant salinity measurements may need to be longer than a month; therefore, estimates of infauna biomass changes may not be as accurate as biofilm. This premise may be supported to some degree by the reported estimates of model fit. Biofilm, with the fastest turnover rates, also had the highest estimates of model fit. Meiofauna, with an intermediate turnover rate between biofilm and macrofauna, had the second best model fit, while macrofauna, with the lowest turnover rate, had the worst model fit. Given the importance of salinity to all three food sources, future analyses should consider including salinity measurements at time scales more appropriate to the turnover rate specific to each individual food source.

5.3 LIMITATIONS AND DATA GAPS

5.3.1 Extrapolation and the Reliance on Correlational Relationships

With Project abundance predictions were dependent on the accuracy of predicted geomorphology changes, the quality of estimated correlational relationships, and the estimated spatial error structure. The biological accuracy of With Project predictions therefore depends on all three components being accurate and robust.

Geomorphology changes were assessed by using percentile summaries of the geomorphology modelling data, which was highly detailed both temporally and spatially (see Northwest Hydraulic Consultants Ltd. 2014). Accuracy of predicted project changes will therefore be a function of the accuracy of the geomorphology modelling data and the choice of percentiles used to summarize the data. The model used to generate the geomorphology modelling data was explicitly designed for making predictions about changes to coastal geomorphology, contained multiple data sources, and underwent extensive verification and validation. A suite of percentile summaries were assessed and screened for descriptive strength and consistency of associations before inclusion into the biomass predictive models. Taken together, both components represent the best knowledge available for representing future hydrological changes.

Correlational relationships used to make With Project predictions were estimated based on associations observed under Existing conditions and by definition represents an extrapolation. Accuracy of these extrapolations depends on the correlational relationships holding under the revised hydrological spatial configuration. This can be a problem if correlational relationships do not accurately reflect underlying mechanisms, such as when a model is over-parameterised. In general, explanatory variables were only included if consistent relationships were demonstrated across the FRE, or if there were well known *a priori* reasons for their inclusion. Because environmental conditions differ greatly across the estuary, as a whole, variables showing consistent relationships with the target variable (e.g., chlorophyll *a* abundance) were more likely to provide robust predictions under the revised hydrological configuration. Model construction also emphasized a balance between fit and reducing the number of parameters required to achieve a given level of fit. Taken together, models were constructed in a manner that emphasized robustness for predictions under novel conditions.

Correlational relationships were also estimated based on data collected in a natural experiment (i.e., in the natural environment), which was the only feasible approach given the size and complexity of the study. In general, natural experiments have a weaker level of inference compared to manipulative experiments due to the potential lack of randomization (e.g., two successive years having similar environmental conditions), the potential lack of interspersion (e.g., the full range of median water column salinities is not observed naturally at all spatial positions on the mudflat), and the potential for lurking variables (e.g., the true explanatory variable not being measured). The potential lack of randomization and interspersion was accommodated through the use of estuary-wide data (i.e., data collected under a diverse set of conditions) and a detailed sensitivity analysis, which considered novel spatial configurations of salinity. The potential for lurking variables was mitigated through the detailed screening of a large number of likely explanatory variables. The only way to completely eliminate these issues from consideration would be through the implementation of manipulative experiments that physically changed the hydrological environment of the estuary. As this option was neither feasible, nor desirable, the approach taken represents the best attainable knowledge.

Finally, estimates of spatial error (e.g., certain areas having higher or lower abundances than predicted by the regression trend) were generated under Existing conditions and were assumed to hold under With Project conditions. Similar to the correlational relationships, this represents a type of exploration that may not hold under With Project conditions. How the spatial error structure may behave under With Project conditions is not testable without making measurements under these conditions. As such, this component cannot be fully assessed. That said, any changes to the true spatial error structure will likely not bias estimates of change, even though the reported error estimates may not be correct.

5.3.2 Temporal and Spatial Sampling

Biomass estimates of shorebird food sources also rely on sufficient temporal and spatial sampling. This allows the target variable (i.e., the biomass measurement) to be observed under a diverse set of environmental conditions, allowing for potentially more robust model predictions. The sampling program was performed over two years and may not fully reflect the diversity of environmental conditions possible in the system through time. That said, one sampling year was conducted during a larger Fraser River freshet (i.e., 2012 was a 1 in 25 year event) that lowered salinity levels across the LSA compared to an average year, and in all years sampling was conducted over a wide spatial scale. Both of these factors should have resulted in sample collection under a diverse set of environmental conditions. Correlational relationships were estimated under these conditions and With Project changes where also considered under these conditions. Sensitivity analyses suggested that this was a potentially conservative approach, as less change was predicted with the Project in place under more typical hydrological conditions compared to under large freshet events. Models trained using data collected solely under more typical conditions could potentially have been less accurate as there would not have been any information on the behaviour of the target variable under more extreme conditions. The only way to ensure higher accuracy would be to sample for a much longer temporal duration (e.g., decades), which was not practically feasible for the current study.

The extent of spatial sampling is also important for ensuring fundamental relationships remain constant over the area of interest. The sampling program had some spatial limitations as sampling primarily occurred within three kilometers of the shoreline and did not extend to the zero tide line. While inferences were limited to the spatial extend of sampling in the LSA, analyses involving predictions across the RSA were made out to the zero tide line. These predictions relied more heavily on the validity of estimated correlational relationships between shorebird food sources and predictor variables compared to predictions within the area covered by the sampling programs. While the biological accuracy outside the spatial extent of sampling could be reduced, the predicted biomass of these lower intertidal areas was less. Furthermore, biomass predictions across the RSA were only used for relative comparisons between areas within the RSA. Both factors should reduce the impact of potential prediction inaccuracies.

5.3.3 Instances of Low Descriptive Powers

The descriptive ability of the macrofauna abundance model was found to be quite low in the LSA, but higher for the RSA. A low descriptive power, in itself, does not bias biomass estimates, but does contribute to the large confidence intervals associated with estimates of With Project change. A number of factors may contribute to the low descriptive ability of the model. If available descriptive variables do not adequately describe the target variable (macrofauna biomass), then the descriptive power will be low. Spatial sampling resolution can further play a role depending on how the target variable is distributed.

Macrofauna abundance variability is known to be greatest at relatively short distances within the Fraser River Estuary (e.g., 10 m to 100 m, Sewell and Elner 2001). These distances also correspond to the typical sampling distance within the LSA, providing an additional factory factor for the low reported descriptive ability of the LSA model. The spacing of samples in areas outside the LSA tended to occur at larger spatial intervals, which is consistent with the higher descriptive ability reported by the RSA model. A sampling scheme that was more spaced out within the LSA would have likely resulted in a model with a higher reported descriptive ability. This improvement would not, however, imply improvements to biologically accuracy. Similarly, sampling schemes that relied on averaging subsamples taken at the 10 to 100 m level could also result in higher reported descriptive ability, but again would not necessarily imply higher biological accuracy.

6.0 CLOSURE

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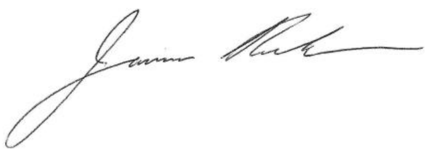
Hemmera Envirochem Inc.



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8.0 STATEMENT OF LIMITATIONS

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

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

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

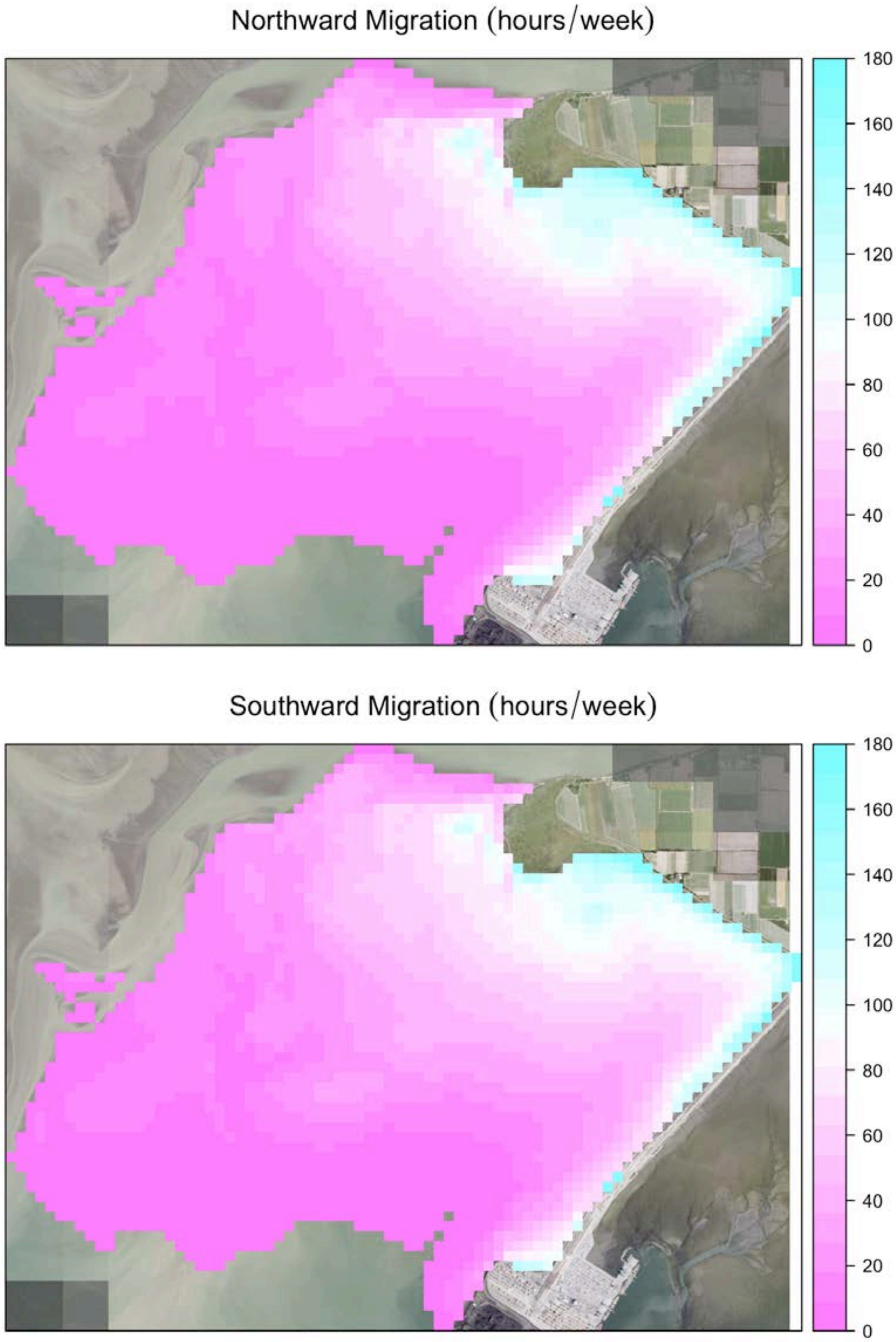
In preparing this Report, LGL and Hemmera have relied in good faith on information provided by others as noted in this Report, and has assumed that the information provided by those individuals is both factual and accurate. LGL and Hemmera accept no responsibility for any deficiency, misstatement or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

APPENDIX A

Figures

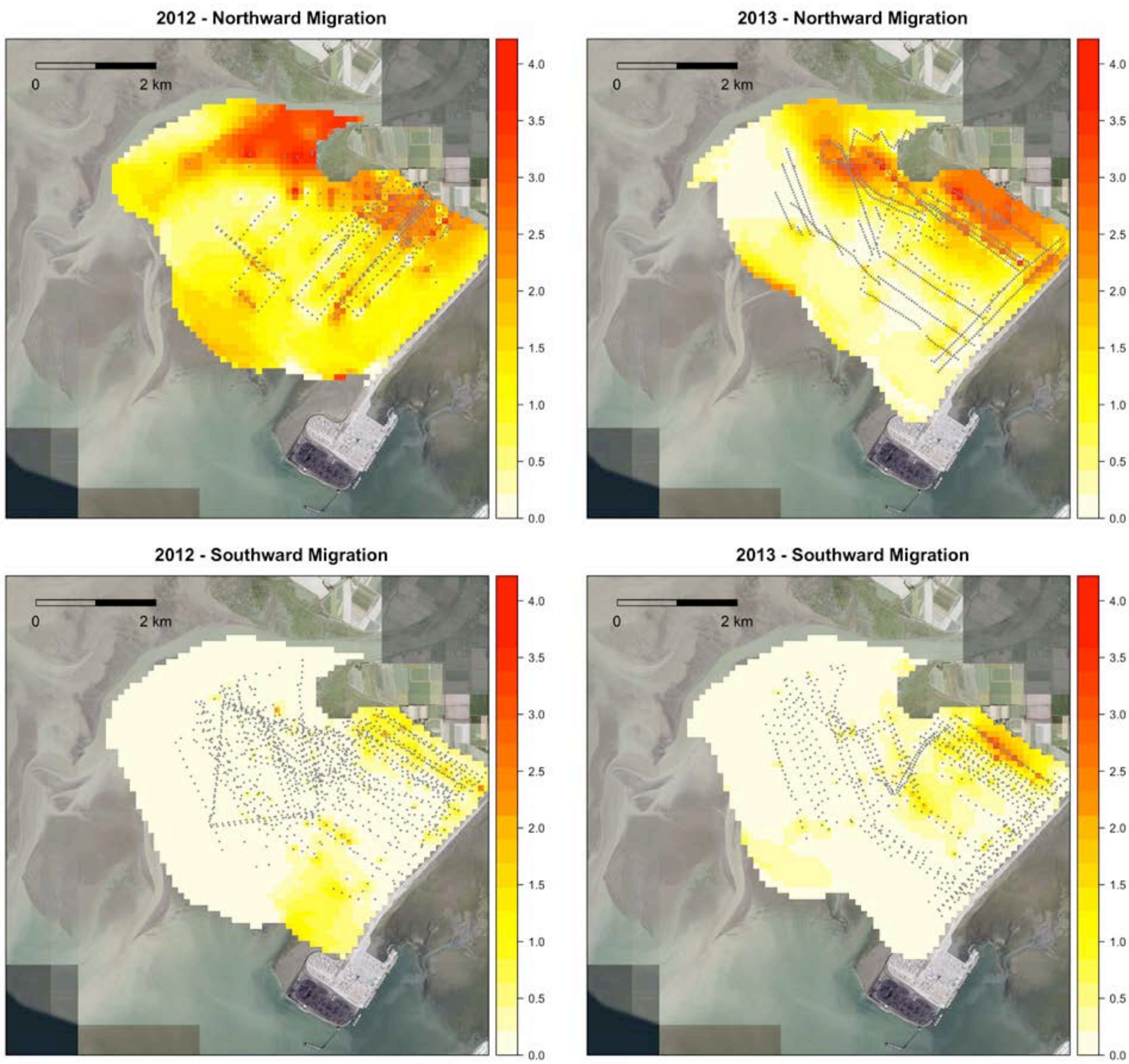
(continued)

Figure 41 **Local Study Area Site Availability during the Northern and Southern Migration Periods**



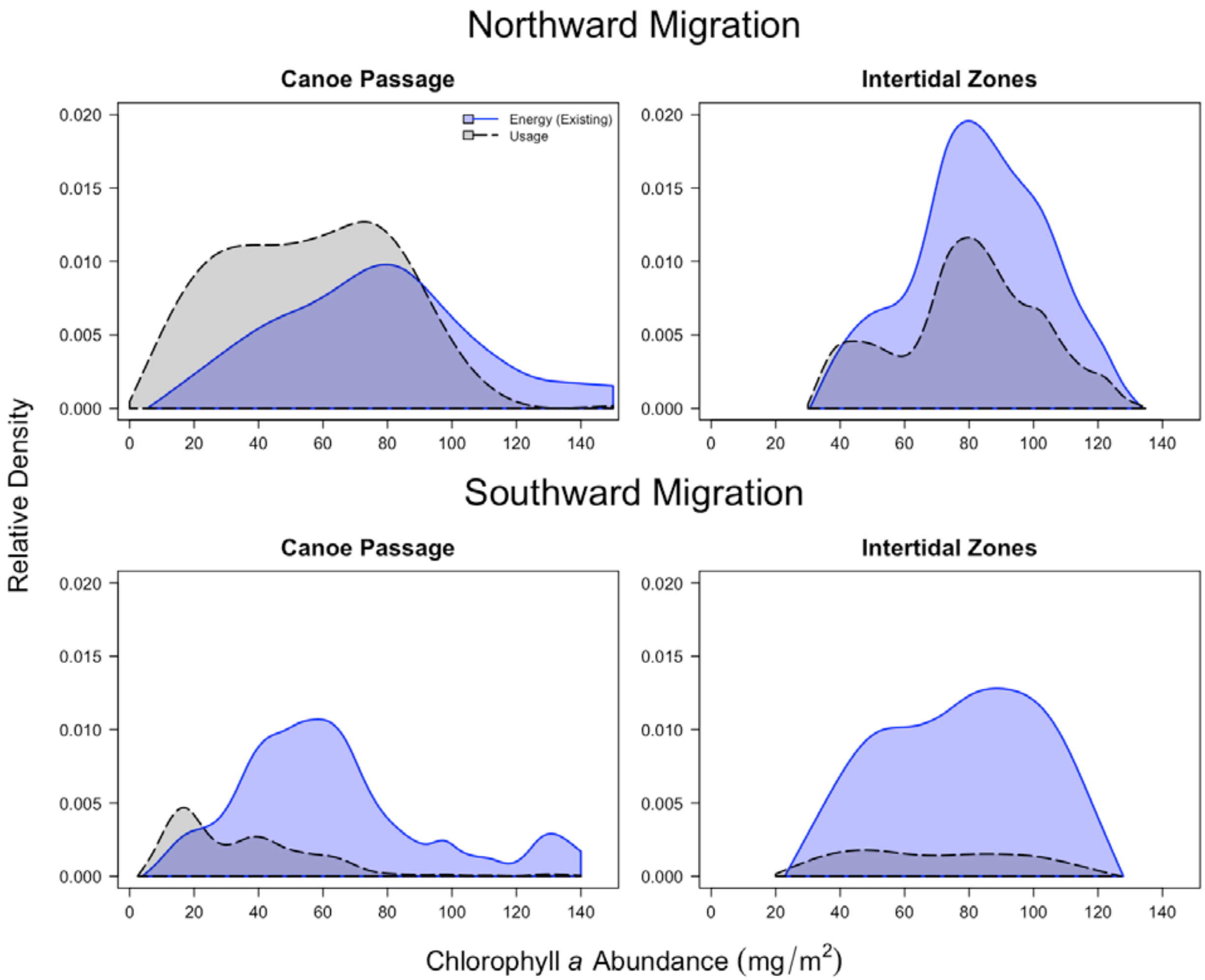
Note: Site availability for each 1-ha grid cell was determined based on minute-to-minute tidal height predictions and site elevation, which was determined, based on LIDAR surveys performed in 2012 and 2013.

Figure 42 Spatial interpolation of Log Transformed Dropping Data



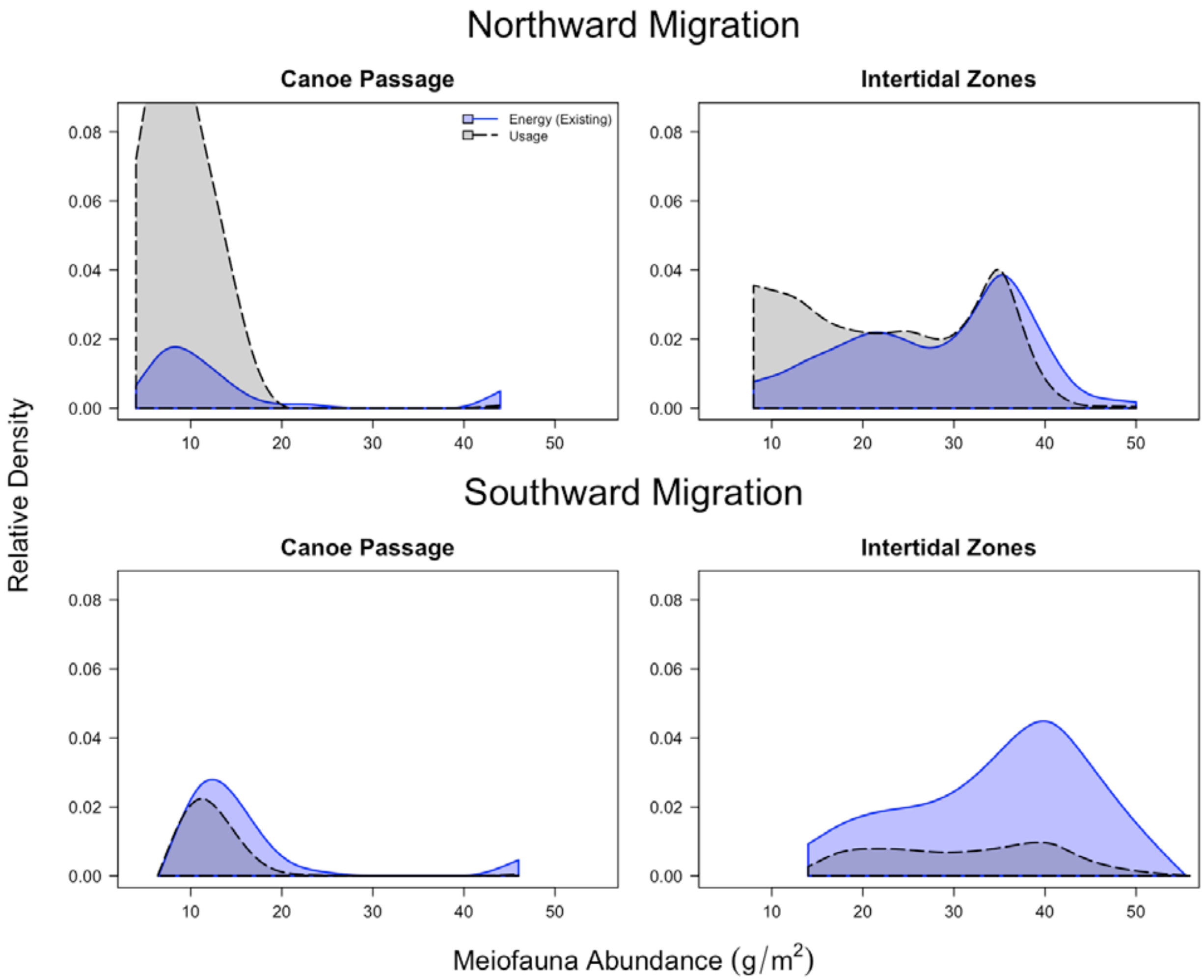
Note: Dropping densities 1-ha grid cell was determined based on minute-to-minute tidal height predictions and site elevation, which

Figure 43 Overlay of Chlorophyll *a* Available Biomass (mg x hr) and Total Usage Densities by Zone during the Northward and Southward Migration Periods without Additional Usage Scaling



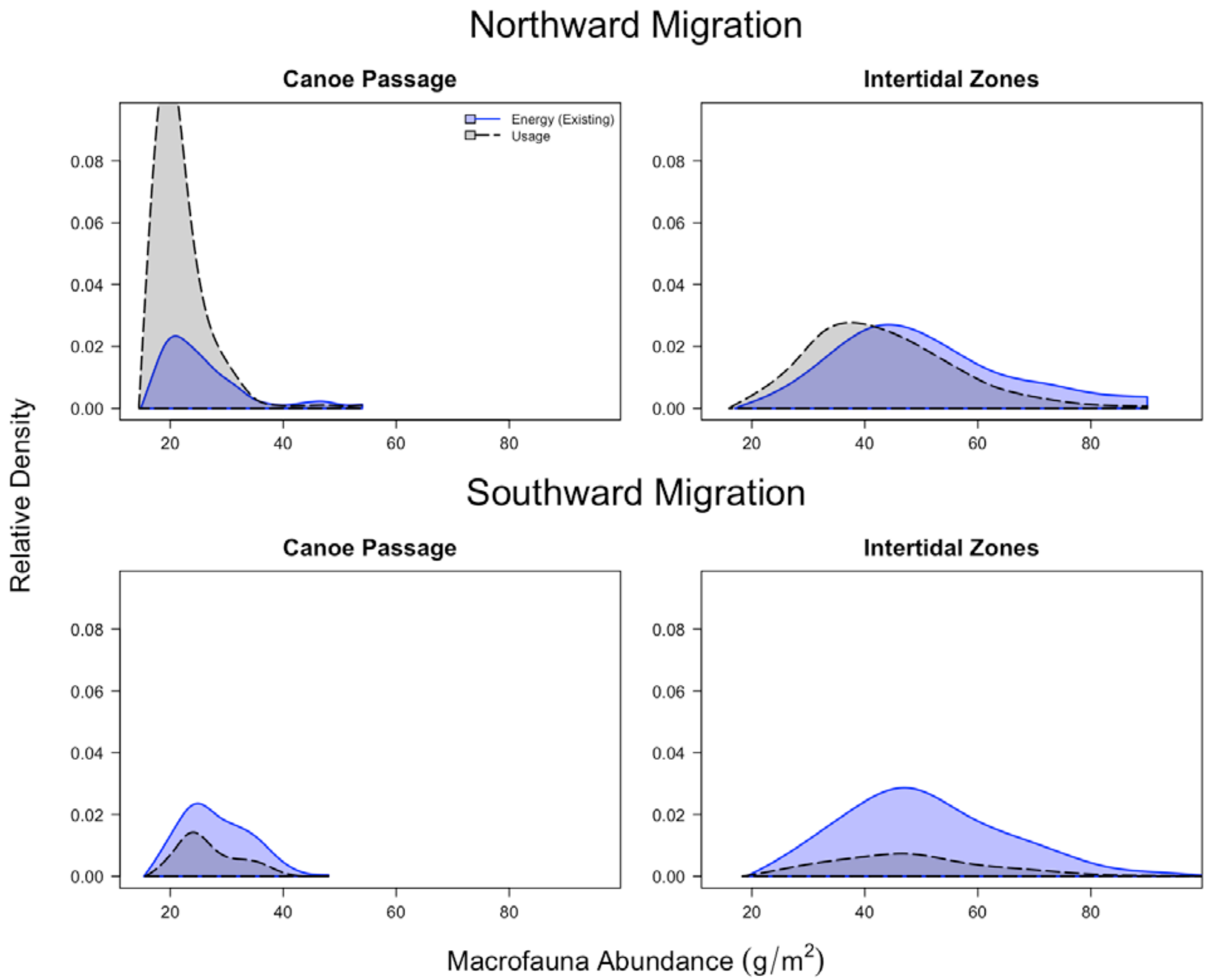
Note: Energy densities have been scaled to represent the proportion of total energy relative to the maximum availability (Intertidal Zones; northward migration). Usage densities have been scaled relative to the maximum usage (Canoe Passage; southward migration). A colour mixture indicates areas of overlap.

Figure 44 Overlay of Meiofauna Available Biomass (g x hr) and Total Usage Densities by Zone during the Northward and Southward Migration Periods without Additional Usage Scaling



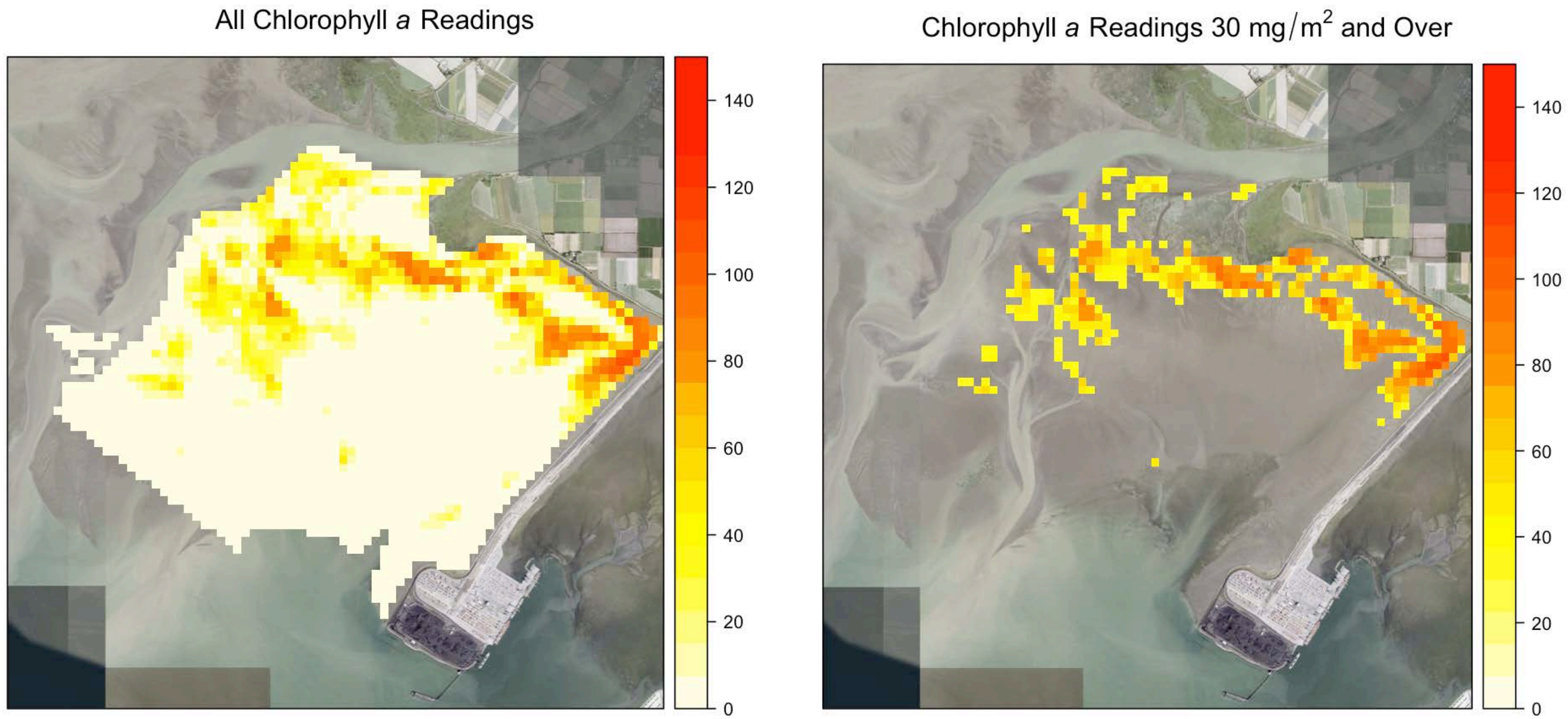
Note: Energy densities have been scaled to represent the proportion of total energy relative to the maximum availability (Intertidal Zones; northward migration). Usage densities have been scaled relative to the maximum usage (Canoe Passage; southward migration). A colour mixture indicates areas of overlap.

Figure 45 Overlay of Macrofauna Available Biomass (g x hr) and Total Usage Densities by Zone during the Northward and Southward Migration Periods without Additional Usage Scaling



Note: Energy densities have been scaled to represent the proportion of total energy relative to the maximum availability (Intertidal Zones; northward migration). Usage densities have been scaled relative to the maximum usage (Canoe Passage; southward migration). A colour mixture indicates areas of overlap.

Figure 46 Chlorophyll *a* Abundance (mg/m^2) Determined through Hyperspectral Survey



Note: The hyperspectral survey was carried out by ASL Environmental Sciences (2013). The left panel shows all chlorophyll *a* readings averaged to 1-ha grid cells. The right panel shows chlorophyll *a* readings equal to or greater than 30 mg/m^2, considered to represent the cut-off for biofilm (see ASL Environmental Sciences 2013). Ability of this standing stock to accommodate daily shorebird population was based biofilm represented in the right panel.

Figure 47 Biofilm Recovery Curve Used in the Biofilm Standing Stock Analysis

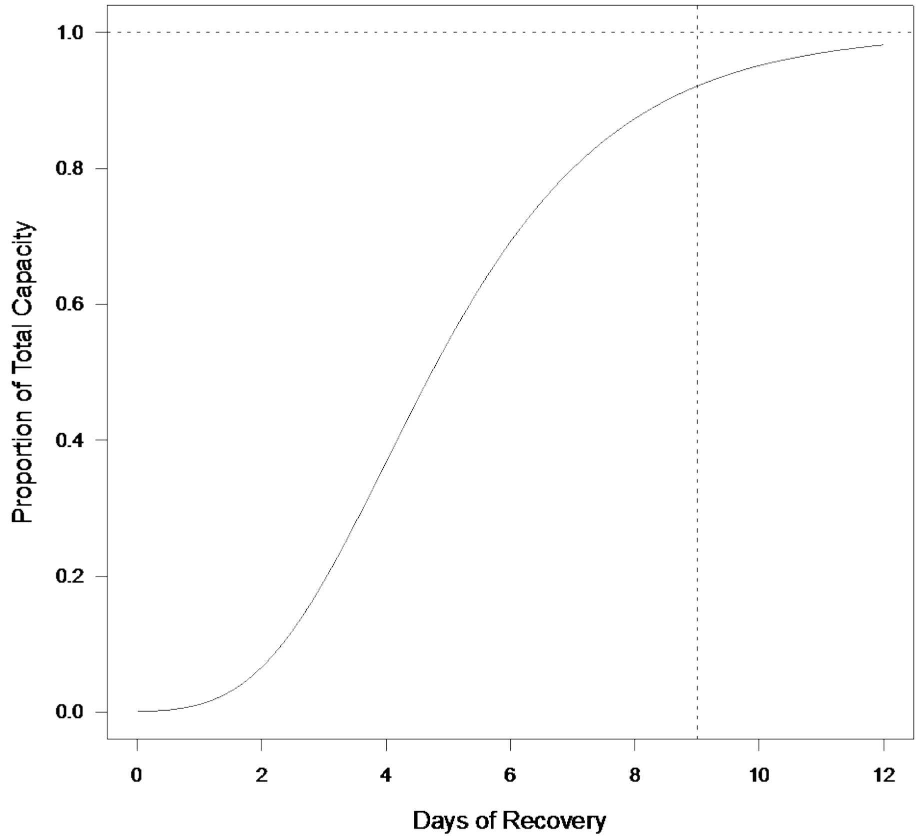
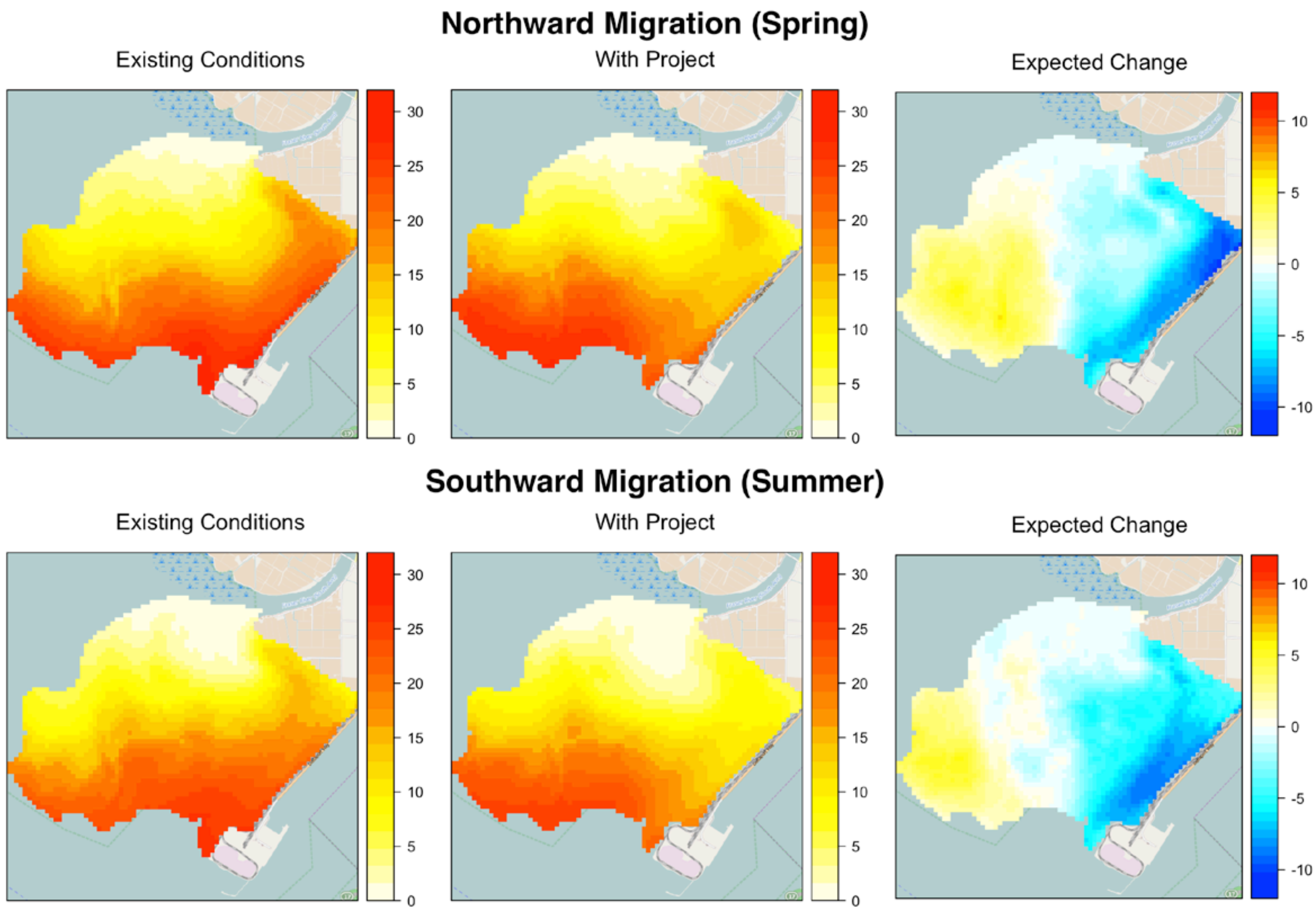
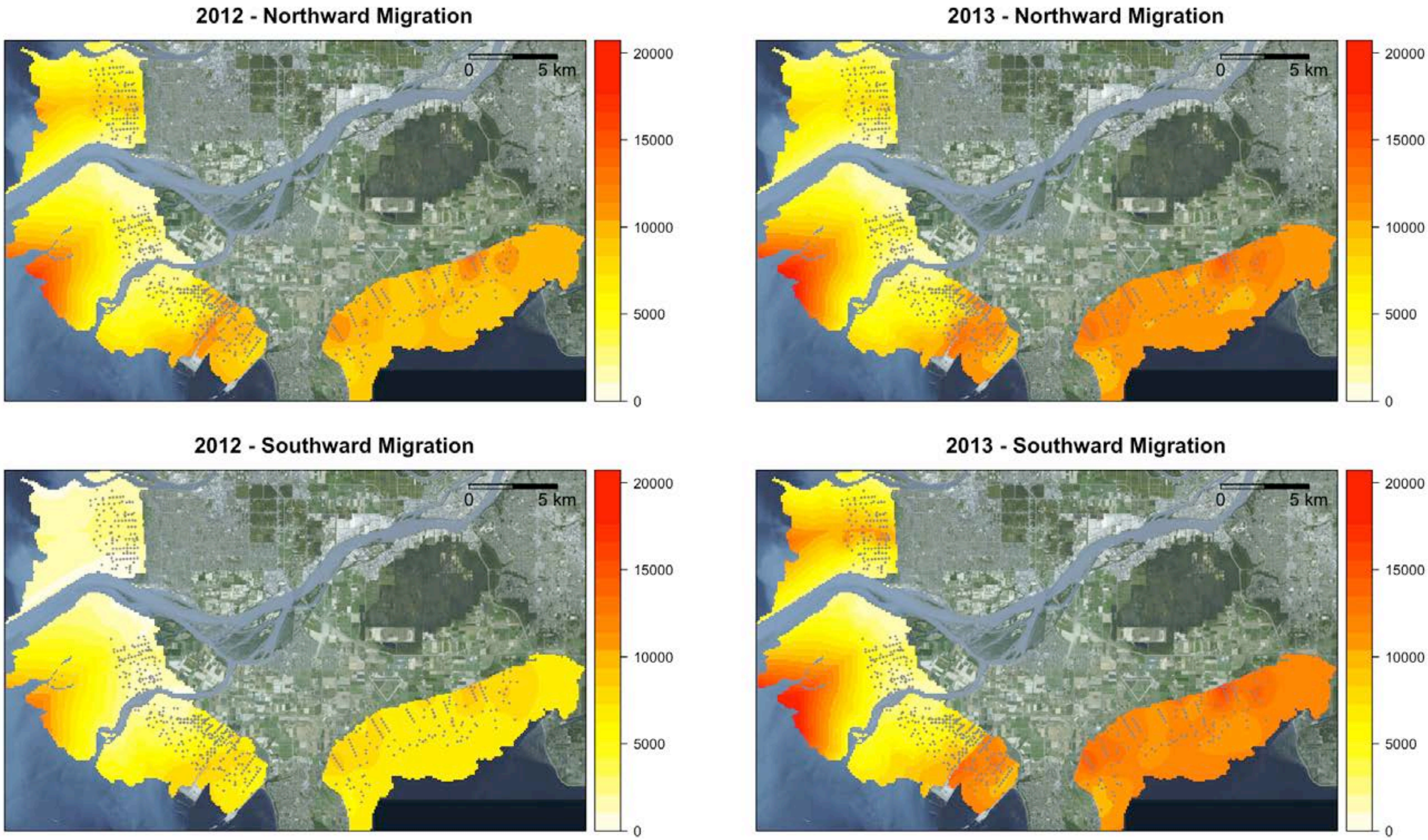


Figure 48 Seasonal 50th Percentile Water Column Salinity (psu) for Existing and with Project Conditions during the Northward and Southward Migration Periods



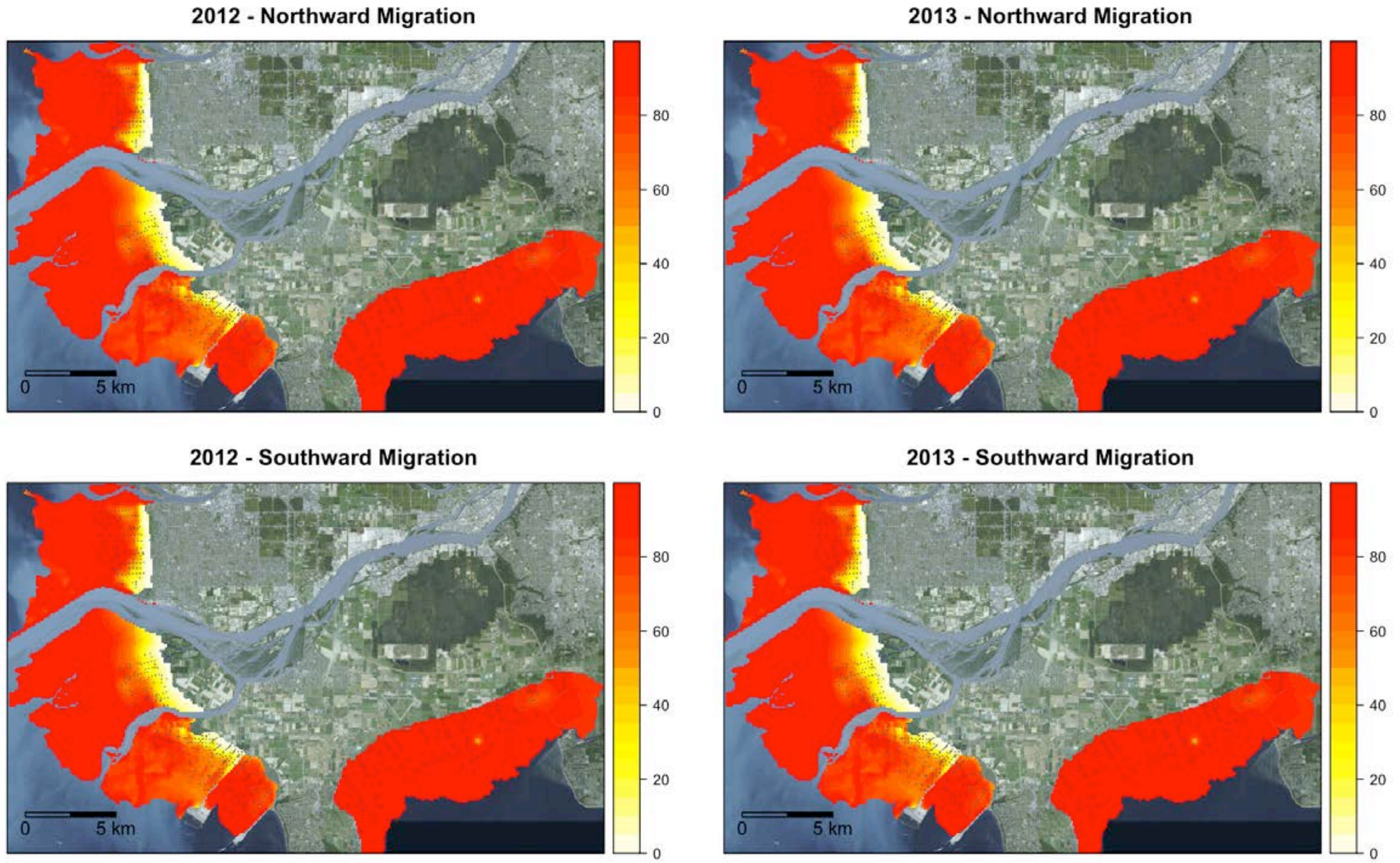
Note: Rows indicate conditions for the Northward and Southward migrations. Far right column indicates the change in salinity between Existing and With conditions during for migration period.

Figure 49 Predicted Adjusted Sediment Chloride Concentration (mg/kg) across the Regional Study Area during the 2012 and 2013 Northward and Southward Migration Periods



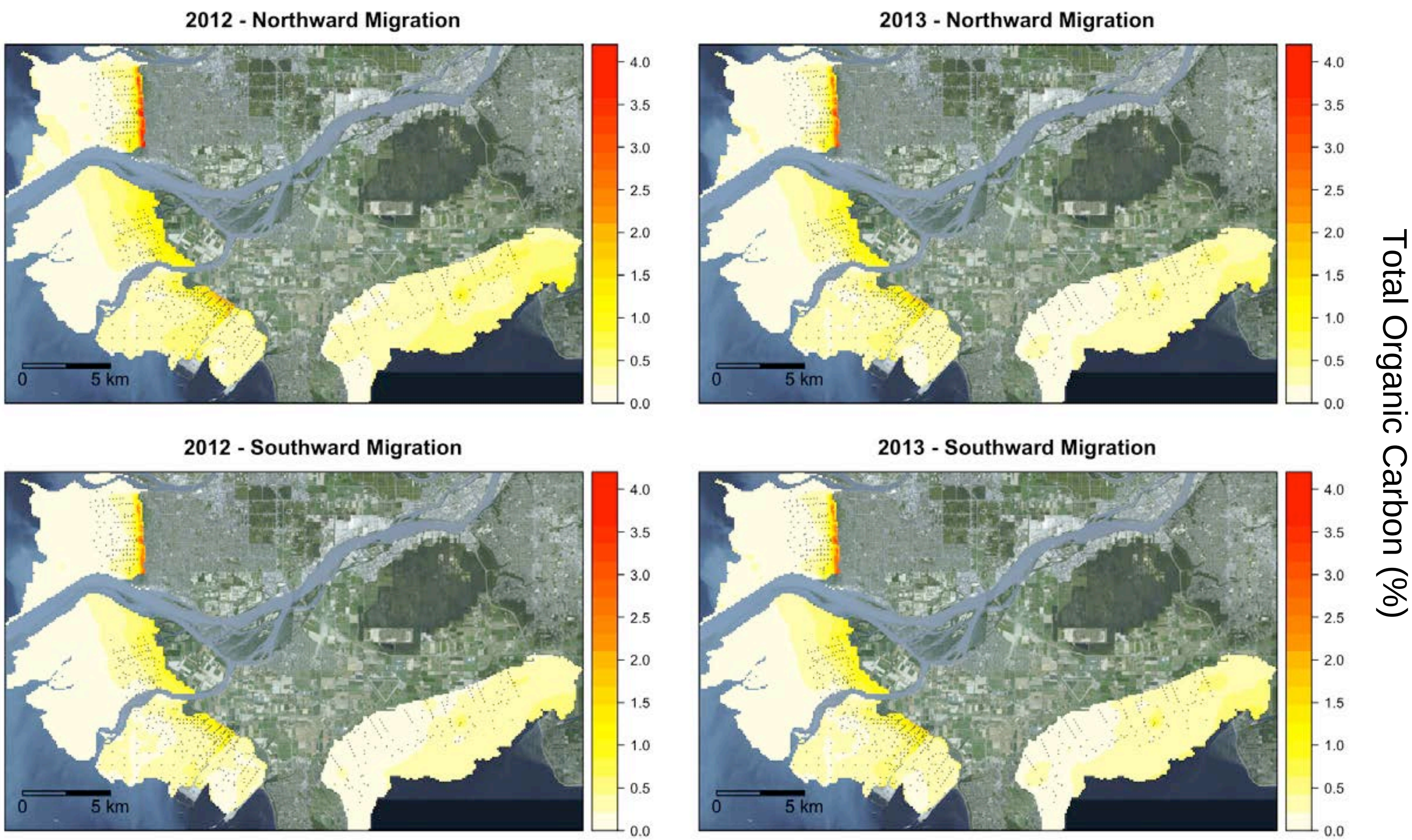
Note: A regression-kriging was fit to log transformed adjusted sediment chloride values. Leave-one-out cross validation indicated that the model explained 74.2% variability in the response.

Figure 50 Predicted Percent Sand (0.63 to 2.0mm) across the Regional Study Area during the 2012 and 2013 Northward and Southward Migration Periods



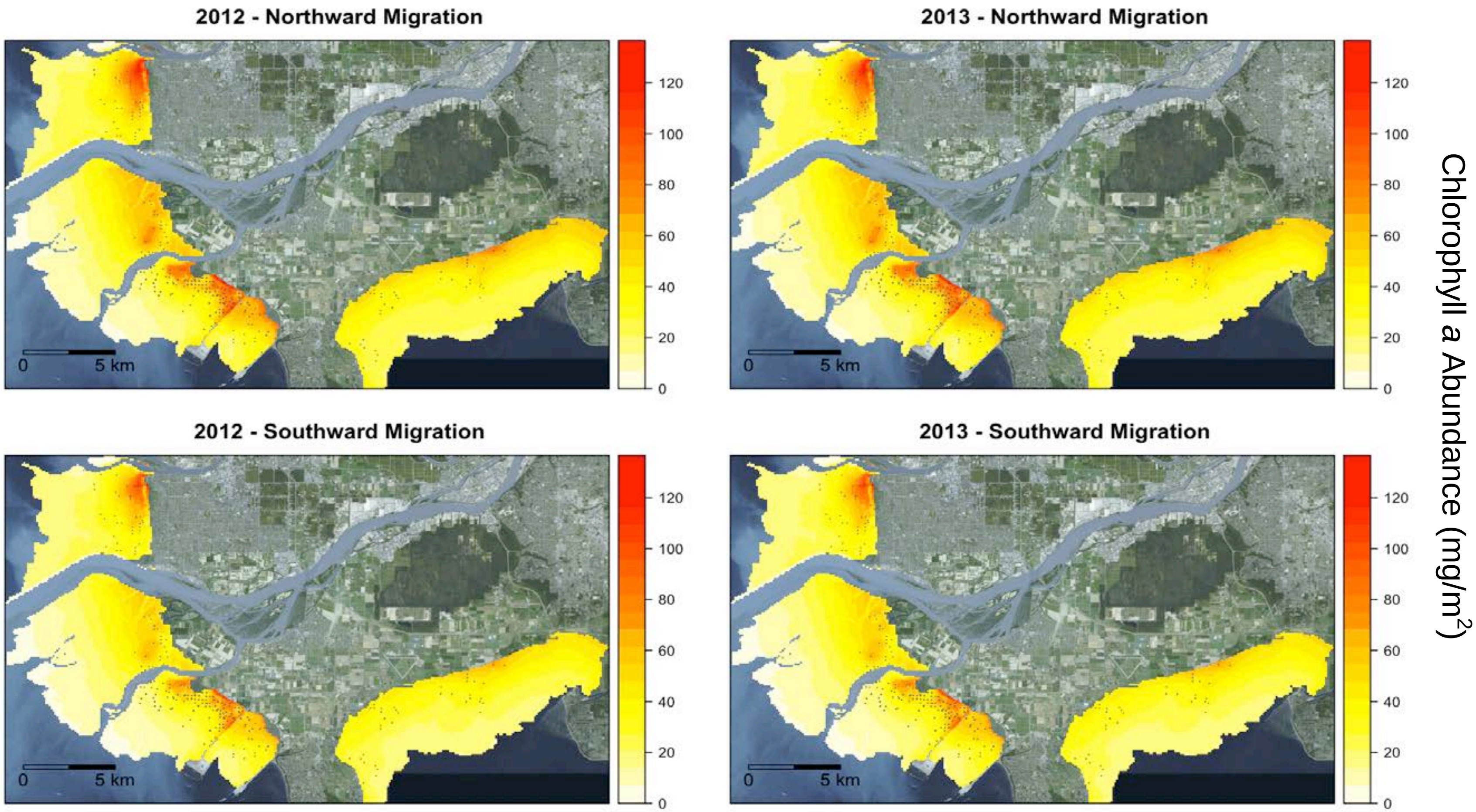
Note: A regression-kriging was fit to a logit transformed of proportion sand values (0.063-2.0mm). Leave-one-out cross validation indicated that the model explained 79.7% variability in the response.

Figure 51 Predicted Adjusted Total Organic Carbon (%) across the Regional Study Area during the 2012 and 2013 Northward and Southward Migration Periods



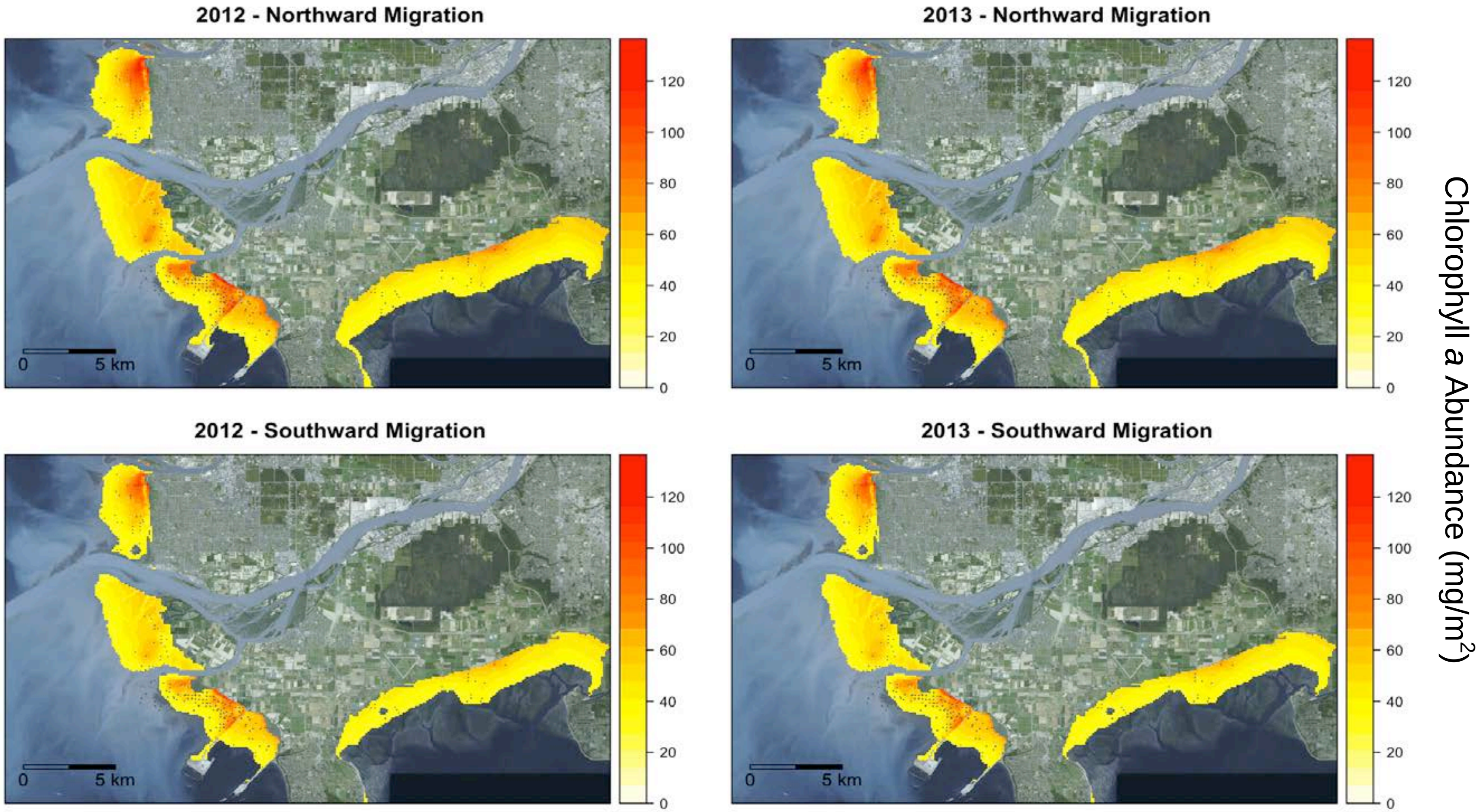
Note: A regression-kriging was fit to a logit transformed of total organic carbon values (proportion). Leave-one-out cross validation indicated that the model explained 88.6% variability in the response.

Figure 52 Predicted Chlorophyll *a* Abundance (mg/m²) across the Regional Study Area during the 2012 and 2013 Northward and Southward Migration Periods



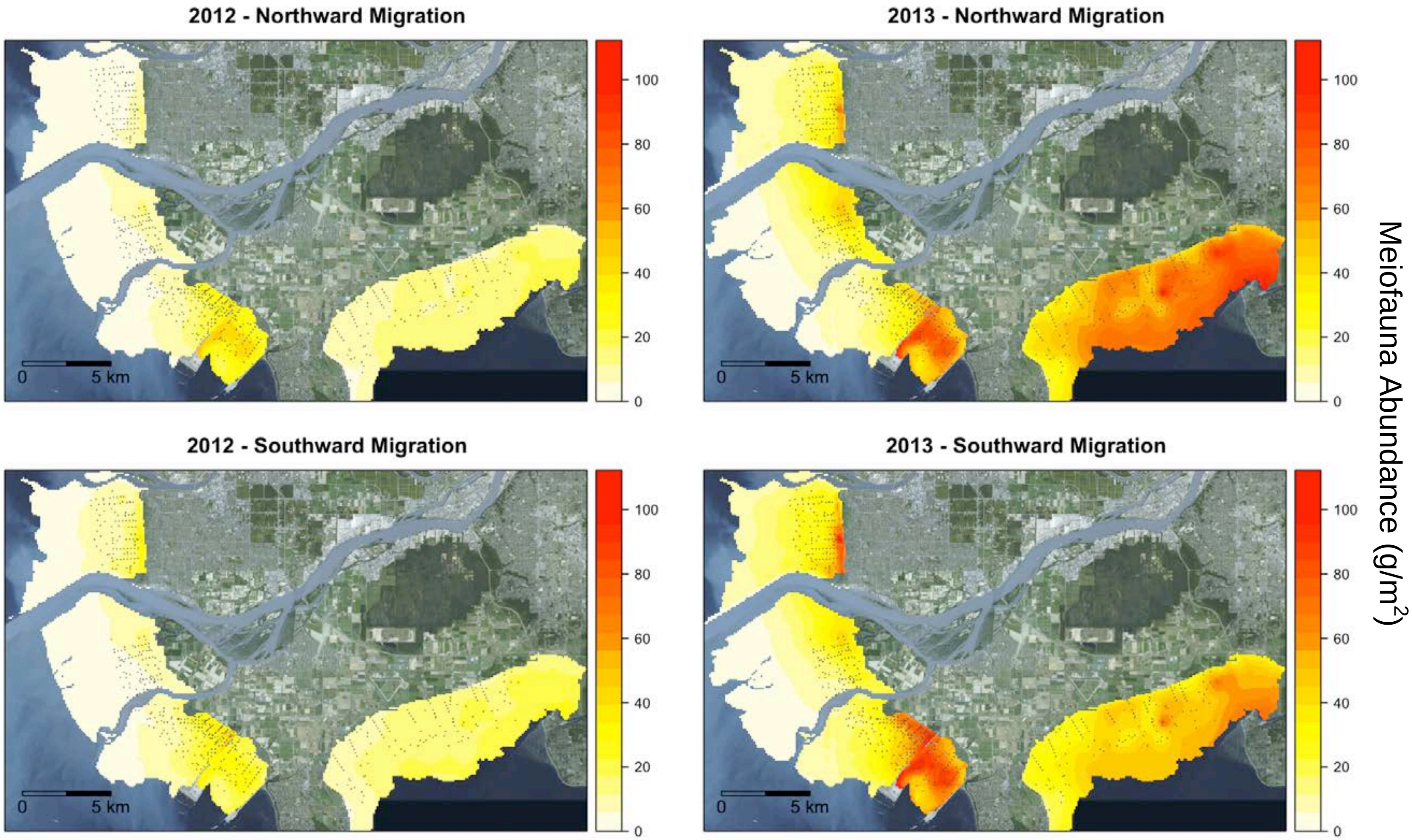
Note: A regression-kriging was fit to log transformed chlorophyll *a* abundance values. Displayed values were back transformed in order to provide predictions in g/m². Leave-one-out cross validation indicated that the model explained 68.2% variability in the response. Sediment sampling locations are indicated on the figure.

Figure 53 Predicted Chlorophyll *a* Abundances (mg/m²) Greater than 30 mg/m²



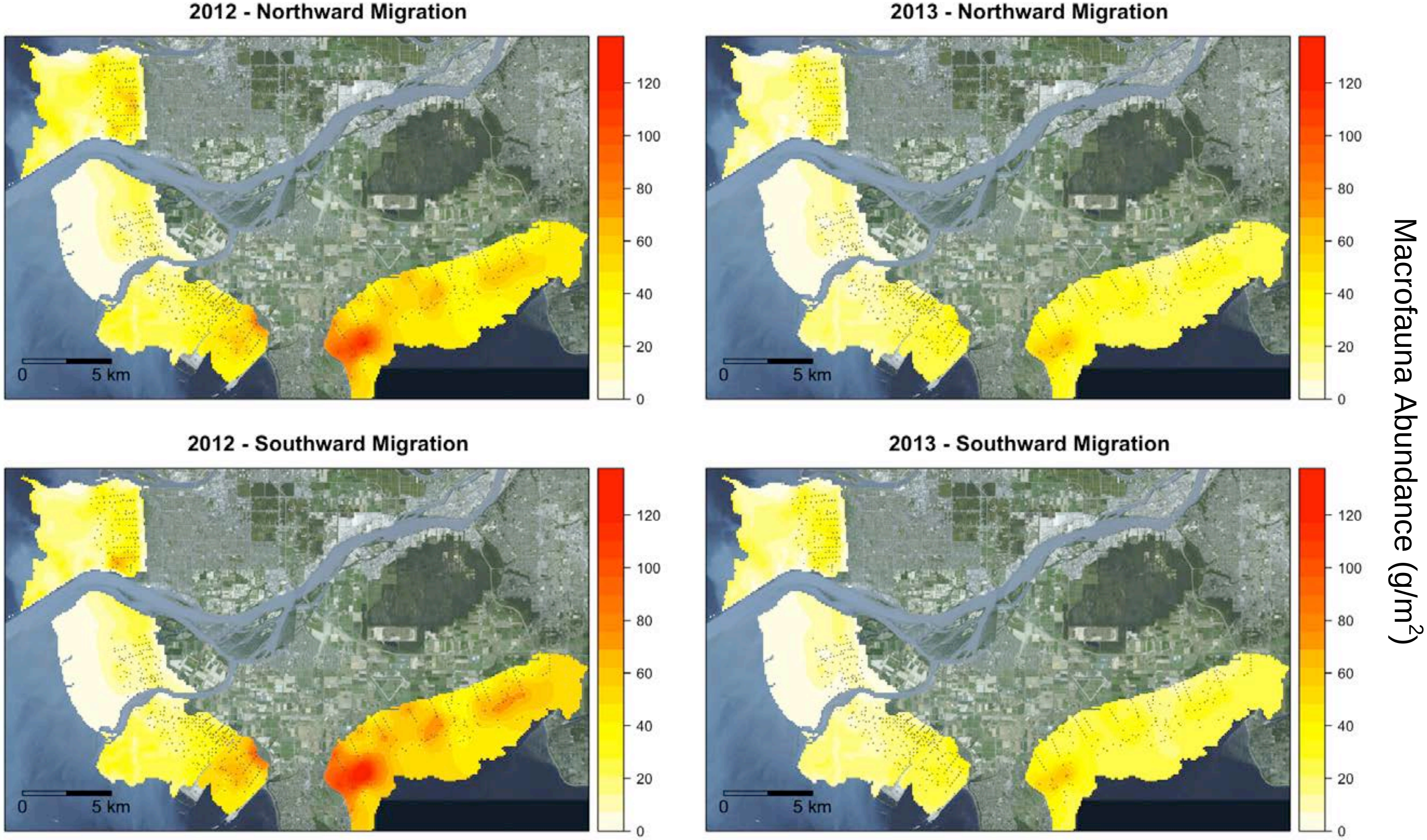
Note: Estimated chlorophyll *a* values in the RSA (see **Figure 52**) that were equal to or greater than 30 mg/m².

Figure 54 Predicted Meiofauna Biomass (g/m^2) across the Regional Study Area during the 2012 and 2013 Northward and Southward Migration Periods



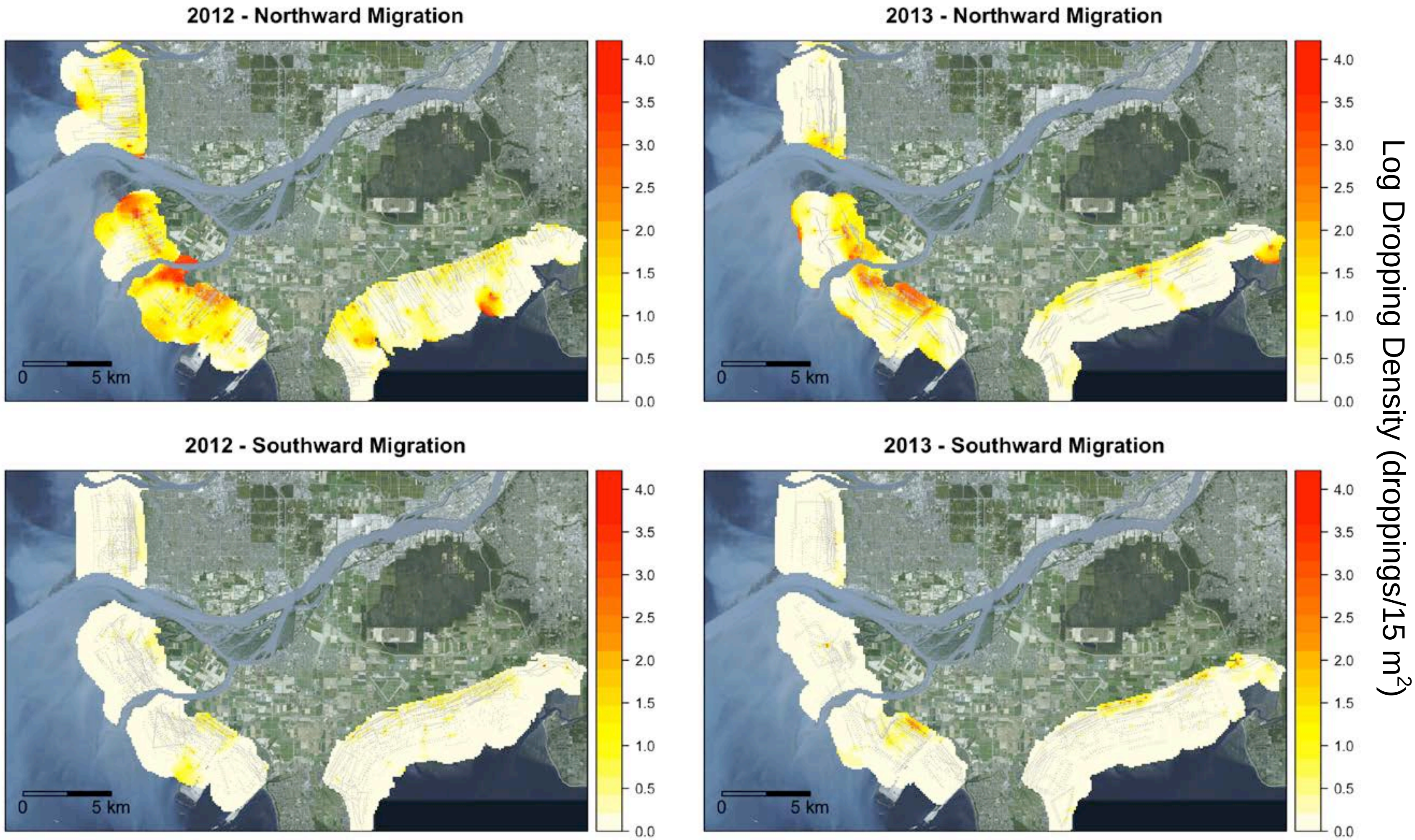
Note: A regression-kriging was fit to log transformed meiofauna abundance values. Displayed values were back transformed in order to provide predictions in g/m^2. Leave-one-out cross validation indicated that the model explained 53.2% variability in the response. Sediment sampling locations are indicated in the figure.

Figure 55 Predicted Macrofauna Biomass (g/m^2) across the Regional Study Area during the 2012 and 2013 Northward and Southward Migration Periods



Note: A regression-kriging was fit to log transformed macrofauna abundance values. Displayed values were back transformed in order to provide predictions in g/m^2. Leave-one-out cross validation indicated that the model explained 24.6% variability in the response. Sediment sampling locations are indicated in the figure.

Figure 56 Spatial Interpolation of Dropping Density across the Regional Study Area during the 2012 and 2013 Northward and Southward Migration Periods



Note: Spatial interpolation was created using inverse distance weighting. A maximum distance of 1 km was used for combining observations for a predicted location. Sediment sampling locations with a given year and migration period are indicated in the figure.

APPENDIX B
Tables

Table 28 Estimated Change in Chlorophyll *a* Abundance (with Upper and Lower 95% Confidence Intervals) for the Northward and Southward migration Periods based Predicted with Project Changes to Seasonal D90 Wave Heights Only

Area	Northward Migration			Southward Migration		
	Estimate	Lower	Upper	Estimate	Lower	Upper
Canoe Passage	0.0%	-22.5%	25.0%	-0.8%	-27.2%	28.3%
Intertidal Zones	-0.1%	-26.0%	31.1%	-1.1%	-30.6%	34.1%
All Areas Combined	0.6%	-24.8%	31.6%	-0.1%	-28.0%	30.9%

Note: Percent change takes into consideration the change in total abundance (mg) by expanding the estimated abundance (mg/m^2) by the total area. Availability due to the tidal cycle was not considered. Estimates are provided for the LSA as well as for Canoe Passage and the Intertidal Zones (see **Figure 2**). Results for are further broken down by northward and southward migration periods.

Table 29 Estimated Change in Chlorophyll *a* Abundance (with Upper and Lower 95% Confidence Intervals) for the Northward and Southward migration Periods based Predicted with Project Changes to Seasonal D50 Water Column Salinities Only

Area	Northward Migration			Southward Migration		
	Estimate	Lower	Upper	Estimate	Lower	Upper
Canoe Passage	-3.4%	-26.0%	23.4%	-12.4%	-35.6%	15.9%
Intertidal Zones	-5.8%	-31.3%	24.3%	-8.2%	-34.4%	25.9%
All Areas Combined	-0.7%	-26.2%	33.0%	-15.3%	-39.9%	15.7%

Note: Percent change takes into consideration the change in total abundance (mg) by expanding the estimated abundance (mg/m^2) by the total area. Availability due to the tidal cycle was not considered. Estimates are provided for the LSA as well as for Canoe Passage and the Intertidal Zones (see **Figure 2**). Results for are further broken down by northward and southward migration periods.

Table 30 Total Available Chlorophyll a Abundance (mg•hrs) for Canoe Passage and the Intertidal Zones during the Northward and Southward Migrations

Season	Zone	Total Available Biomass (mg x hr)	Ratio
Northern Migration	Canoe Passage	1.78E+11	**0.71**
	Intertidal Zones	2.51E+11	**1.00**
Southern Migration	Canoe Passage	1.53E+11	**0.61**
	Intertidal Zones	2.27E+11	**0.90**

Note: Ratios between total energy values were used to scale total availability densities (see **Figure 15**)

Table 31 Total Usage for Canoe Passage and the Intertidal Zones during the Northward and Southward Migrations for the Biofilm Analysis

Season	Zone	Total Area (ha)	Usage (log scale)		Usage (anti-log scale)				Ratio
			Mean	SD	Mean	SE	Total	SE	
Northern Migration	Canoe Passage	794	1.44	0.93	7.70	6.52	6113.41	5173.14	**1.00**
	Intertidal Zones	503	1.53	0.65	4.11	5.70	2067.47	2864.61	**0.55**
Southern Migration	Canoe Passage	794	0.07	0.12	0.13	1.08	100.73	858.33	**0.17**
	Intertidal Zones	503	0.27	0.31	0.43	1.38	217.77	692.41	**0.13**

Note: Usage and standard deviation was computed first on the log scale based on the IDW surface (Figure 42). Assuming a log normal distribution for usage, estimates of mean usage on the anti-log (regular) scale were generated. Using the total area these estimates were expanded to provide estimate of total usage. The ratio of total usage for each biofilm type by migration period was computed relative to the max usage (freshwater biofilm during the northward migration). Area was restricted to the biofilm analysis area of inference (**Figure 7**).

Table 32 Estimated Percent Change in Total Meiofauna Biomass between Existing and With Project conditions during the Northward and Southward Migration Periods with only Wave Height Changes

Area	Northern Migration			Southern Migration		
	Estimate	Lower CI	Upper CI	Estimate	Lower CI	Upper CI
Canoe Passage	3.6%	-31.9%	54.1%	9.8%	-25.0%	54.5%
Intertidal Zones	2.2%	-21.7%	33.7%	4.1%	-19.2%	32.9%
All Areas Combined	2.2%	-21.1%	34.0%	5.2%	-17.9%	34.5%

Note: Percent change takes into consideration the change in total abundance (g) by expanding the estimated abundance (g/m^2) by the total area. Availability due to the tidal cycle was not considered. Estimates are provided for the LSA as well as for Canoe Passage and the Intertidal Zones (see **Figure 2**). Results are further broken down by Northward and Southward migration periods.

Table 33 Estimated Percent Change in Total Meiofauna Biomass between Existing and With Project conditions during the Northward and Southward Migration Periods with only Water Column Salinity Changes

Area	Northern Migration			Southern Migration		
	Estimate	Lower CI	Upper CI	Estimate	Lower CI	Upper CI
Canoe Passage	-1%	-36%	49%	-2%	-37%	43%
Intertidal Zones	-15%	-42%	20%	-17%	-41%	14%
All Areas Combined	-12%	-38%	22%	-13%	-36%	14%

Note: Percent change takes into consideration the change in total abundance (g) by expanding the estimated abundance (g/m^2) by the total area. Availability due to the tidal cycle was not considered. Estimates are provided for the LSA as well as for Canoe Passage and the Intertidal Zones (see **Figure 2**). Results are further broken down by Northward and Southward migration periods.

Table 34 Total Available Meiofauna Abundance (g x hr) for Canoe Passage and the Intertidal Zones during the Northward and Southward Migrations

Season	Zone	Total Available Biomass (g x hr)	Ratio
Northern Migration	Canoe Passage	2.15E+10	**0.17**
	Intertidal Zones	9.17E+10	**0.73**
Southern Migration	Canoe Passage	3.31E+10	**0.26**
	Intertidal Zones	1.25E+11	**1.00**

Note: Ratios between total energy values were used to scale total availability densities (see **Figure 24**).

Table 35 Total Usage for Canoe Passage and the Intertidal Zones during the Northward and Southward Migrations for the Infauna Analysis area of inference

Season	Zone	Total Area (ha)	Usage (log scale)		Usage (anti-log scale)				Ratio
			Mean	SD	Mean	SE	Total	SE	
Northern Migration	Canoe Passage	668	1.42	0.94	7.64	6.41	5104.81	4284.52	**1.00**
	Intertidal Zones	766	1.37	0.62	3.26	4.77	2499.67	3653.51	**0.85**
Southern Migration	Canoe Passage	668	0.06	0.11	0.11	1.07	76.22	716.23	**0.17**
	Intertidal Zones	766	0.28	0.30	0.43	1.38	327.42	1059.46	**0.25**

Note: Usage and standard deviation was computed first on the log scale based on the IDW surface (**Figure 42**). Assuming a log normal distribution for usage, estimates of mean usage on the anti-log (regular) scale were generated. Using the total area these estimates were expanded to provide estimate of total usage. The ratio of total usage for each biofilm type by migration period was computed relative to the max usage (freshwater biofilm during the northward migration). Area was restricted to the infauna analysis area of inference (**Figure 7**).

Table 36 Estimated Percent Change in Total Macrofauna Biomass between Existing and With Project conditions during the Northward and Southward Migration Periods with only Wave Height Changes

Area	Northern Migration			Southern Migration		
	Estimate	Lower CI	Upper CI	Estimate	Lower CI	Upper CI
Canoe Passage	6.0%	-46.4%	88.4%	10.2%	-36.8%	76.6%
Intertidal Zones	4.6%	-34.4%	58.9%	5.0%	-29.3%	52.0%
All Areas Combined	4.0%	-33.3%	61.8%	5.8%	-25.8%	45.2%

Note: Percent change takes into consideration the change in total abundance (g) by expanding the estimated abundance (mg/m^2) by the total area. Availability due to the tidal cycle was not considered. Estimates are provided for the LSA as well as for Canoe Passage and the Intertidal Zones (see **Figure 2**). Results are further broken down by northward and southward migration periods.

Table 37 Estimated Percent Change in Total Macrofauna Biomass between Existing and With Project conditions during the Northward and Southward Migration Periods with only Water Column Salinity Changes

Area	Northern Migration			Southern Migration		
	Estimate	Lower CI	Upper CI	Estimate	Lower CI	Upper CI
Canoe Passage	2.9%	-49.3%	92.2%	0.3%	-45.0%	63.9%
Intertidal Zones	-17.5%	-49.3%	26.7%	-18.9%	-46.7%	20.8%
All Areas Combined	-12.1%	-47.3%	36.0%	-13.6%	-42.0%	25.4%

Note: Percent change takes into consideration the change in total abundance (g) by expanding the estimated abundance (mg/m^2) by the total area. Availability due to the tidal cycle was not considered. Estimates are provided for the LSA as well as for Canoe Passage and the Intertidal Zones (see **Figure 2**). Results are further broken down by northward and southward migration periods.

Table 38 Total Available Macrofauna Abundance (g x hr) for Canoe Passage and the Intertidal Zones during the Northward and Southward Migrations

Season	Zone	Total Available Biomass (g x hr)	Ratio
Northern Migration	Canoe Passage	5.49E+10	**0.30**
	Intertidal Zones	1.71E+11	**0.93**
Southern Migration	Canoe Passage	6.76E+10	**0.37**
	Intertidal Zones	1.84E+11	**1.00**

Note: Ratios between total energy values were used to scale total availability densities (see **Figure 31**)

Table 39 Regional Study Area Chlorophyll *a* Regression Model Parameters, Role and Applied Transformations

Model Parameter	Type	Transformation	Description / Interpretation
Log Chlorophyll a	Response	Natural Log	Natural log transformed chlorophyll *a* values (mg/m^2). Regression model predicts changes in terms of orders of magnitude.
Technique	Explanatory	None	Categorical variable accounting for technique used (2mm or 10mm cores). Also confounded with year effects.
Seasonal Wave Height	Explanatory	None	Seasonal D90 percentile of the geomorphology wave height modelling value. Extreme wave events predict log chlorophyll *a* abundance in a linear manner
Seasonal Salinity	Explanatory	None	Seasonal D50 percentile of the geomorphology water column salinity modelling value. Median salinity predict log chlorophyll *a* abundance in parabolic fashion (inverted-U) indicating an optimal salinity range.
Seasonal Salinity^2	Explanatory	Squared	
Seasonal Marsh Distance	Explanatory	Square root	Square root transformed distance to the nearest seasonal marsh. Based on spring and summer marsh lines from the TRIM dataset.
Elevation	Explanatory	None	Elevation based on the following datasets, in order of precedence: 1) Lidar 2011; 2) Lidar 2013; and 3) NRCan Multibeam.

Table 40 Regional Study Area Meiofauna Regression Model Parameters, Role, and Applied Transformations

Model Parameter	Type	Transformation	Description / Interpretation
Log Meiofauna	Response	Natural Log	Natural log transformed meiofauna abundance values (g/m^2). Regression model predicts orders of magnitude changes in meiofauna abundance.
Stratum	Explanatory	None	Categorical variable accounting for differences between study strata.
Year:Season	Explanatory	None	Categorical variable accounting for differences between sampling sessions that occurred once within each season within each year (see Table 4 for sampling efforts).
Bank:ShoreDist	Explanatory	Square root	Square root transformed distance to the natural shoreline within the West Bank and South Bank stratum. Square root distance predicts meiofauna abundance in a parabolic fashion (inverted-U) distance from shore within each bank. The West Bank was defined as the Sturgeon Bank, Westham Island and Brunswick Point strata, while the South Bank was defined as the Inter-causeway and Boundary Bay strata.
Bank:ShoreDist^2			
TOC	Explanatory	Logit	Logit transformed values of the total organic carbon (TOC) predict meiofauna abundance. Logit transformations are common for measures that saturate.
Sediment Chloride	Explanatory	Natural Log	Natural log transformed adjusted sediment chloride values (mg/m^2) predicts meiofauna abundance. Sediment chloride values were adjusted for sample interstitial water content and should represent biologically available chloride anions.

Note: Leave-one-out cross validation indicates the model explained 53% of the variability in the response. Details on adjustments made to sediment chloride concentrations can be reviewed in Hemmera 2014c.

Table 41 Regional Study Area Macrofauna Regression Model Parameters, Role, and Applied Transformations

Model Parameter	Type	Transformation	Description / Interpretation
Log Macrofauna	Response	Natural Log	Natural log transformed macrofauna abundance values (g/m^2). Regression model predicts orders of magnitude changes in macrofauna abundance.
Year	Explanatory	None	Categorical variable accounting for differences between year.
Stratum	Explanatory	None	Categorical variable accounting for differences between study strata.
BP: Seasonal Salinity	Explanatory	None	Seasonal 50^{th} percentile of the geomorphology water column salinity modelling value within Brunswick Point. A May percentile was used for the northward migration and a July percentile for the southward migration. Median salinity predicts log macrofauna abundance in a linear within Brunswick Point.
NBP:Sediment Chloride	Explanatory	Natural Log	Natural log transformed adjusted sediment chloride values (mg/m^2) predicts macrofauna abundance in non Brunswick Point strata. Sediment chloride values were adjusted for sample interstitial water content and should represent biologically available chloride anions.
WestBank:SandTexture	Explanatory	Logit	West Bank logit transformed proportion of sand 0.063-2.0mm. Logit transformations are common for saturation measures. Logit proportion of sand predicts predicts log macrofauna abundance in a parabolic fashion (inverted-U) indicating an optimal sand texture within the West Bank (Sturgeon Bank, Westham Island, and Brunswick Point).
WestBank:SandTexture^2	Explanatory	Logit and Square	
SouthBank:ShoreDistance	Explanatory	Square root	South Bank square root distance to the natural shoreline. Square root transformations are common for distance measures. Square root distance to shore describes log macrofauna abundance in a simple linear manner with the South Bank (Inter-causeway and Boundary Bay).

Note: Leave-one-out cross validation indicates the model explained 25% of the variability in the response. Details on adjustments made to sediment chloride concentrations can be reviewed in Hemmera 2014c.

APPENDIX 15-C

Overwintering Dunlin Foraging Opportunity

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ROBERTS BANK TERMINAL 2
TECHNICAL REPORT
Coastal Birds
Overwintering Dunlin Foraging Opportunity

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December 2014

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environmental research associates

HEMMERA

20 YEARS
1994 – 2014

Technical Report / Technical Data Report Disclaimer

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

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

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

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

EXECUTIVE SUMMARY

The Roberts Bank Terminal 2 Project (RBT2 or Project) is a proposed new three-berth marine terminal at Roberts Bank in Delta, B.C. that could provide 2.4 million TEUs (twenty-foot equivalent unit) of additional container capacity annually. The project is part of Port Metro Vancouver's Container Capacity Improvement Program, a long-term strategy to deliver projects to meet anticipated growth in demand for container capacity to 2030. This study was conducted as part of an environmental program for the RBT2 Project, and focused on developing an understanding of the existing conditions in the study area.

The FRE is one of the most important migratory stopover and wintering sites for Pacific dunlin (*Calidris alpina pacifica*). This study's objectives were to: 1) estimate Existing and With Project shorebird foraging opportunity in the Local Study Area (LSA); and 2) summarise the existing winter macrofauna biomass across the FRE to place the LSA's foraging opportunity in perspective relative to the entire estuary. Foraging opportunity was defined as a measure of energy available to shorebirds taking into consideration tidal exposure and site safety (i.e., predation danger).

The first requirement to meeting these objectives was the independent creation of winter macrofauna density estimates for the LSA and the FRE. Density estimates were created at a resolution of 1 hectare using spatially explicit models (i.e., regression-kriging models), which incorporated data from field sampling programs, geomorphology modelling data, and other known landscape variables. Models were tailored to the goals of estimating macrofauna densities in either the LSA or the FRE. Predictions in the LSA were created under Existing conditions and With Project conditions by incorporating the appropriate geomorphology modelling data.

To determine foraging opportunity for shorebirds, macrofauna density estimates, along with measures of site availability and safety (i.e., predation risk), were combined to generate foraging opportunity topologies, which illustrate the amount of available biomass (i.e., biomass density by area by hours available) for a combination of safety and density (i.e., g/m^2). Topologies were generated under both sets of conditions. Finally, estimates of macrofauna biomass (i.e., density adjusted for area) were partitioned across all major intertidal mudflats in the FRE (e.g., Sturgeon Bank, Roberts Bank, Boundary Bay) to place estimates of predicted with Project change within the context of the entire functional area.

Estimated changes in total available biomass predicted under the proposed Project were generally small and, due to large confidence intervals associated with high natural variability in the system, were not statistically significant; however, all investigated food sources were predicted to increase. That said, due to the large degree of uncertainty declines in available biomass could not be ruled out either. Available biomass changes in the LSA were also found to be driven by multiple hydrodynamic factors.

The general nature of winter shorebird foraging opportunity was predicted to remain largely unchanged with some increases in available biomass associated with the predicted biomass increase. Areas of high and low opportunity (i.e., high and low available biomass) were predicted to remain at the same safety and macrofauna density co-ordinates. Finally, predictions of total macrofauna biomass across the FRE showed comparable levels in areas outside of the LSA indicating that macrofauna is fairly plentiful and evenly distributed across the FRE. This suggests a depth of resources exist outside of the area likely to be affected.

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GLOSSARY / LIST OF ACRONYMS

AIC	Akaike Information Criterion (AIC) is a measure of the model support given the data set and candidate model set. AIC attempts to find a balance between model fit (minimising the information loss) and the number of modelling parameters (avoid over-fitting).
CI	Confidence Interval
DEE	Daily Energy Expenditure
DUNL	Pacific dunlin (*Calidris alpina pacifica*)
IDW	Inverse Distance Weighting is a deterministic spatial model that does not rely on an underlying statistical model.
FRE	Fraser River estuary
LSA	Local Study Area
PMV	Port Metro Vancouver
psu	Practical Salinity Unit
RSA	Regional Study Area
Regression-kriging	A geospatial technique that is a hybrid of regression and Kriging techniques that produces geospatial predictions along with an estimate of error.
RMSE	Root Mean Squared Error
OSFOM	Overwintering Shorebird Foraging Opportunity Model
SCGS	Stochastic Conditional Gaussian Simulations
TAG	Technical Advisory Group
TOC	Total Organic Carbon
TRIM	Terrain Resources Inventory Management
WESA	Western sandpiper

1.0 INTRODUCTION

1.1 PROJECT BACKGROUND

The Roberts Bank Terminal 2 Project (RBT2 or Project) is a proposed new three-berth marine terminal at Roberts Bank in Delta, B.C. that could provide 2.4 million TEUs (twenty-foot equivalent unit) of additional container capacity annually. The project is part of Port Metro Vancouver's Container Capacity Improvement Program, a long-term strategy to deliver projects to meet anticipated growth in demand for container capacity to 2030.

Port Metro Vancouver (PMV) has retained Hemmera to undertake environmental studies to inform a future effects assessment for the Project. This technical report describes the results of the Overwintering Dunlin Foraging Opportunity Study completed by LGL and Hemmera.

1.2 DUNLIN FORAGING OPPORTUNITY OVERVIEW

A review of available information and state of knowledge was completed for dunlin (*Calidris alpina pacifica*) foraging opportunity to identify key data gaps and areas of uncertainty within the general RBT2 area. This technical report describes the study findings for key components identified from this gap analysis. Study components, major objectives and a brief overview are provided in **Table 1**.

Table 1 Dunlin Foraging Opportunity Study Components and Major Objectives

Component	Major Objective	Brief Overview
1) Estimate Existing and With Project dunlin foraging opportunity in the Local Study Area (LSA) and the Fraser River Estuary (FRE)	• Generate spatial estimates of abundances for macrofauna under Existing and With Project conditions. • Combine estimates of macrofauna biomass with measures of site availability and safety (i.e., predation risk) for shorebirds to create estimates of foraging opportunity. • Compare changes in foraging opportunity under Existing and With Project conditions.	• Develop a regression-kriging model to estimate spatial distribution of macrofauna biomass density in the LSA based on geomorphology modeling data. • Create predictions (1-ha resolution) of macrofauna biomass density under Existing and With Project conditions based on results of the regression-kriging model. • Convert biomass density estimates to an estimate of total biomass (i.e., g or mg) in each 1 ha grid cell or "site". • For each 1-ha grid cell also determine site safety from predation and tidal availability values. • Derive foraging opportunity estimates based on site safety, tidal availability and macrofauna biomass. • Compare foraging opportunity between Existing and With Project conditions.
2) Partition estimates of total macrofauna biomass across the Regional Study Area (RSA).	• Generate spatial estimates of abundances for macrofauna across the RSA. • Compare the distribution of macrofauna across the RSA and within the LSA.	• Develop a regression-kriging model to estimate the spatial distribution of macrofauna biomass density across the RSA. • Summarise total macrofauna biomass across the RSA and within the LSA. • Investigate the importance of overwintering macrofauna biomass in the LSA relative to the RSA and assess potential changes in macrofauna biomass and distribution in the LSA resulting from the Project relative to the RSA.

2.0 REVIEW OF AVAILABLE LITERATURE AND DATA

The expansive mudflat, marsh, and adjacent agricultural areas of the Fraser River estuary (FRE) provide habitat to numerous birds and as a result has been designated a "Wetland of International Importance" (Ramsar Convention 2014), an "Important Bird Area" (IBA Canada 2013), and shorebird "Site of Hemispheric Importance" (Western Hemisphere Shorebird Reserve Network 2005).

Shorebirds are one of the most abundant groups of birds found in the FRE throughout much of the year, but especially during migration (Butler and Vermeer 1994, Sutherland et al. 2000). The most abundant shorebird in the FRE during migratory periods is the western sandpiper (*Calidris mauri*) followed by the dunlin. Dunlin migrations occur in two phases (northward and southward migrations) with the FRE being used as both a stopover site and an overwintering site during non-breeding periods. The overwintering dunlin population within the FRE is one of the largest populations on the Pacific coast, numbering 25,000 to 60,000 birds and, as such, the FRE is an important overwintering site for the species (Fernández et al. 2010, Hemmera 2014*a*).

Dunlin primarily use mud- and sand-flats (hereafter, collectively referred to as "mudflats") as foraging habitat and supplement their diet by foraging in nearby agricultural fields (Evans Ogden et al. 2005, Evans-Ogden et al. 2008a). Studies of dunlin habitat usage indicate that an average of 38% of their diet is obtained from agricultural sources, and that diets of individuals range from entirely intertidal to entirely agricultural (Evans-Ogden et al. 2008b). Dunlin diet consists largely of macrofauna (Bengtson and Svensson 1968, Senner et al. 1989, Brennan et al. 1990, Mathot et al. 2010) and over-wintering foraging use by dunlin in the FRE is apparently driven by invertebrate biomass (Hemmera 2014*a*). Shepherd (2001) investigated wintering dunlin movements in the FRE over periods of four to five weeks. During these periods, dunlin exhibited approximately 65% site-fidelity to the FRE region, regular movement within FRE home ranges of 11 to 50 km^2, and limited movement outside of home ranges. Within intertidal habitat, relationships between dunlin distributions and environmental characteristics have been examined at Roberts Bank (Zharikov et al. 2009) and other sites (Yates et al. 1993, Miller and de Rivera 2014). These studies have found that over-wintering shorebird distributions are influenced by sediment grain size and organic content, as well as proximity to tidal channels and shore.

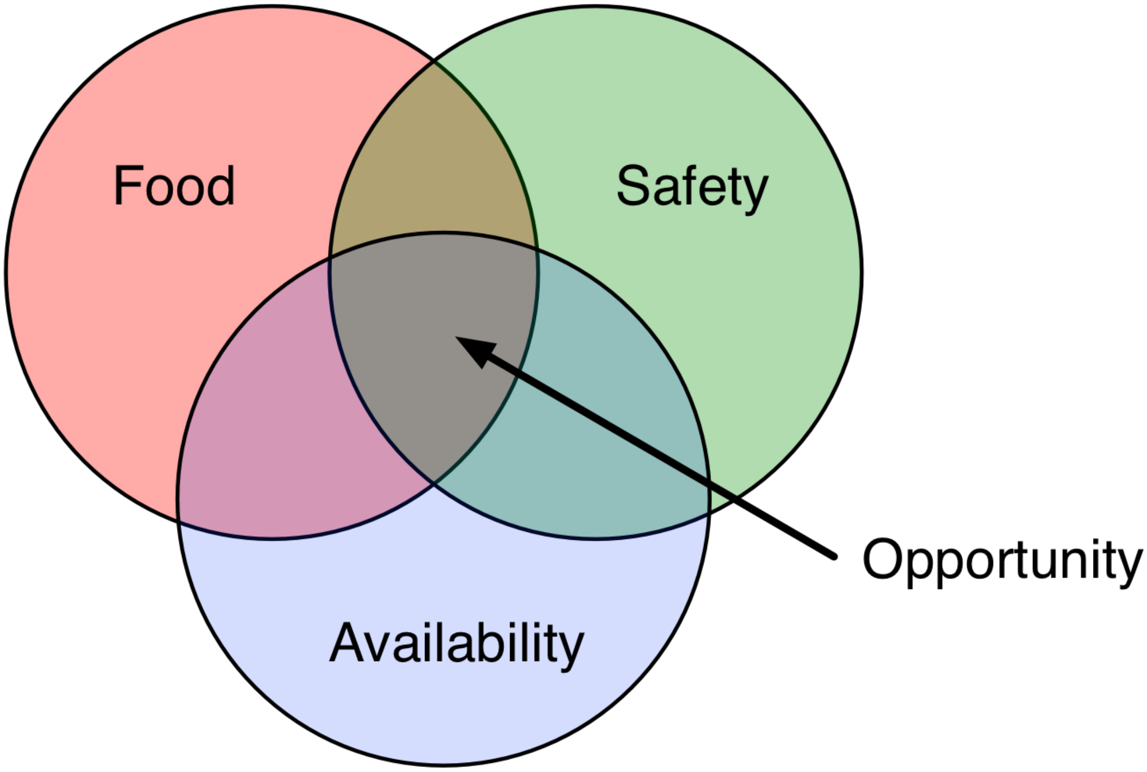
PMV initiated studies to fill information gaps pertinent to the environmental assessment and established the Technical Advisory Group (TAG) (Compass Resource Management Ltd. 2013). The TAG process entailed consulting with and gathering input from external experts on topics of considerable importance to the environmental assessment. The TAG relevant to dunlin was the termed the Biofilm and Shorebird TAG. TAG members reviewed existing data and provided recommendations on how to improve ongoing studies as well as recommended methods to investigate potential changes to the LSA relevant to migrating and overwintering shorebirds.

A key recommendation from the Biofilm and Shorebird TAG was the recommendation to assess the potential effects of RBT2 on shorebirds (western sandpiper and dunlin) by investigating changes in shorebird foraging opportunity during migration (see LGL and Hemmera 2014) and the overwintering period. Shorebird foraging opportunity was defined in the TAG as a measure of energy available to a foraging shorebird at any one location, weighted against a site's safety from predation (e.g., safety from preying peregrine falcons), and availability (which is related to tidal exposure) (Compass Resource Management Ltd. 2013). **Figure 1** depicts a conceptual diagram of shorebird foraging opportunity. A site's safety was defined as the distance a site is from obstructive cover, such as a shoreline. Raptors are known to have higher kill rates close to cover than sites further away; therefore, sites close to obstructive cover are more dangerous to foraging shorebirds and may be used less frequently than safer sites (Pomeroy 2006, Pomeroy et al. 2008). In response to the Biofilm and Shorebird TAG recommendations a conceptual foraging model was developed, that entailed:

1. Assigning a food value based on biomass of prey items to sites across the intertidal mudflats;
2. Assigning site safety scores to sites;
3. Determining the amount of time sites were available to foraging shorebirds during a tidal cycle;
4. Inferring shorebird opportunity at sites;
5. Predicting shorebird opportunity post RBT2; and
6. Evaluating change in shorebird opportunity as a result of RBT2.

The following Technical Report (TR) overviews how this conceptual modeling approach was implemented, termed the Overwintering Shorebird Foraging Opportunity Model (OSFOM). Foraging opportunity was determined for macrofauna, dunlin's primary food source during the overwintering period, under both current conditions (termed "Existing"), as well as post RBT2 construction (termed "With Project").

Figure 1 Conceptual Relationship between a Site's Shorebird Food Abundance (i.e., macrofauna biomass), a Site's Safety from Predation, and a Site's Availability to Foraging Shorebirds



3.0 METHODS

The focus of this TR is the implementation of the OSFOM. The descriptions herein relate mainly to the creation of the OSFOM, with some discussion of the spatial and temporal scopes of the various studies used as data sources (see **Section 3.3**).

3.1 STUDY AREA

The OSFOM has two primary spatial scopes, the Regional Study Area (RSA) (**Figure 2**) and the Local Study Area (LSA) (**Figure 3**)**.** The LSA was used to investigate changes in foraging opportunity in the area believed most likely to undergo geomorphological changes as a result of the Project. Only estimates of foraging opportunity, as defined in the Biofilm and Shorebird TAG, were investigated within this area. The RSA encompasses a large portion of the FRE and was used to place LSA changes within the context of the larger estuary.

3.1.1 Local Study Area

For the purpose of the OSFOM the LSA was defined as extending from Canoe passage to the Roberts Bank causeway (within the RSA, the LSA was termed the Brunswick Point stratum; see **Figure 2**). The LSA is the only area predicted to undergo geomorphological changes as a result of Project construction (Northwest Hydraulic Consultants Ltd. 2014). Areas directly adjacent, such as the inter-causeway area, and Westham Island (**Figure 3**) were not expected to experience geomorphological changes due to the proposed Project and thus were excluded from the LSA. Inclusion of these areas would have resulted in reduced estimates of change (whether positive or negative). Additionally, the geomorphology modelling data on which estimates of change were derived had the highest spatial resolution in the LSA compared to the remainder of the RSA, with the exception in the inter-causeway (see Northwest Hydraulic Consultants Ltd. 2014). Based on the biofilm zone designations proposed by WorleyParsons (2015) the LSA was further divided into two main zones: Canoe Passage and the Intertidal Zone (**Figure 3**). This zonation retains the Canoe Passage designation but combines the Upper, Mid and Lower intertidal zones proposed by WorleyParsons (2015) into a single zone within the LSA. Both the Canoe Passage and Intertidal Zone were believed to represent distinct conditions that may affect macrofauna distribution and abundance (Per Comm., Winterbottom 2014).

3.1.2 Regional Study Area

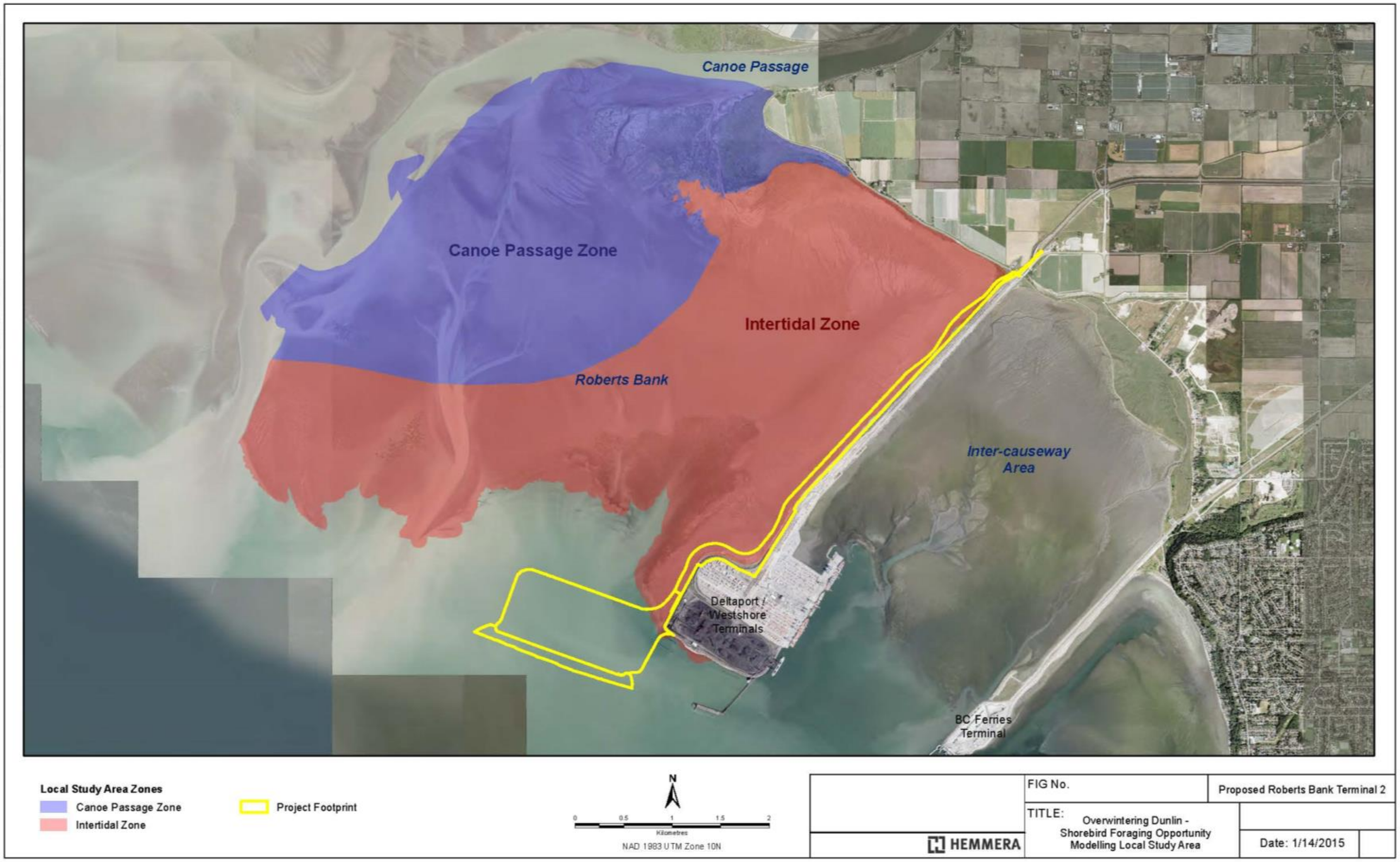
The RSA encompasses a large proportion of the FRE, starting just south of the Vancouver International Airport (Sturgeon Bank) and extended south and east to encompass Roberts Bank and Boundary Bay (**Figure 2**)**.** The RSA was divided into five study stratum corresponding to accepted geographic features within the estuary: Sturgeon Bank, Westham Island, Brunswick Point, Inter-causeway area, and Boundary

Bay. For the purposes of this study Mud Bay was included within the Boundary Bay stratum. Further designations developed by grouping stratum possessing similar sediment quality characteristics were termed the: West Bank (Sturgeon Bank, Westham Island, and Brunswick Point) and South Bank (Inter-causeway and Boundary Bay). The stratum and bank designations were chosen as they were believed to represent differing environmental conditions and were incorporated into RSA abundance models as required.

Figure 2 Regional Study Area and Stratum Designations

Note: The five stratum designations where chosen for the differing environmental conditions represented within each area. Initial exploratory analyses revealed differences in the variables of interest within these five areas. The LSA (**Figure 3**) consists of the Brunswick Point stratum. The West Bank was defined as Sturgeon Bank, Westham Island and Brunswick Point, while the South Bank was defined as the Inter-causeway and Boundary Bay. The 1-ha grid cells used in the OSFOM are indicated on the figure.

Figure 3 Local Study Area, Zones, and Area of Inference used in the Foraging Opportunity Assessment



Note: The LSA was restricted to the Brunswick Point stratum (**Figure 2**) and can be broken down into two distinct zones: Canoe Passage and the Intertidal Zone. All analyses considered both zones.

3.2 Temporal Scope

The overwintering dunlin foraging opportunity study was intended to establish the current-day (i.e., “Existing conditions”) macrofauna prey abundance (and by extension foraging opportunity) available to dunlin in the LSA (**Figure 3**) and the RSA (**Figure 2**) during the winter period. To better estimate correlational relationships between macrofauna abundance and explanatory factors (e.g., sediment grain size, salinity, wave height) data collected from periods within and outside the dunlin overwintering period were used to develop models. The time periods of data collection used to develop the macrofauna predictive model are shown in (**Table 2**).

Table 2 Summary of the Temporal Scope of Study Sampling Programs

Year	Season	Dates
2012	Spring	Apr 18 – May 7
	Summer	Jul 2 – Aug 28
2013	Winter	Feb 1 – Feb 2
	Spring	Apr 16 – May 7
	Summer	Jul 11 – Sep 6
2014	Winter	Jan 8 – Feb 14

3.3 Study Methods

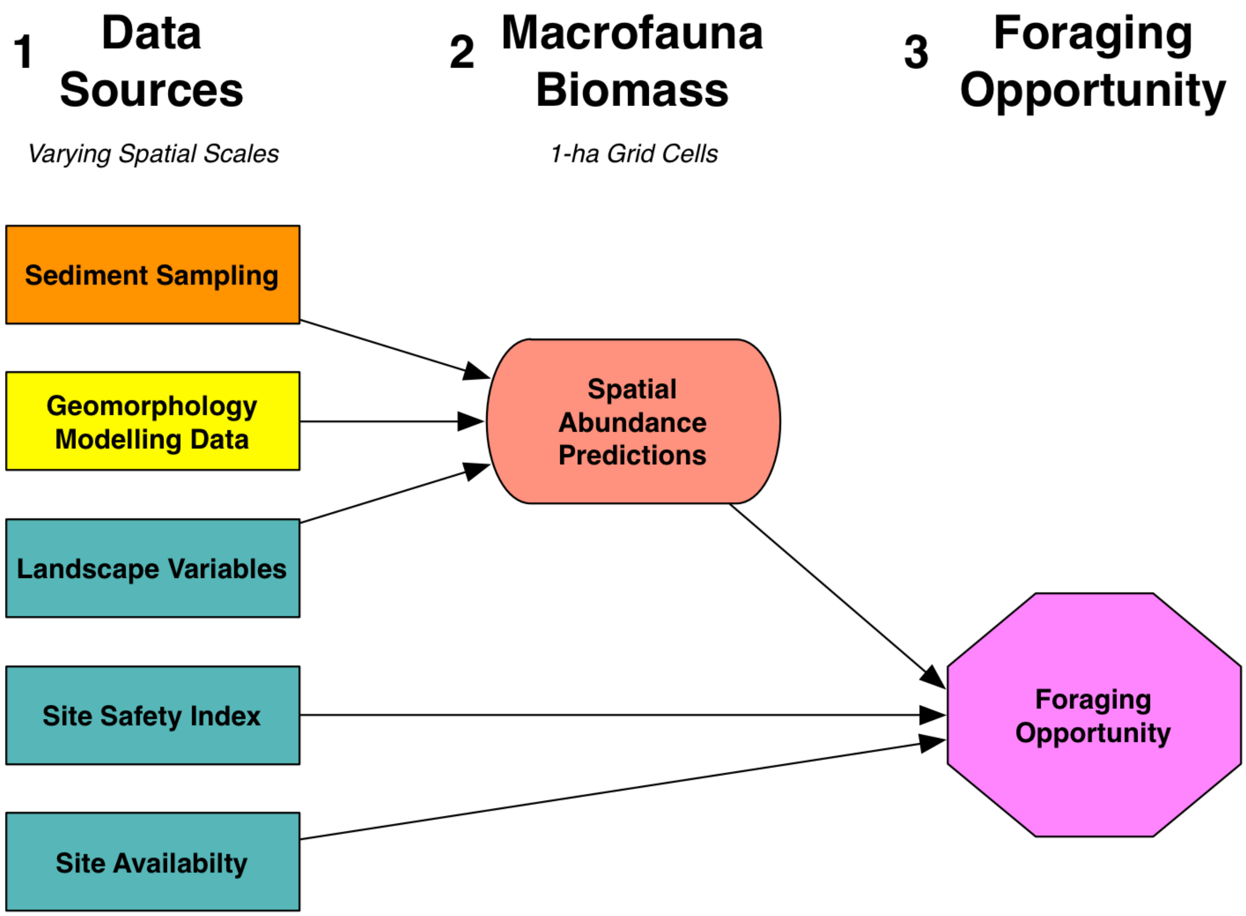
For procedures detailing methods of collection and processing of macrofauna samples see Hemmera (2014b).

3.4 Data Analysis

3.4.1 General approach to the Shorebird Foraging Opportunity Model

The OSFOM as specified by the Biofilm and Shorebird TAG represents a multi-step approach that relies on a mixture of statistical models and a type of “ledger sheet” approach in order to quantify opportunity (**Figure 4**). As a first step, multiple data sources were combined with spatial statistical models to provide estimates of macrofauna biomass within a series of contiguous 1 ha (10,000 m^2) grid cells covering the LSA (**Figure 5**). Biomass values from each grid cell were combined with measures of site safety (i.e., predation risk) for shorebirds and tidal availability to produce the final estimates of foraging opportunity (see **Section 3.4.4**). Tidal availability was determined as the average weekly hours a site was available during the winter period (see **Appendix A: Figure 12**). Spatial statistical models were trained based on biomass samples taken in the LSA and RSA.

Figure 4 Workflow for the Shorebird Foraging Opportunity Model



Note: Sediment sampling involved taking physical samplings in the intertidal mud flats across the LSA and RSA. The geomorphology data (e.g., salinity concentration, water velocity) modelled physical processes occurring within the LSA under Existing and With Project conditions. Landscape variables and site safety were calculated using GIS software and the availability of sites (i.e., grid cells) to foraging dunlin was based on high-resolution elevation and tidal data.

Within the LSA, spatial statistical predictions of macrofauna biomass were made based on estimated correlational relationships with the 2012 geomorphology modelling data (Northwest Hydraulic Consultants Ltd. 2014) and were used to generate “Existing” estimates of macrofauna density per grid cell (i.e., g/m^2). Geomorphology data modelled with the RBT2 structure in place were used to generate “With Project” macrofauna biomass predictions. With Project predictions also removed grid cells associated with the Project footprint. These datasets were then used to generate Existing and With Project predictions of foraging opportunity within the LSA (**Figure 4**).

As a final step, existing macrofauna densities were calculated in all gird cells across the RSA to compare total macrofauna biomass found within the LSA relative to the FRE as a whole.

Figure 5 Local Study Area Overlaid with One Hectare Grid Cells used in Predictive Modelling

Note: Macrofauna abundance predictions were calculated on a per grid cell basis. Analyses using the predicted grid cells that were less than 1 ha were either excluded from the analysis or values were adjusted to account for the smaller area.

3.4.2 Spatial Predictions of Macrofauna Density

Macrofauna density predictions were made using regression-kriging models using gstat package for geospatial modeling (Pebesma 2004) in the R statistical environment (R Core Team 2014). Models were trained based on sediment sampling programs and variables that were known across the landscape. For analyses occurring in the LSA, models included geomorphology modelling data (Northwest Hydraulic Consultants Ltd. 2014), so that Existing and With Project density predictions could be made. After fitting, models were checked using leave-one-out cross validation (Hengl 2009). Model residuals and the descriptive ability of each model were noted. Finally, because macrofauna density predictions are not independent, error propagation associated with estimated Existing and With Project biomass changes were investigated using a Monte Carlo approach (see **Section 3.4.3.1**).

Sample sizes used to spatially model macrofauna densities are presented in **Table 3** (Hemmera 2014b). LSA foraging opportunity models only used samples taken in the Brunswick Point stratum, while all available samples were used for the RSA models.

Table 3 Sample Sizes for the Infauna Sampling Program used to Spatially Model Macrofauna Biomass

Area	2012		2013			2014	TOTAL
	Spring	Summer	Winter	Spring	Summer	Winter	
Brunswick Point (LSA)	55	66	8	28	33	50	**240**
Boundary Bay	42	58	6	30	28	75	**239**
Inter-causeway	14	23	–	15	15	33	**100**
Sturgeon Bank	32	52	–	30	30	30	**174**
Westham Island	23	31	–	20	17	–	**91**
All Areas Combined	**166**	**230**	**14**	**123**	**123**	**188**	**844**

Note: For details on the sampling program see Hemmera (2014b).

3.4.2.1 Regression-kriging General Procedure

Regression-kriging is a hybrid technique combining standard generalised least squares regression techniques with Kriging techniques that consider spatial autocorrelation. The general procedure for fitting a regression-kriging starts by first determining the structure of the regression relationship (i.e., the trend model) between the response or target variable (i.e., macrofauna biomass) and potential explanatory variables, such as sediment grain size and salinity. Any explanatory variable under consideration must be known for all grid cells in the prediction area otherwise an abundance prediction is not possible. Observations (and predictions) are also in close proximity and can be expected to be more similar than samples father apart due to the spatial proximity. As a result a spatial autocorrelational structure (i.e., a model of how the response variable naturally varies by distance) is also required for the analysis. This was done using an empirical variogram, which takes into account the chosen regression structure. Anisotropy (non-symmetrical autocorrelation) was also checked and adjustments were made to the spatial autocorrelation model if required.

After the regression and autocorrelational structure were determined, the regression-kriging was fit to the sediment sampling points and 1 ha resolution density predictions (i.e., g/m^2) were generated across the spatial area of interest (e.g., the LSA). Biomass estimates were generated by expanding density estimates (i.e., g/m^2) by the grid cell area (i.e., 10,000 m^2) and combing the appropriate grid cells for the area of interest.

As part of fitting the regression-krigging, leave-one-out cross validation was used to investigate model fit (Pebesma 2004, Hengl 2009). Leave-one-out cross validation removes one observation from the dataset and refits the regression-kriging model. On each refit, density predictions at the corresponding spatial location are compared to the observed value that was left out. Residuals from this process are then checked for assumptions of normality and can also be used to provide an estimate how much variation in the observations has been explained by the model.

Modelling within the LSA used the above described regression-kriging and geomorphology modeling data (see Northwest Hydraulic Consultants Ltd. 2014) to investigate changes in shorebird foraging opportunity between existing conditions and conditions with the Project in place. Outside of the LSA exploratory analyses revealed that the geomorphology modeling data was not at a sufficient spatial resolution to make accurate density predictions. Therefore, density predictions across the RSA used a different set of explanatory variables (see **Section 3.4.5**).

3.4.2.2 Determining the Regression Structure

Due to the large number of potential explanatory variables available, a two-step approach involving visualisation and model ranking was used when determining the regression model structure. The model needed to adequately describe variation, yet remain relatively general so as to ensure predictions could be as robust as possible, especially when extrapolating under With Project conditions. Visualisation techniques were used to choose a set of explanatory variables that were passed to a model ranking routine used to choose the final regression model. Visualisations entailed primarily scatter plots of macrofauna abundance against all possible remaining explanatory variables. Scatterplots were repeated for each study stratum (**Figure 2**) as well as by season and year in order to look for consistent trends. Appropriate data transformations for explanatory variables were also chosen at this time (e.g., logit transformation for proportions, square root for distances, and log transformations for heavily skewed variables). Transformations were chosen to reduce characteristics such as skew, as well as produce linear relationships with macrofauna biomass.

Variables showing strong descriptive power in explaining macrofauna biomass were iteratively included in the regression model. Revised models were fit and resulting model residuals were compared to the remaining explanatory variables not currently included in the model. This process was repeated until the remaining variables showed little descriptive power. Variables identified through this process were used in the final selection process.

The main set of explanatory variables identified by the visualisation techniques, along with secondary interactions terms, were then passed to a stepwise regression procedure using the **Akaike information criterion (**AIC) as the selection criteria (see Burnham and Anderson 2002). Where possible all descriptive variables were also scaled and centered by subtracting the mean value of the respective variable and dividing by the respective standard deviation for that variable. Descriptive variables used in the model selection process had mean of zero and a standard deviation of one. The use of centered and scaled explanatory variables allowed variance inflation factors (a measure of multicollinearity) to be more interpretable (especially for polynomial terms) and ensured that computer round-off errors were minimised. In the case where a high degree of multicollinearity existed, a subset of variables was selected to minimise multicollinearity prior to using the stepwise regression procedure.

Finally, due to the highly skewed nature of macrofauna densities measurements, the response variable was log transformed to meet assumptions required for regression-kriging methods.

3.4.2.3 Geomorphology Modelling Data

Geomorphology modelling data included four main parameters (water column salinity, wave height, shear stress and bottom velocity) and was created based on the 2012 conditions (see Northwest Hydraulic Consultants Ltd. 2014). Modelled data was available as monthly percentiles (10^{th} percentile, 50^{th} percentile, and 90^{th} percentile) and as a percentile computed from May to July and October to December. All percentiles were investigated for explanatory power. For water column salinity, December 50^{th} percentile values showed the strongest and most consistent correlation with biomass measurements, while for wave height, shear stress and bottom velocities the October to December 90^{th} percentile values showed the strongest and most consistent correlation. These relationships appeared to hold across all samples from different seasonal periods.

3.4.2.4 Landscape Variables

Additional landscape variables also considered in modelling macrofauna biomass were:

- The distance from a site (i.e., grid cell) to:
  - Fresh water (separated three size class dependent on stream width);
  - The natural shoreline;
  - Seasonal marsh line based on the Terrain Resources Inventory Management (TRIM) database;
- Sediment texture (percent sand 0.063 mm to 2.0 mm);
- Adjusted sediment chloride concentration (mg/kg);
- Total organic carbon (TOC); and
- Habitat type (e.g., eel grass, marsh type, and exposed substrate).

All variables were included in model development for the RSA. For the LSA, sediment texture, sediment chloride concentration and TOC were excluded from model development due to the difficulty in predicting With Project changes to these variables.

3.4.3 Predicting Densities under Existing and With Project Conditions

Macrofauna density predictions from the models were made on the log scale, and then back transformed to the anti-log scale (regular scale) for presentation and interpretation. Back transformations were generated based on applying the formula for the expected value of log-normal distributions, as model predictions will be normal on the log scale.

With Project biomass predictions in the LSA were made using the same fitted model as predictions under Existing conditions, but used With Project geomorphology modelling data for predictions. All other explanatory variables used for predictions remained unchanged. Geomorphology modelling data used to fit the model also remained unchanged (i.e., Existing conditions geomorphology data).

3.4.3.1 Estimating Change in Total Available Biomass

Changes in macrofauna abundance were summarised as a percentage change in total available biomass (g x hrs) in the LSA under With Project conditions. Available biomass for each grid cell was estimated by expanding the grid cell specific estimate of macrofauna abundance (g/m^2) by the grid cell area (10,000 m^2) and estimated grid cell weekly tidal exposure time (hrs) (see **Appendix A: Figure 12**). Combining the individual grid cell estimates then produced the estimate of LSA total available biomass. Percent change in LSA total available biomass was then computed by comparing the total available biomass estimate under With Project conditions relative to Existing conditions.

Because the macrofauna abundance predictions of each grid cell are not independent, error propagation in the percent change statistics needs to be considered. Regression-kriging predictions at each grid cell are the result of two components, the underlying regression trend and the estimate of spatial error (i.e., some areas are higher or lower than predicted by the regression trend; grid cells closer in proximity are more likely to have a similar discrepancy than cells with greater spatial separation). As a result, the statistical distribution of the percent change statistic (i.e., sampling distribution) will be defined by uncertainty in both components. The sampling distribution of the percent change statistic was therefore approximated using a Monte Carlo approach (i.e., parametric bootstrap).

Stochastic Conditional Gaussian Simulations (SCGS), as implemented in the `gstat` package (Pebesma 2004), was used to randomly generate prediction surfaces of Existing and With Project macrofauna biomass abundances across the LSA. This provided a distribution of possible prediction surfaces under both conditions, which reflect uncertainty in the regression estimates and the uncertainty associated with the estimated spatial error. A total of 1,000 prediction surfaces were generated under each scenario. For each prediction surface the total available biomass was determined and a percent change statistic computed, generating an approximation of the sampling distribution for the percent change statistic. The reported percent change estimate was based on the mean of the approximated distribution and the reported 95% confidence intervals were determined based on the 2.5% and 97.5% distribution percentiles.

3.4.4 Creation of the Foraging Opportunity Topology

Foraging opportunity topologies were created to visualise the interplay between site safety from raptor predation, macrofauna abundance (g/m^2) (i.e., density), and available biomass (g x hrs) (i.e., a measure of energy) under Existing and With Project conditions. The foraging opportunity topology is therefore a three-dimensional surface with macrofauna abundance and site safety defining the first two dimensions, with the total biomass (i.e., the product of abundance, total area, and total available tidal exposure) representing the final dimension. The topology surface was rendered in two-dimensional space by presenting abundance on the x-axis, safety on y-axis and available biomass as a colour gradient representing the z-axis. Contour lines were also added to topologies indicating area. The interpretation is similar to a topological elevation map.

Topologies were constructed by first creating a series of two-dimensional bins of the 1-ha grid cells based on macrofauna abundance (x-axis) and safety index (y-axis) values. Macrofauna abundance values were based on regression-kriging predictions and the site safety index was measured as the distance (m) to the nearest shoreline (i.e., obstructive cover); either the natural shoreline or the Roberts Bank causeway.

For each two-dimensional bin the available biomass (g x hrs) was computed by combining the estimated available biomass of the individual 1-ha grid cells associated with a particular bin. Available biomass for each 1-ha grid cell was computed in the same manner as previously stated (see **Section 3.4.3.1**), representing the topology height (z-axis). Contour lines indicating curves of constant available biomass were also added to topology plots to help identify peaks.

After total available biomass was computed for every two-dimensional bin, a local polynomial trend surface was fit to the bin values to smooth the surface. The local polynomial trend surface was fit using the `loess` procedure in R (R Core Team 2014). The resulting surface was then normalised to ensure that the total energy or total usage matched the original two-dimensional bin totals. After the smoothed surface was fit, the resulting topology surface was compared to topologies constructed using raw bin values to ensure the major features were retained and that the general form and structure remained consistent.

3.4.5 Total Macrofauna Biomass within the Regional Study Area

Total macrofauna biomass was estimated and compared across the RSA. Comparisons were first made in between the LSA and study stratum directly surrounding the LSA. Together these areas were referred to as the Roberts Bank area and include Westham Island, Brunswick Point and the Inter-causeway study strata (**Figure 2**). Further comparisons were then made between Roberts Bank and the remaining study strata within the RSA.

Total macrofauna biomass was determined by first estimating macrofauna densities (g/m^2) across the entire RSA using regression-kriging approaches (see **Section 3.4.2**). Density estimates within each 1-ha grid cell (g/m^2) were then expressed as measurements of biomass by expanding estimates of grid cell abundance by the corresponding grid cell area. Grid cell specific estimates of biomass were then combined to give estimates of total biomass for individual study stratum or combinations of study strata (i.e., Roberts Bank).

Predicting macrofauna biomass across the RSA required additional explanatory variables due to the fact variables used in the LSA abundance models were not available across the RSA. Outside of Brunswick Point (the LSA) and the Inter-causeway strata, the spatial resolution of the geomorphology modelling data was too coarse to get consistent correlations between modelling parameters and sampling biomass measurements from the sediment sampling program (see **Table 3**). As such, other explanatory variables were used to predict biomass in areas outside of the LSA (see **Section 3.4.2.4**). Variables used to model macrofauna biomass across the RSA were: sediment chloride, percent sand, and total organic carbon. Regression-kriging surfaces were developed for each variable and are presented in **Appendix A** (see **Figure 13**, **Figure 14**, and **Figure 15**). Regression model structures used for the sediment chloride, percent sand, and total organic carbon prediction surfaces can be found in **Appendix B** (see **Table 7**, **Table 8**, and **Table 9**).

4.0 RESULTS

This section presents the main findings of the study, and briefly describes data gaps, potential biases and incidental observations.

4.1 LOCAL STUDY AREA

4.1.1 Predicting Winter Macrofauna Density

4.1.1.1 Regression Model

After a suite of potential descriptor variables were selected from, starting with visualisation techniques, an AIC stepwise regression procedure was used to select the final regression model:

Log Macrofauna ~ Year 2012 + Season + Wave Height (Oct-Dec) + Salinity (Dec) + Year 2012 Salinity (Dec)*

Variance inflation factors (VIF) were computed for each of the centered and scaled explanatory variables in the model. All values were within acceptable limits (i.e., VIF less than 10) indicating that multicollinearity was not a substantial problem. The response variable was log transformed in order to meet statistical assumptions of the regression-kriging approach. The definition of each model parameter is outlined in **Table 4**.

Table 4 Macrofauna Regression Model Parameters, Role and Applied Transformations

Model Parameter	Type	Transformation	Description / Interpretation
Log Macrofauna	Response	Natural Log	Natural log transformed macrofauna biomass values (g/m^2). Regression model predicts orders of magnitude changes in macrofauna density.
Year 2012	Explanatory	None	Categorical variable allowing differences between 2012 versus all other years.
Season	Explanatory	None	Categorical variable allowing for differences in the response between spring, summer and winter observations.
Wave Height (Oct-Dec)	Explanatory	None	90^{th} percentile of the geomorphology wave height modeling data computed over the months of October to December. Extreme wave events predict log macrofauna density in a linear manner.
Salinity (Dec)	Explanatory	None	50^{th} percentile of the geomorphology water column salinity modeling value for the month of December. Median water column salinity predicts log macrofauna density in a simple linear fashion.
*Year 2012 * Salinity (Dec)*	Explanatory	None	An interaction term allowing for a different association between salinity and log macrofauna density in 2012 (a 1 in 25 year freshet event).

Note: All explanatory variables were standardised and scaled prior to fitting the regression model. Variance inflation factor analysis was used to assess multicollinearity of centered and scaled explanatory variables. In all cases multicollinearly was found to be within acceptable levels.

4.1.1.2 Spatial Predictions

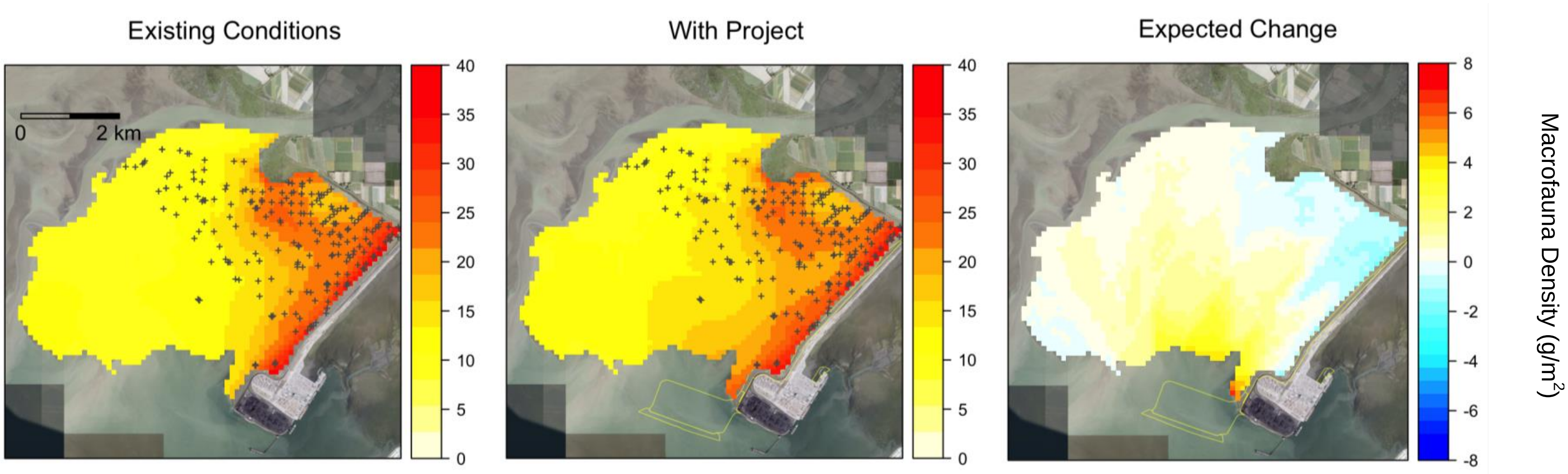
Using the top supported regression model a regression-kriging surface of macrofauna density was created for the wintering period under both Existing and With Project conditions (**Figure 6**). Expected changes between Existing and With Project surfaces are also indicated. The regression model was trained using the Brunswick Point data from 2012, 2013, and 2014 (see **Table 3**). A single set of winter biomass predictions are presented, representing the combined 2013 and 2014 overwintering periods, as there was insufficient winter sampling in 2013 to distinguish between the 2013 and 2014 wintering periods.

Under Existing conditions the highest macrofauna densities were predicted near the shore (both the natural shoreline and the Roberts Bank causeway shoreline) and away from Canoe Passage (**Figure 6**). There were also reduced macrofauna densities predicted in the known biomat area, even though the model structure did not specifically accommodate this area. Predictions in Canoe Passage were also generally lower than the Intertidal Zone.

Macrofauna density under the With Project scenario varied spatially compared to Existing conditions (**Figure 6**). Decreases were estimated close to both the natural and Roberts Bank causeway shorelines, while increases were predicted further from shore and towards the RBT2 terminal. The estimated decreases were typically small, on the order of -1 g/m^2 or less. The largest estimates of With Project biomass increases were around 4 g/m^2 and also occurred in areas that had little or no sampling. The accuracy of these predictions is unclear.

The leave-one-out cross-validation procedure indicated that the model explained roughly 7% of the variation in observed log macrofauna density, which indicates poor descriptive power. Investigation of model residuals from leave-one-out cross-validation indicated well-behaved residuals. There were no strong indications of a lack-of-fit, despite the poor predictive powers.

Figure 6 Estimated Macrofauna Density (g/m²) under Existing and With Project Conditions during the Winter Period



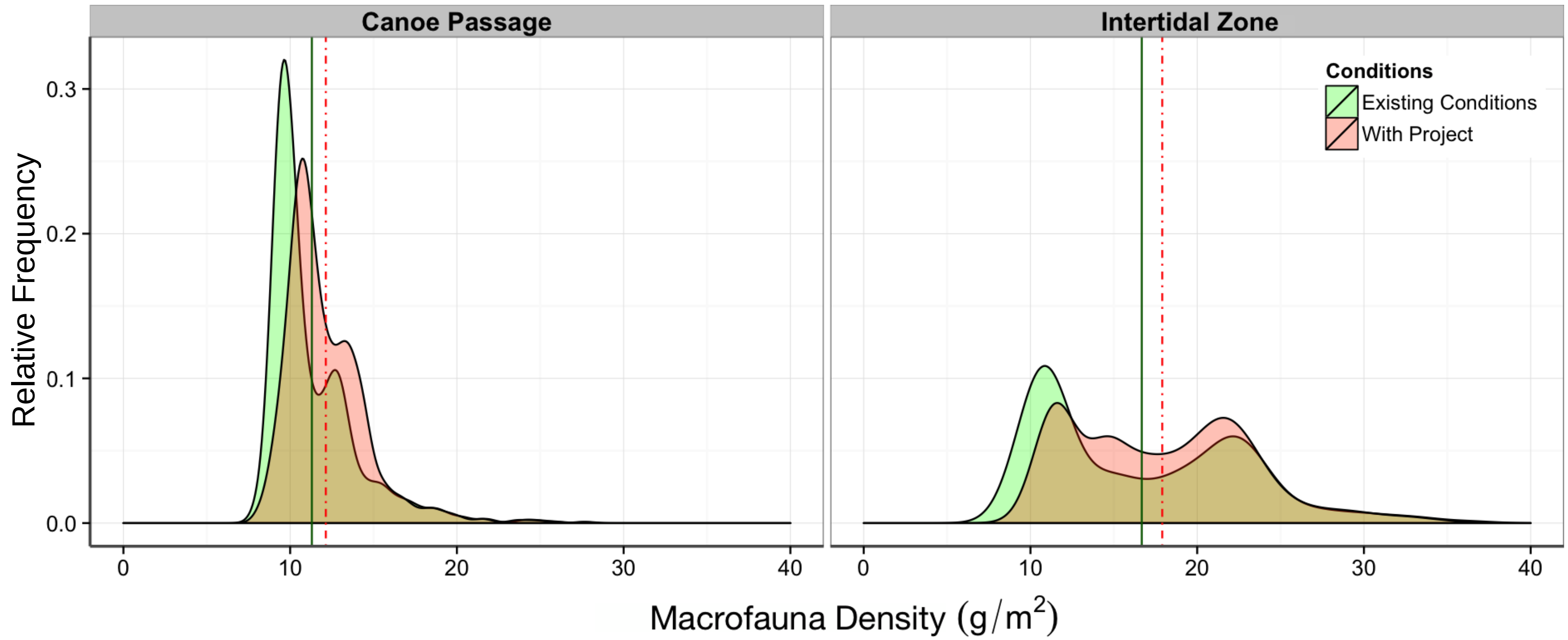
Note: Macrofauna density (g/m²) was estimated for each 1-ha grid using a regression-kriging based on the 2012 coastal geomorphology modelling data. Each row shows density estimates under Existing and With Project conditions for the overwinter period. Coastal geomorphology modelling data used in the model was specific to the wintering period. The final column indicates predicted changes in macrofauna density. Brunswick Point sediment samples (see **Table 3**) were used to train the regression-kriging model. Sampling locations are indicated on the figure.

4.1.2 Distributional Changes in Macrofauna Densities

While spatial plots of macrofauna density can be useful, it can be difficult to assess what proportion of the landscape supports a particular density. As such, the spatial dimension was removed and the distribution of macrofauna density was investigated by zone (Canoe Passage Zone and Intertidal Zone, **Figure 3**) within the LSA. Macrofauna distribution has been summarised by a plot, that represents the relative frequency of different macrofauna densities across the LSA (**Figure 7**).

Overall the distribution of predicted macrofauna showed a tendency of lower densities in Canoe Passage relative to the Intertidal Zone under Existing conditions. High densities of macrofauna appeared to occur in relatively low frequency, while lower and mid-range densities occurred in greater frequency in both zones. These features were preserved under With Project conditions, with little change predicted in the frequency of higher macrofauna densities. Under With Project conditions the frequency of lower density macrofauna was predicted to decrease, while mid and upper-mid density macrofauna were estimated to increase. The overall change resulted in an estimated increase in average With Project macrofauna density (dashed line; **Figure 7**) in both Canoe Passage and the Intertidal Zone.

Figure 7 Distribution of Predicted Canoe Passage and Intertidal Zone Macrofauna Density (g/m²) under Existing and With Project Conditions during the Winter Period



Note: Density curves show the relative frequency of macrofauna density over Canoe Passage and the Intertidal Zone under Existing and With Project conditions. The area under each curve is one. The area under the curve corresponding to a range of densities indicates the proportion of the landscape exhibiting those densities. The green vertical solid line indicates mean density under Existing conditions and the red vertical dashed line mean densities under the With Project conditions.

4.1.3 Estimating Change in Total Available Biomass

The percent change in total available macrofauna biomass (**Table 5**) was determined and computed independently for each zone (Canoe Passage and the Intertidal Zone) for the winter period. Overall, increases in total available macrofauna biomass (i.e., macrofauna density (g/m^2) multiplied by area (m^2) and availability (hrs)) were predicted for both Canoe Passage and the Intertidal Zone with the Project in place. A large amount of uncertainty was also associated with the estimates. In all cases the 95% confidence interval for the percent change contained zero, so the null hypothesis of no change cannot be ruled out either.

Table 5 Estimated Percent Change in Macrofauna Total Available Biomass between Existing and With Project conditions during the Overwintering Period

Area	Estimate	Lower CI	Upper CI
Canoe Passage	11.2%	-47.7%	102.5%
Intertidal Zone	3.2%	-45.0%	82.2%
LSA	4.3%	-43.3%	78.5%

Note: Total available biomass for each 1-ha grid cell was computed as the product of the area, abundance and tidal cycle availability (see **Appendix A: Figure 12**). Total available biomass for an area under Existing and With Project conditions was then computed for 1,000 Monte Carlo simulations and percent change computed. The Monte Carlo distribution was then used to approximate the distribution of the percent change statistic providing the point estimate and 95% confidence intervals. Estimates are provided for the LSA as well as for Canoe Passage and the Intertidal Zone (see **Figure 3**).

4.1.4 Sensitivity Analyses

The impact of different geomorphology modeling parameters on estimated macrofauna biomass changes was investigated by re-running analyses with and without With Project changes. Estimates of percent change in macrofauna biomass were recomputed using only changes to wave heights or changes to water column salinities under With Project conditions.

With Project estimates of percent change based only on changes to wave heights or water column salinities both showed similar increases in total available biomass relative to Existing conditions (**Appendix B: Table 10** and **Table 11** respectively). Taken together this suggests that Project related changes to water column salinity and wave height are driving factors behind estimated With Project macrofauna increases.

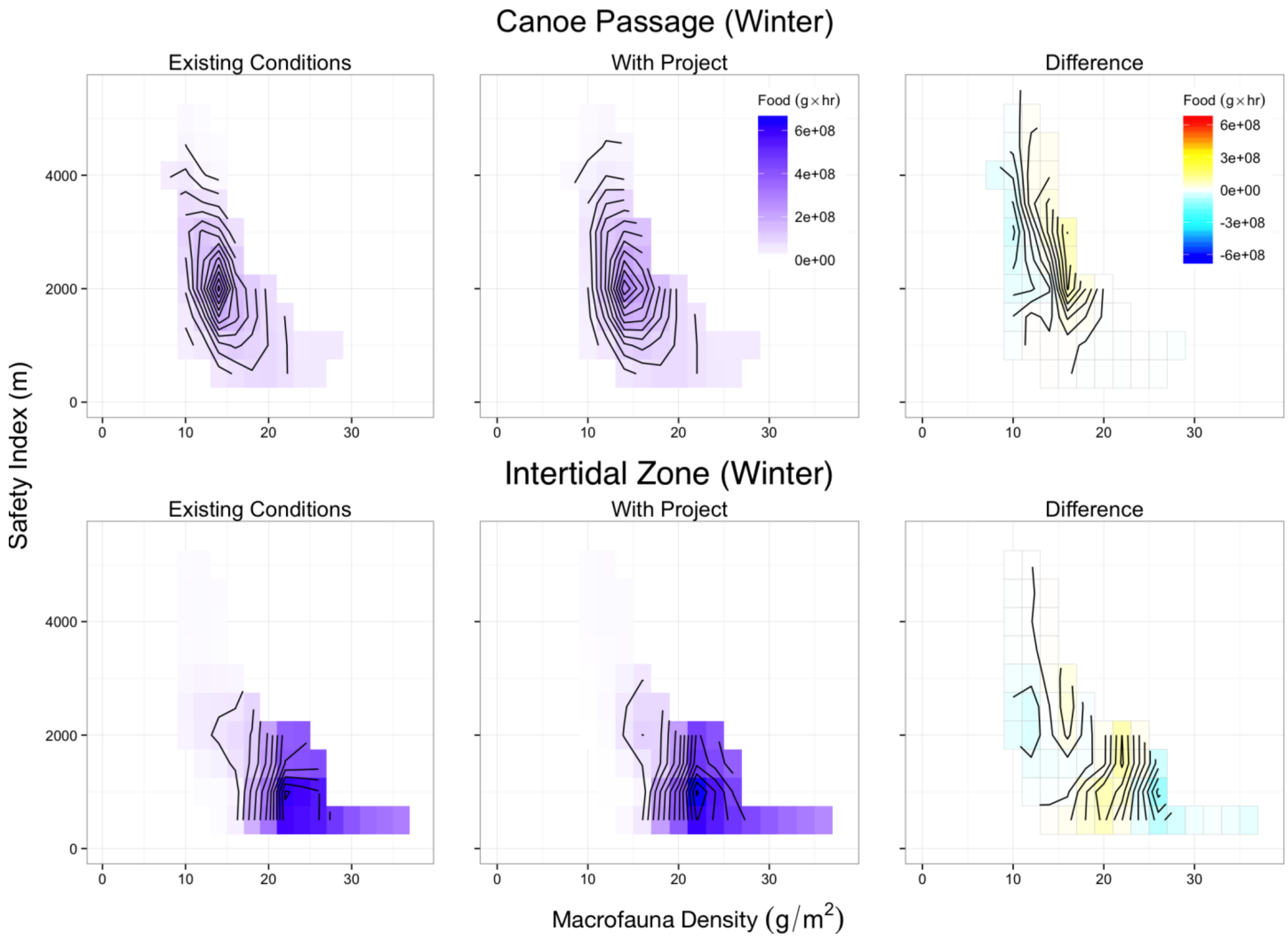
4.1.5 Estimating Foraging Opportunity

Macrofauna foraging opportunity topologies were constructed for both Canoe Passage and the Intertidal Zone and during the wintering period for the LSA (**Figure 8**). Macrofauna foraging opportunity presented is not year specific.

During the wintering period, foraging opportunity under Existing conditions showed peak opportunity in the Intertidal Zone occurred at a biomass of around 25 g/m^2 and across a range of safety values (ca. from 0 to 1,000 m from shore). In Canoe Passage, the highest opportunity peak occurred at approximately half the abundance (around 12.5 g/m^2), but within areas possessing higher safety (around 2,000 m from shore). In general, the Intertidal Zone had more than twice the total available macrofauna abundance relative to Canoe Passage during the wintering period (see **Appendix B: Table 12**).

Under With Project conditions, peak opportunity in the Intertidal Zone remained in areas of similar safety compared to Existing conditions, but with the foraging topology peak abundance shifting to around 30 g/m^2, instead of 25 g/m^2. Within Canoe Passage the position of peak foraging opportunity remained constant with respect to abundance and safety. For both Canoe Passage and the Intertidal Zone, opportunity showed little change in opportunity at higher macrofauna abundances and increasing opportunity at mid-abundances. This predicted increase also appears to occur in areas of higher safety in Canoe Passage relative to the Intertidal Zone.

Figure 8 Estimated Macrofauna Foraging Opportunity under Existing and With Project Conditions during the Winter Period



Note: Foraging opportunity is represented as a topology, where the height represents available food (available biomass) (g x hr) for a given combination of food density (g/m^2) and safety (m). Safety Index was measured as distance (m) to either the natural shoreline or the Roberts Bank causeway. Contour lines represent a curve along which the total available biomass is constant. The difference topology simply highlights the differences between the Existing and With Project topologies. Separate topologies were created for Canoe Passage and the Intertidal Zone (**Figure 3**).

4.2 TOTAL BIOMASS ACROSS THE REGIONAL STUDY AREA AND ROBERTS BANK

4.2.1 Predicting Densities across the Regional Study Area

Winter macrofauna densities (g/m^2) were estimated across the RSA (**Figure 9**) based on the following regression model:

> *Log Macrofauna ~ Stratum + Season + Year 2012 + BP:WaveHeight(Oct-Dec) + BP:Salinity(Dec) + WestBank:SandTexture + WestBank:SandTexture*^{2} *+ SouthBank:ShoreDistance*

Leave-one-out cross validation indicated that the model explained roughly 21% of the variation in observed log macrofauna density (see **Table 3** for sample sizes), which indicates somewhat poor descriptive power, but better than the LSA biomass model (see **Section 4.1.1**). Investigation of model residuals from leave-one-out cross-validation indicated well-behaved residuals. There were no strong indications of a lack-of-fit, despite the poor predictive powers.

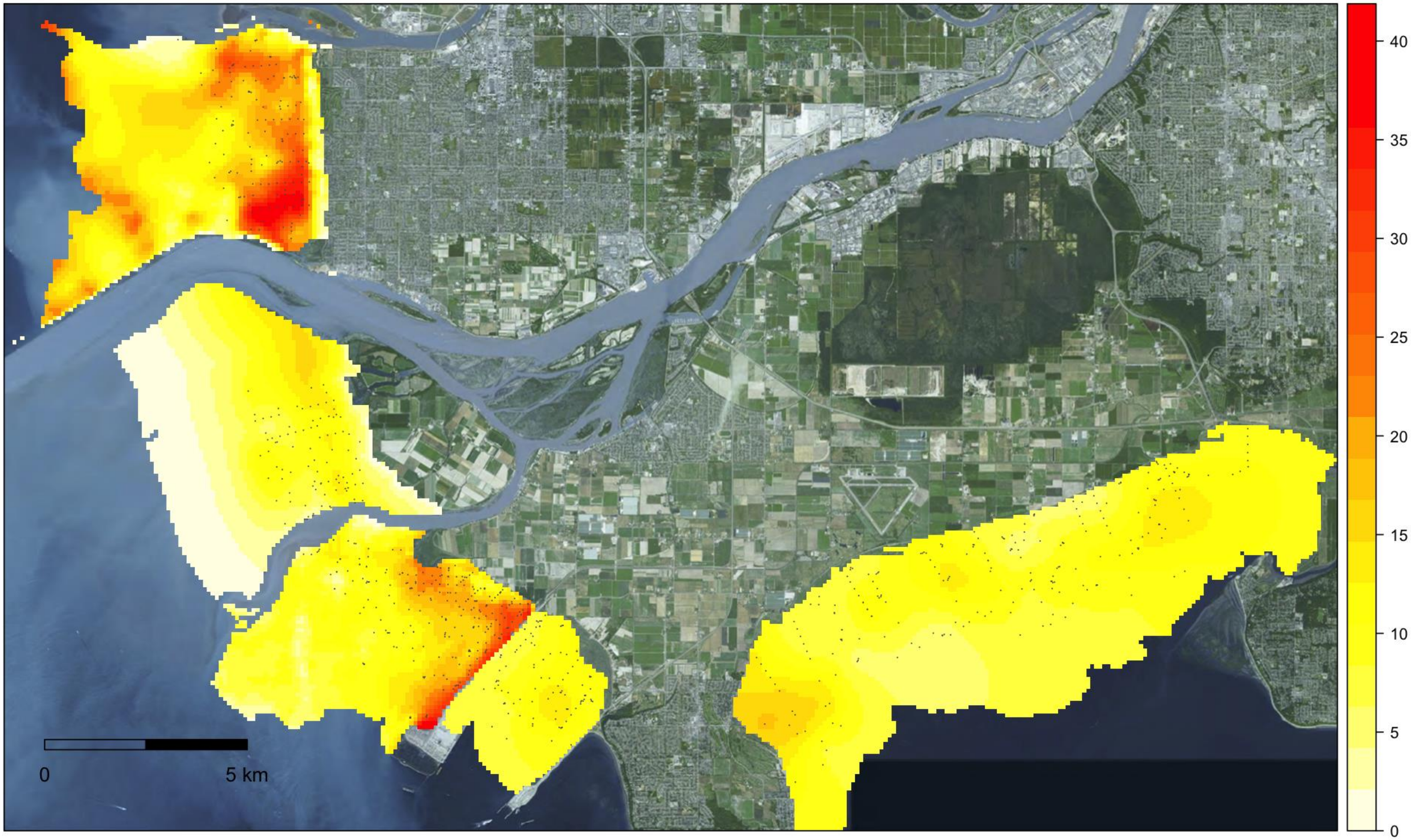
The definition of each model parameter is outlined in **Table 6**. The *Stratum*, *Season* and *Year 2012* terms allowed for differences between study stratums, years and for observations collected during the 1-in-25 year freshet event of 2012. Similar to the LSA abundance model geomorphology data governing wave height and water column salinity were used within the Brunswick point stratum. Finally, sand texture was found to predict macrofauna density in the West Bank (Sturgeon Bank, Westham Island, and Brunswick Point; **Figure 2**), while distance to the natural shore line was found to be an important predictor within the South Bank (Inter-causeway and Boundary Bay; **Figure 2**).

Table 6 Macrofauna Regression Model Parameters, Role and Applied Transformations

Model Parameter	Type	Transformation	Description / Interpretation
Log Macrofauna	Response	Natural Log	Natural log transformed macrofauna biomass values (g/m^2). Regression model predicts orders of magnitude changes in macrofauna biomass.
Stratum	Explanatory	None	Categorical variable allowing differences between each of the five study stratum (see **Figure 2**).
Season	Explanatory	None	Categorical variable indicating whether or not sampling occurred in one of three seasons (spring, summer, or winter).
Year 2012	Explanatory	None	Category variable indicating if the sampling year was 2012 (the 1 in 25 year freshet event).
BP:Wave Height (Oct-Dec)	Explanatory	None	Brunswick Point 90th percentile of the geomorphology wave height modeling data computed over the months of October to December. Extreme wave events predict log macrofauna density in a linear manner within the Brunswick Point stratum.

Model Parameter	Type	Transformation	Description / Interpretation
BP:Salinity (Dec)	Explanatory	None	Brunswick Point 50th percentile of the geomorphology water column salinity modeling value for the month of December. Median water column salinity predicts log macrofauna density in a simple linear fashion within the Brunswick Point stratum.
WestBank:SandTexture	Explanatory	Logit	West Bank logit transformed proportion of sand 0.063 to 2.0mm. Logit transformations are common for saturation measures. Logit proportion of sand predicts log macrofauna density in a parabolic fashion (inverted-U) indicating an optimal sand texture within the West Bank (Sturgeon Bank, Westham Island, and Brunswick Point).
WestBank:SandTexture^2	Explanatory	Logit and Square	
SouthBank:ShoreDistance	Explanatory	Square root	South Bank square root distance to the natural shoreline. Square root transformations are common for distance measures. Square root distance to shore describes log macrofauna density in a simple linear manner with the South Bank (Inter-causeway and Boundary Bay).

Figure 9 Predicted Macrofauna Density (g/m^2) across the Regional Study Area during the 2013/2014 Wintering Period

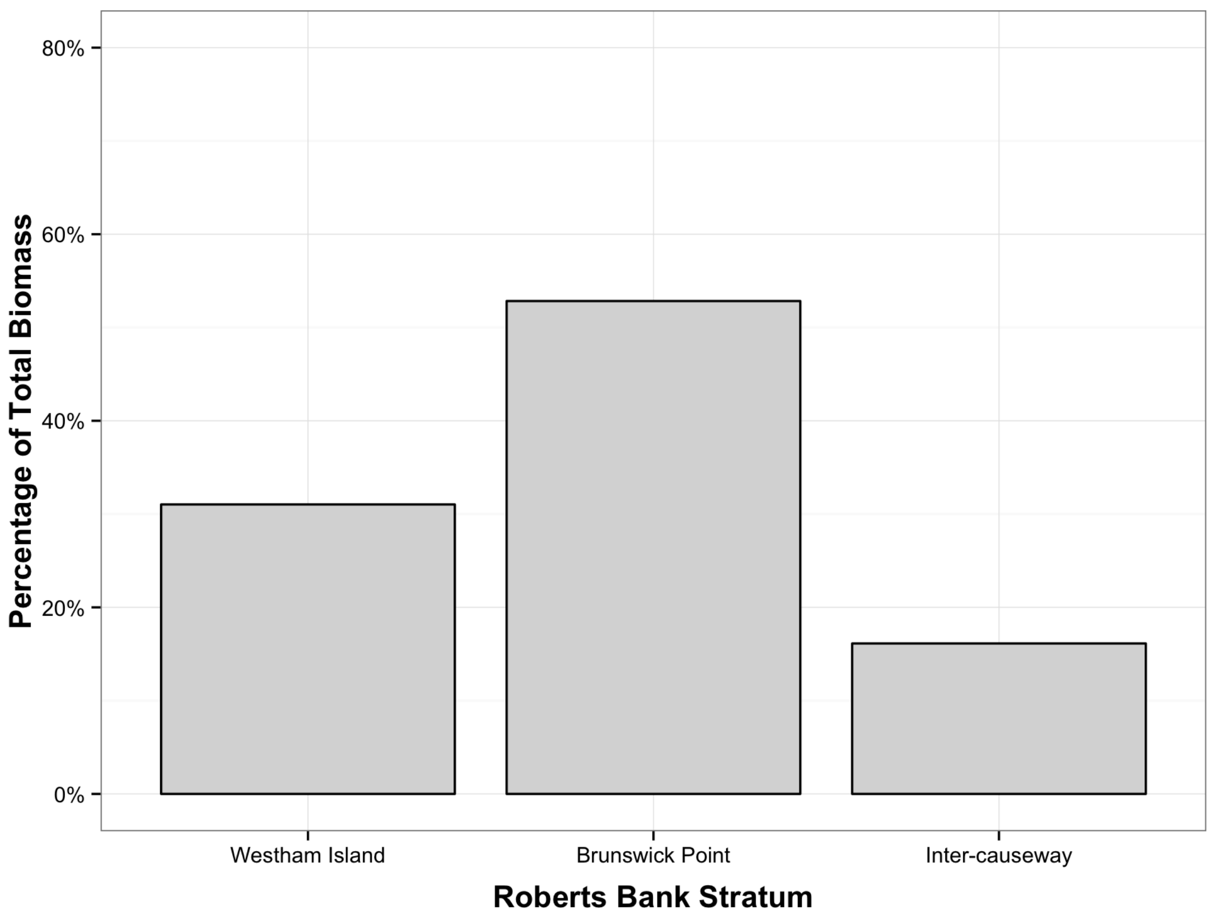


Note: A regression-kriging was fit to log transformed macrofauna density values. Displayed values were back transformed in order to provide predictions in g/m^2. Leave-one-out cross validation indicated that the model explained 21.1% variability in the response. Sediment sampling locations are indicated in the figure.

4.2.2 Comparison of Total Biomass in Roberts Bank

Estimates of total macrofauna abundance were compared within Roberts Bank (Westham Island, Brunswick Point and Inter-causeway; **Figure 10**). Overall the highest total biomass was found in Brunswick Point, followed by Westham Island and the Inter-causeway. Combining Westham Island and the Inter-causeway resulted in similar levels of total macrofauna abundance compared to Brunswick Point (**Appendix A: Figure 16**).

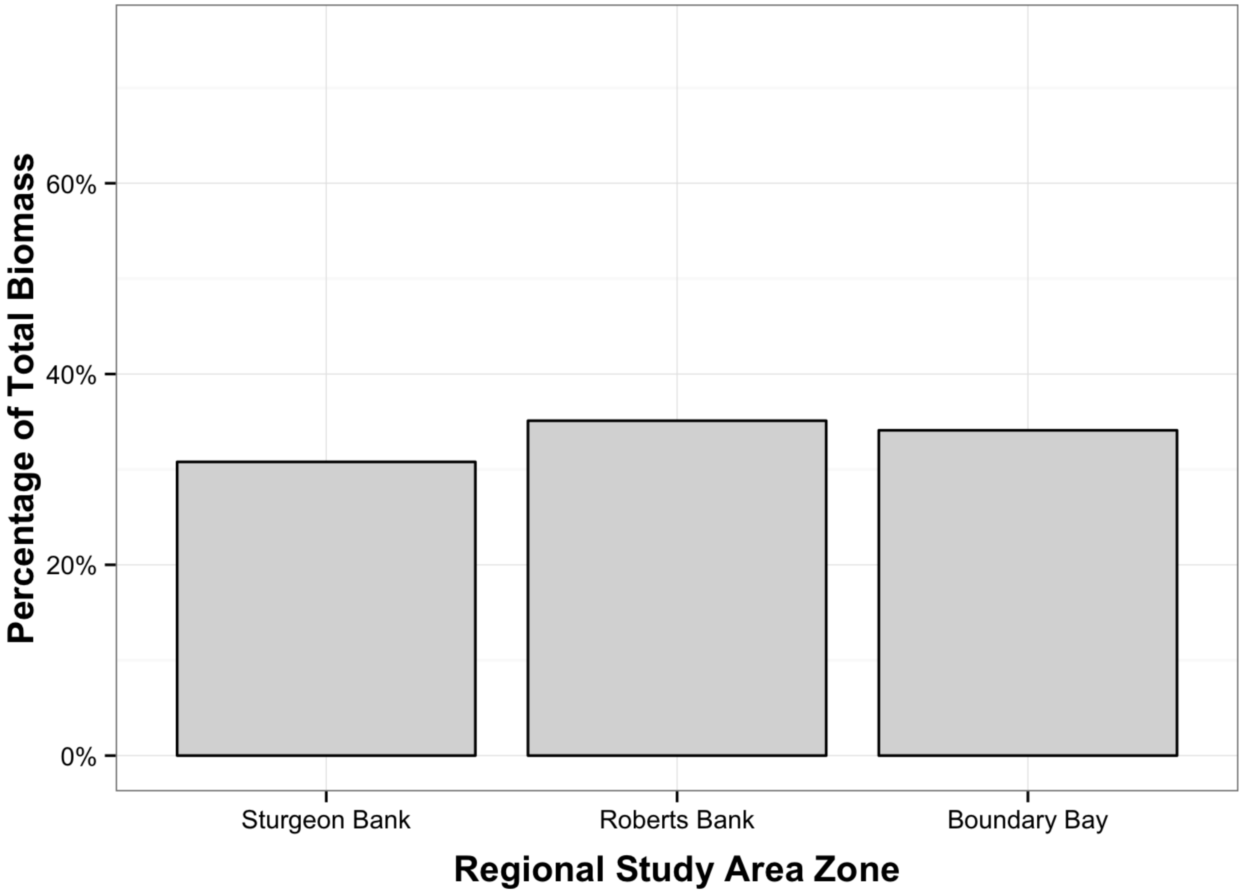
Figure 10 Summary of Roberts Bank Total Macrofauna Biomass during the Winter Period



4.2.3 Comparison of Total Biomass across the Regional Study Area

Total winter macrofauna biomass as also determined for the Roberts Bank area relative to the remainder of the RSA (**Figure 11**). Similar levels of total macrofauna biomass were found in Roberts Bank, Boundary Bay, with Sturgeon Bank. Sturgeon Bank showed remarkably similar levels of total biomass despite only accounting for roughly 20% of the total area relative to Roberts Bank (47%) and Boundary Bay (33%).

Figure 11 Summary of Total Biomass in Regional Study Area



5.0 DISCUSSION

A discussion of the major results arising from the Overwintering Dunlin Foraging Opportunity Study and data gaps are provided below.

5.1 DISCUSSION OF KEY FINDINGS

Macrofauna biomass within the LSA during the overwintering period was predicted to increase under With Project conditions. The estimated increase appears to be attributable to With Project changes to both wave height and water column salinity. These With Project estimates differed from the western sandpiper (WESA) Shorebird Foraging Opportunity Model (SFOM), which predicted declines during the spring and summer migration periods (see LGL and Hemmera 2014). This discrepancy is not surprising as the migration biomass density models used geomorphology data associated with the Fraser River freshet periods, while the winter models use geomorphology data associated with months outside the freshet period. Sensitivity analyses in the WESA SFOM found that smaller Fraser River flows were associated with reduced With Project effect sizes. Results from the dunlin OSFOM were consistent with this result as estimates were derived during periods of lowest Fraser River output.

Winter macrofauna foraging opportunity in the LSA showed general trends similar to those observed in spring and summer migration periods (see LGL and Hemmera 2014). Under existing conditions, peak macrofauna foraging opportunity was higher in Intertidal Zone relative to Canoe Passage, but also occurred in areas that had lower safety. Within the Intertidal Zone, peak foraging opportunity also occurred in areas with higher densities of macrofauna biomass and thus may also represent more efficient foraging habitat relative to Canoe Passage.

Winter macrofauna foraging opportunity estimated under With Project conditions showed only subtle changes relative to estimates under Existing conditions. Most of the changes represented an increase in foraging opportunity and occurred near the current peaks estimated under Existing conditions. This suggests that few changes to foraging opportunity are expected and that the general nature of the existing foraging opportunity will remain largely unchanged, assuming the estimated changes under With Project conditions were accurate.

Large uncertainty was also associated with estimates of biomass change. Confidence intervals associated with the estimated changes were wide and covered zero (or no change). Two interpretations can be drawn from this result and are interrelated. The first interpretation is associated with classical hypothesis testing and suggests that there is not enough evidence to reject the null hypothesis of no change. However, the shortcoming of *p*-value based hypothesis tests has been well documented (e.g., Hung et al. 1997) as the inability to find evidence against a null hypothesis can simply represent lack of statistical power rather than evidence for the null hypothesis. The second approach is the direct interpretation of confidence intervals, which is an approach that is often preferred (Cherry 1998). In this case we have little evidence to support With Project changes larger than a 79% increase or a 43% decrease biomass in the LSA.

In all likelihood the true change in macrofauna biomass will differ from the average estimated change, but the in general the foraging opportunity (i.e., the relative position of peak opportunity) will likely remain relatively unchanged. If the true increase is larger than the predicted average increase of 4%, the opportunity peaks will likely shift towards higher density macrofauna biomass. Similarly, smaller increases, or decreases, will likely shift the peak towards lower density macrofauna biomass. The position of the peak with respect to safety will likely remain relatively unchanged. In the current study, which estimated an average increase in available biomass, there was little change in the opportunity peak relative to safety. In WESA SFOM, which estimated declines and larger average changes in available biomass, shifts in the opportunity peak were generally related to changes in biomass densities rather than safety (LGL and Hemmera 2014). As such, individuals in the LSA are likely to face similar types of foraging trade-offs between safety, feeding efficiency, and available resources as currently exist.

While an increase in available biomass was estimated, declines cannot be entirely ruled out either. Declines may be concerning if the total available biomass is not sufficient. While the current study did not estimate capacity during this period, capacities to accommodate even the worst-case estimate of change in macrofauna biomass likely exist within the system. The WESA SFOM lower confidence bound for macrofauna available biomass change during northward migration was similar to the lower bound estimate for winter macrofauna available biomass (42% versus 43%). In the WESA SFOM analysis the lower bound estimate of With Project change still resulted in a large capacity estimate (ca. 58%) during northward migration, even though northward migration represents the period of highest demand when the FRE acts as a stopover site for large numbers of both WESAs and dunlin during this period (Butler et al. 1987, Butler and Vermeer 1994, Drever et al. 2014). By extension it is likely that large macrofauna capacities also exist during the overwintering period when total demands are lower, more protracted, and foraging habitat outside the LSA and FRE are also important sources of food (Evans Ogden et al. 2005 et al. 2008).

Finally, the estimates of macrofauna biomass across the RSA generally showed a large standing-stock of macrofauna biomass within the FRE. Within Roberts Bank, similar levels of total macrofauna biomass were found in the areas directly adjacent to the LSA and within the LSA itself. Comparisons of total biomass between Roberts Bank and the rest of the FRE found similar levels of biomass in both Boundary Bay and Sturgeon Bank. Because areas outside of the LSA are not expected to experience With Project changes, there should be further capacity within the RSA to accommodate With Project changes if changes within the LSA result in a biomass decline.

5.2 Expanded Discussion

5.2.1 Foraging Opportunity as a Topology

Foraging opportunity was visualised as a topology surface, with safety and biomass density making up the axes with the topology height representing the amount of available biomass for a combination of safety and biomass density. Safety from raptor predation was measured as the distance to the nearest shoreline (natural shoreline or the Roberts Bank causeway) and can be viewed as the inverse of predation risk, which is known to increase for shorebirds with proximity to shoreline cover (Dekker and Ydenberg 2004, Pomeroy 2006). Higher biomass density can represent a more efficient and profitable feeding environment. The measure of available biomass measures the total biomass, corrected for both tidal exposure and total area.

Measuring the topology height in terms of available biomass, rather than biomass (i.e., biomass density adjusted for area) was consistent with the concept of foraging opportunity. While the consumption biomass is important, the availability of the area may also impact foraging decisions. For example, if two areas under comparison are of similar size and possess similar average biomass densities, the total macrofauna biomass between the two areas would also be similar. However, if the positioning on the mud flat was such that one area was exposed more often than the other, this area could represent more foraging opportunity to dunlin. By including tidal exposure in the measure of available biomass these types of scenarios could be distinguished. Using biomass, rather than biomass density, is another important distinction. While high biomass density may be important in terms of foraging efficiency, if the total area is small, then the total amount resources available to dunlin will also be small. By expanding biomass density by the corresponding area a more relevant measure of the resources was presented.

Interpretation of a foraging opportunity topology is also relatively straightforward, but nuanced. An area that had the highest safety, highest biomass density, and highest available biomass can easily be interpreted as having the highest foraging opportunity. Similarly, an area that had the lowest safety, lowest biomass density, and lowest available biomass would represent the lowest foraging opportunity. For areas with intermediate values of safety, biomass density, and available biomass the opportunity ranking is less clear as there are clear trade-offs between predation risks, feeding efficiency and total available resources. These types of trade-offs represent an individual based decision that may be mitigated by a number of factors specific to an individual (e.g., risk tolerance). Summarising foraging opportunity as a single value would require explicit assumptions to be made about these kinds of trade-offs. Because different individuals or different groups of individuals may make fundamentally different decisions about these types of trade-offs, making such explicit assumptions is problematic. By viewing opportunity as a topology surface rather than a single summary value, such explicit assumptions were avoided.

This approach deviates slightly from the Shorebird and Biofilm TAG interpretation of safety, which recommended using a weighting to represent site safety. Safety is generally known to be an important modifier of shorebird behaviour during the migration period (Lank et al. 2003, Dekker and Ydenberg 2004, Pomeroy 2006, Pomeroy et al. 2008). However, using a weighting implies a quantitative assessment of predation risk exists, and is robust and uniform for all individuals. This is somewhat in contrast to current knowledge for shorebirds, which views risk tolerance to potential predation as variable between individual shorebirds and is dependent on a variety of factors (Burns and Ydenberg 2002, Lank and Ydenberg 2003, Lank et al. 2003, Dekker and Ydenberg 2004, Pomeroy 2006, Pomeroy et al. 2008, van den Hout et al. 2010). The visualisation approach allowed the general relationship between food and safety to be explored without the difficulty of trying to create a single definable safety relationship. Also avoided was the requirement to explicitly define how food and safety interact to define foraging opportunity. These components will likely interact dynamically, based on individual shorebird condition and risk tolerance, rather than a single constant and definable relationship. The only quantitative assessment made about foraging opportunity, was the location of the topology peak defined as the combination of site safety and biomass density associated with the highest available biomass.

5.3 DATA GAPS AND LIMITATIONS

With Project abundance predictions were dependent on the accuracy of predicted geomorphology changes, the quality of estimated correlational relationships, and the estimated spatial error structure. The biological accuracy of With Project predictions therefore depends on all three components being accurate and robust.

Geomorphology changes were assessed by using percentile summaries of the geomorphology modelling data, which was highly detailed both temporally and spatially (see Northwest Hydraulic Consultants Ltd. 2014). Accuracy of predicted project changes will therefore be a function of the accuracy of the geomorphology modelling data and the choice of percentiles used to summarize the data. The model used to generate the geomorphology modelling data was explicitly designed for making predictions about changes to coastal geomorphology, contained multiple data sources, and underwent extensive verification and validation. A suite of percentile summaries were assessed and screened for descriptive strength and consistency of associations before inclusion into the biomass predictive models. Taken together, both components represent the best knowledge available for representing future hydrological changes.

The current study provided estimates of winter macrofauna biomass across the entirety of the LSA as well as the RSA. As such these estimates rely on sufficient temporal and spatial sampling. The majority of the sampling program (642 out of 844 total samples) was performed in the spring and summer periods of 2012 and 2013, with the majority of winter samples occurring in the winter of 2014 (188 out of 202). The models made use of all available samples to train correlational relationships, by making some allowances for yearly and seasonal changes. While the model explicitly considered the extreme Fraser River freshet event of 2012 (a 1-in-25 year event), similar temporal allowances were not made for winter estimates due to a lack of temporal winter sampling. Due to the heavy winter sampling within 2014, these results rely on 2014 being a representative year for winter seasonal effects.

Spatially, model estimates also were produced for all grid cells out to the zero tide line, while the sampling program only covered areas within roughly three kilometers of the shoreline. The exact extent of coverage also varied by study stratum, as the distance to the zero tide line also varied by study stratum. Predictions outside the spatial extent of sampling relied heavily on regression relationship compared to predictions within the spatial extent of sampling. Within the spatial extent of sampling predictions are influenced by the regression relationship and estimates of the of spatial error process (i.e., deviations between the observation and regression predictions). Outside the spatial extent of sampling there is a lack of information about potential deviations from the regression trend. As such, confidence in the biological accuracy of predictions outside the spatial extent of sampling will be lower. This lower confidence will be captured to some degree in the statistical confidence intervals around With Project changes, but cannot account for potential fundamental deviations from the regression relationship that may also occur in these areas. No data was available to assess such possibilities.

The descriptive ability of the biomass density model was found to be quite low in the LSA, but higher for the RSA. A low descriptive power, in itself, does not bias biomass estimates, but does contribute to the large confidence intervals associated with estimates of With Project change. A number of factors may contribute to the low descriptive ability of the model. If available descriptive variables do not adequately describe the response variable (i.e., macrofauna density), then the descriptive power will be low. Spatial sampling resolution can further play a role depending on how the target variable is distributed.

Macrofauna biomass variability is known to be highest at relatively short distances within the Fraser River estuary (e.g., 10m to 100m, Sewell and Elner 2001). These distances also correspond to the typical sampling distance within the LSA, providing an additional explanatory factor for the low reported descriptive ability of the LSA model. The spacing of samples in areas outside the LSA tended to occur at larger spatial intervals, which is consistent with the higher descriptive ability reported by the RSA model. A sampling scheme that was more spaced out within the LSA would have likely resulted in a model with a higher reported descriptive ability. This improvement, however, would not necessarily imply increased biologically accuracy. Similarly, sampling schemes that relied on averaging subsamples taken at the 10m to 100m level could also result in higher reported descriptive ability, but again would not necessarily imply higher biological accuracy.

6.0 CLOSURE

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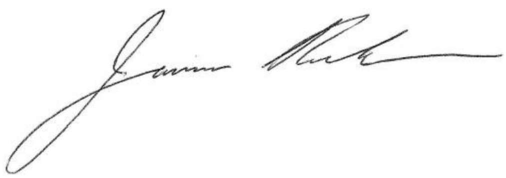

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8.0 STATEMENT OF LIMITATIONS

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

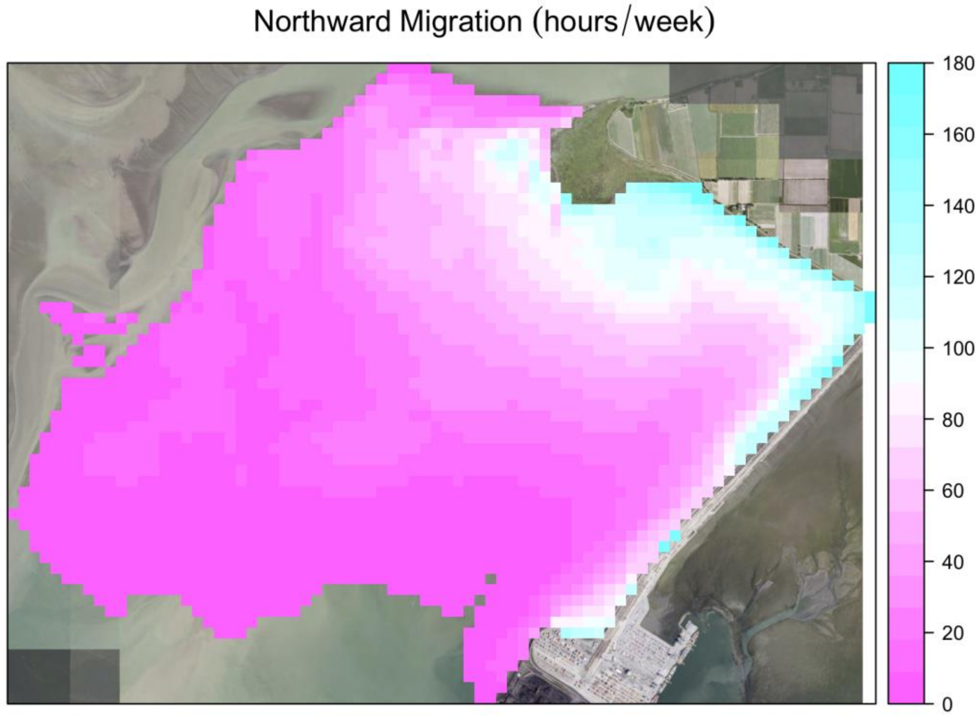
LGL and Hemmera have performed the work as described above and made the findings and conclusions set out in this Report in a manner consistent with the level of care and skill normally exercised by members of the environmental science profession practicing under similar conditions at the time the work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

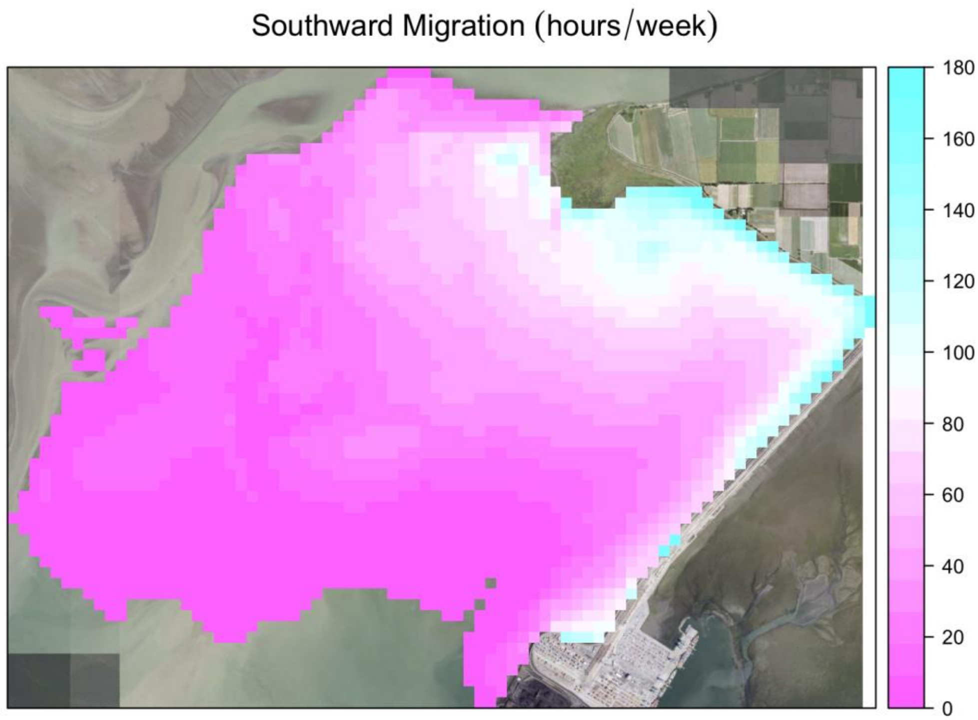
This Report represents a reasonable review of the information available to LGL and Hemmera within the established Scope, work schedule and budgetary constraints. The conclusions and recommendations contained in this Report are based upon applicable legislation existing at the time the Report was drafted.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

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

APPENDIX A
Figures

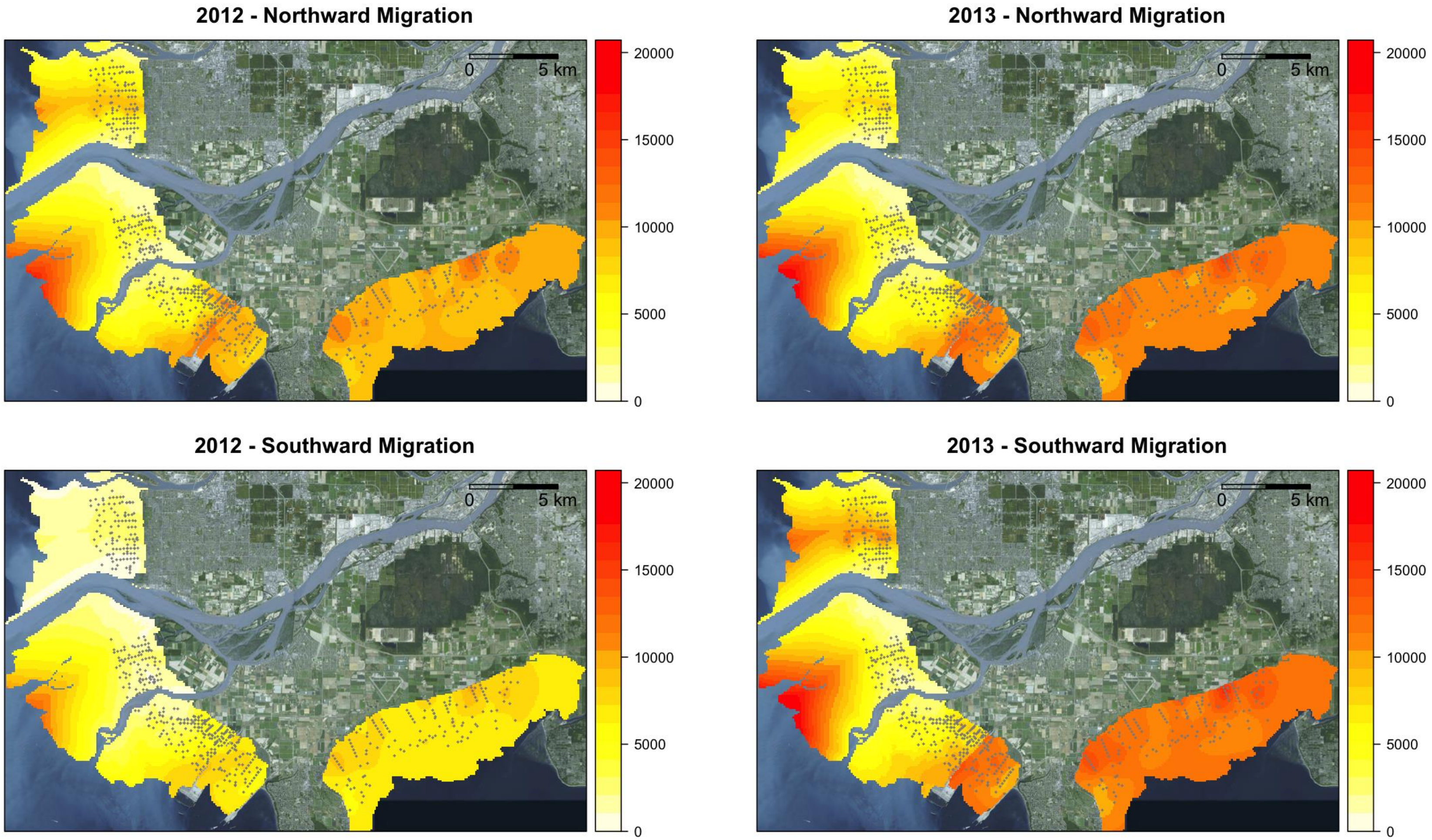
Figure 12 Local Study Area Site Availability during the Winter Period





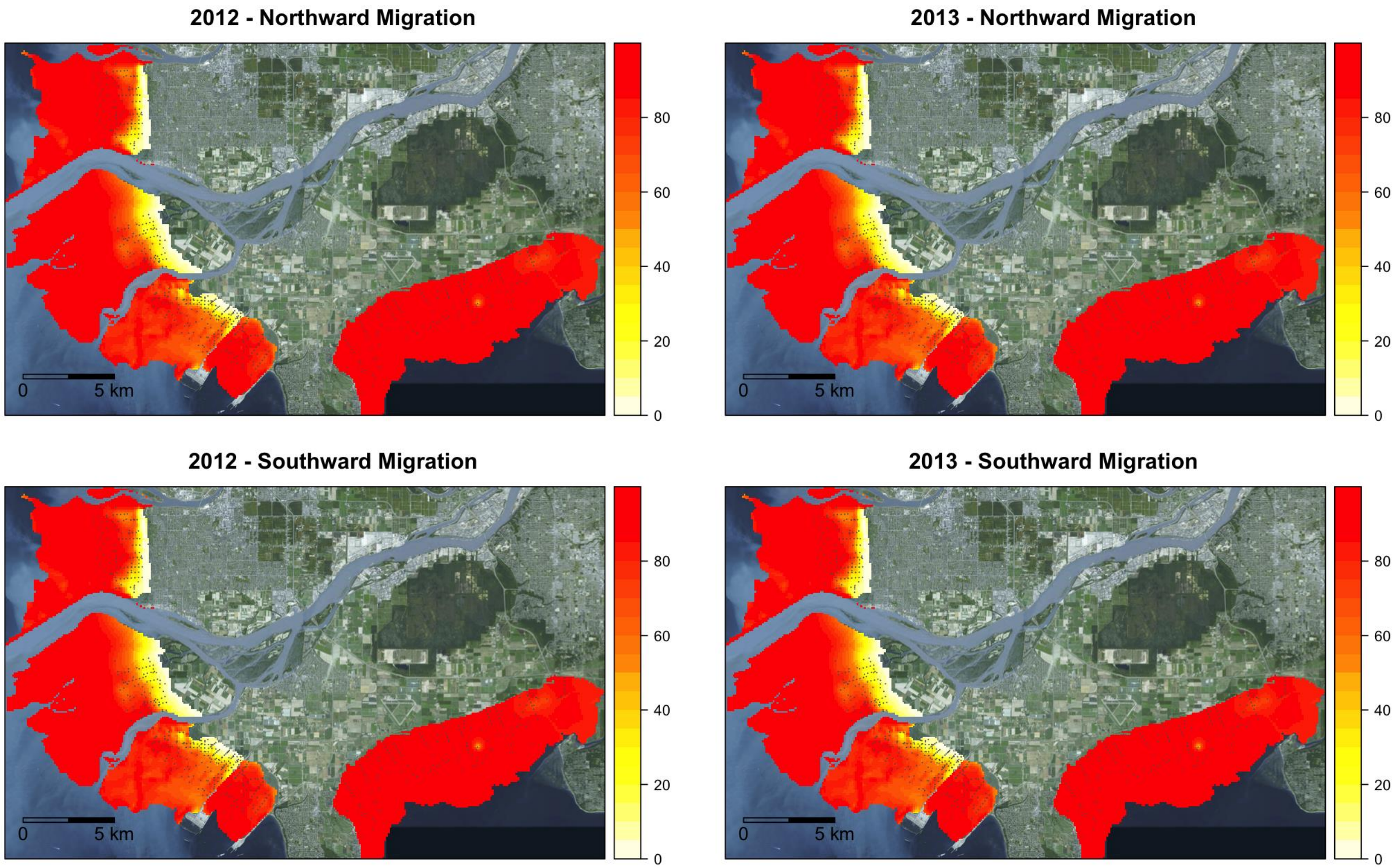
Note: Site availability for each 1-ha grid cell was determined based on minute-to-minute tidal height predictions and site elevation, which was determined, based on Lidar surveys performed in 2012 and 2013.

Figure 13 Predicted Adjusted Sediment Chloride Concentration (mg/kg) across the Regional Study Area during the 2012 and 2013 Spring (Northward) and Summer (Southward) Migration Periods



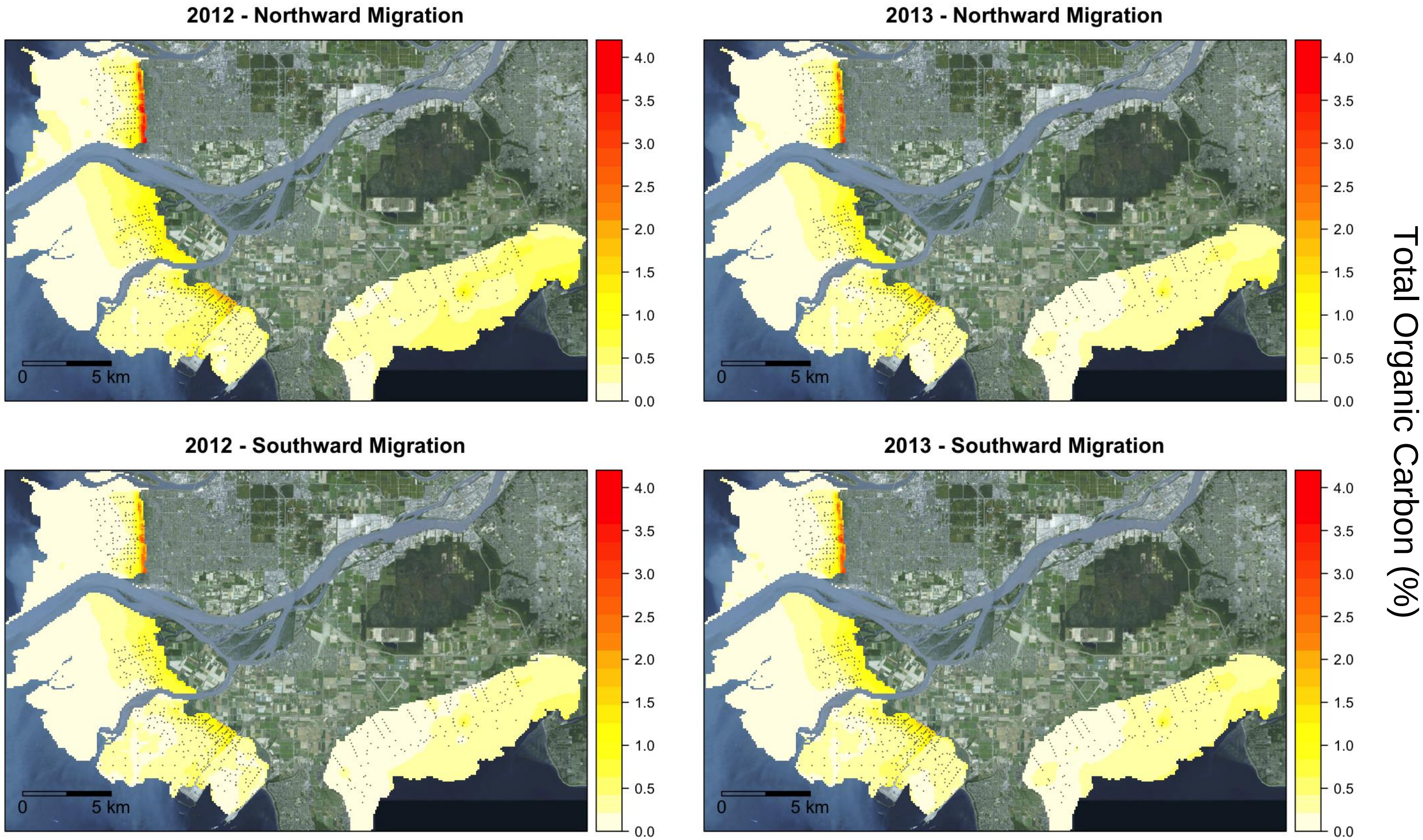
Note: A regression-kriging was fit to log transformed adjusted sediment chloride values. Leave-one-out cross validation indicated that the model explained 74.2% variability in the response. Summer (i.e., southward migration) estimates were considered for the over-wintering abundance models.

Figure 14 Predicted Percent Sand (0.63-2.0mm) across the Regional Study Area during the 2012 and 2013 Spring (Northward) and Summer (Southward) Migration Periods



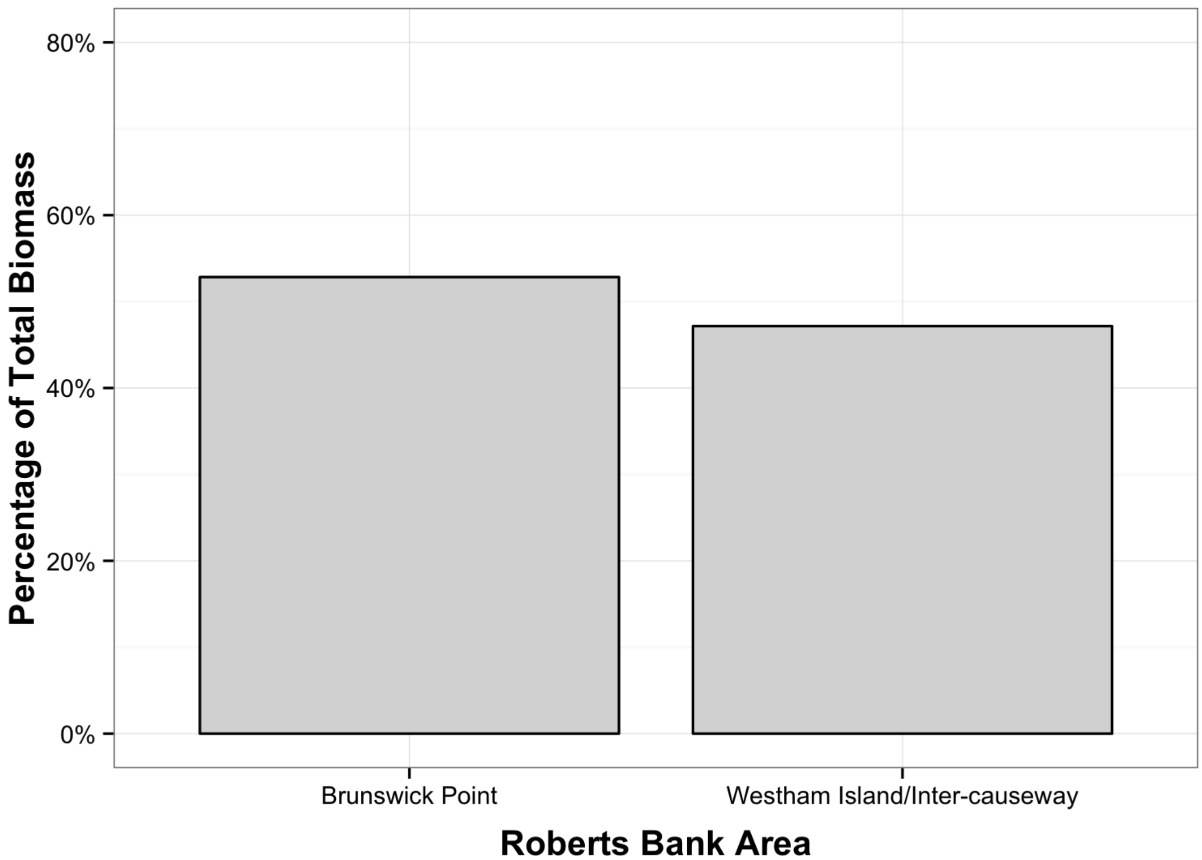
Note: A regression-kriging was fit to a logit transformed of proportion sand values (0.063-2.0mm). Leave-one-out cross validation indicated that the model explained 79.7% variability in the response. Summer (i.e., southward migration) estimates were used for the over-wintering abundance models.

Figure 15 Predicted Adjusted Total Organic Carbon (%) across the Regional Study Area during the 2012 and 2013 Spring (Northward) and Summer (Southward) Migration Periods



Note: A regression-kriging was fit to a logit transformed of total organic carbon values (proportion). Leave-one-out cross validation indicated that the model explained 88.6% variability in the response. Summer (i.e., southward migration) estimates were considered for the over-wintering abundance models.

Figure 16 Summary of Roberts Bank Total Macrofauna Biomass during the Winter Period



APPENDIX B
Tables

Table 7 Regional Study Area Adjusted Sediment Chloride Concentration (mg/kg) Regression Model Parameters, Role and Applied Transformations

Model Parameter	Type	Transformation	Description / Interpretation
Log Sediment Chloride	Response	Natural Log	Natural log transformed adjusted sediment chloride values (mg/m^2). Regression model predicts changes in terms of orders of magnitude. Sediment chloride values were adjusted for sample interstitial water content and should represent biologically available chloride anions.
Stratum	Explanatory	None	Categorical variable accounting for differences between study strata.
Year:Season	Explanatory	None	Categorical variable accounting for differences between sampling sessions that occurred once within each season within each year (see **Table 3** for sampling efforts).
BP: Seasonal Salinity	Explanatory	None	Seasonal 50th percentile of the geomorphology water column salinity modeling value within the Brunswick Point stratum. Median salinity predicts log sediment chloride concentration within Brunswick Point.
SB:Seasonal Salinity	Explanatory	None	Seasonal 50th percentile of the geomorphology water column salinity modeling value within the Sturgeon Bank stratum. Median salinity predicts log sediment chloride concentration within Sturgeon Bank.
SB:C1FWDist	Explanatory	Square root	Square root transformed distance to the nearest Class 1 freshwater source (i.e., average stream width > 200m) within Sturgeon Bank. Square root distance predicts log sediment chloride concentration within Sturgeon Bank.
IC:C3FWDist	Explanatory	Square root	Square root transformed distance to the nearest Class 3 freshwater source (i.e., average stream width < 40m) within the Inter-causeway stratum. Square root distance predicts log sediment chloride concentration within the Inter-causeway.
SB:MarshDist	Explanatory	Square root	Square root transformed distance to the nearest seasonal marsh within Sturgeon Bank. Based on spring and summer marsh lines from the TRIM dataset. Square root distance predicts log sediment chloride concentration within Sturgeon Bank.
WI:MarshDist	Explanatory	Square root	Square root transformed distance to the nearest seasonal marsh predicts log sediment chloride concentration within Westham Island. Marsh line based on spring and summer marsh lines from the TRIM dataset.

Table 8 Regional Study Area Sediment Texture Regression Model Parameters, Role and Applied Transformations

Model Parameter	Type	Transformation	Description / Interpretation
Logit Sediment Texture	Response	Logit	Logit transformation of the proportion of sand (0.063 to 2.0 mm sand) in the sample. Regression model predicts changes in terms of orders of magnitude. Logit transformations are common for measures that saturate.
Stratum	Explanatory	None	Categorical variable accounting for differences between study strata.
SB:BedVelocity	Explanatory	Square root	90^{th} percentile of the geomorphology bed velocity modeling values computed over the May to July period within Sturgeon Bank. Extreme bed velocity events predict sediment texture in the Sturgeon Bank stratum.
BP: BedVelocity	Explanatory	Square root	90^{th} percentile of the geomorphology bed velocity modeling values computed over the May to July period within Brunswick Point. Extreme bed velocity events predict sediment texture in the Brunswick Point stratum.
IC: BedVelocity	Explanatory	Square root	90^{th} percentile of the geomorphology bed velocity modeling values computed over the May to July period within the Inter-causeway. Extreme bed velocity events predict sediment texture in the Inter-causeway stratum.
BB: BedVelocity	Explanatory	Square root	90^{th} percentile of the geomorphology bed velocity modeling values computed over the May to July period within Boundary Bay. Extreme bed velocity events predict sediment texture in the Boundary Bay stratum.
WI:ShoreDist	Explanatory	Square root	Square root transformed distance to the natural shoreline within Westham Island. Square root distance predicts sediment texture in the Sturgeon Bank stratum.
BB:ShoreDist	Explanatory	Square root	Square root transformed distance to the natural shoreline within Boundary Bay. Square root distance predicts sediment texture in the Boundary Bay stratum.
BB:C2FWDist	Explanatory	Square root	Square root transformed distance to the nearest Class 2 freshwater source (i.e., average stream width > 40m and < 200 m) within Boundary Bay. Square root transformed distance predicts sediment texture in a parabolic function (inverted-U) indicating an optimal distance.
BB:C2FWDist2	Explanatory	Square root & squared	

Table 9 Regional Study Area Total Organic Carbon Regression Model Parameters, Role and Applied Transformations

Model Parameter	Type	Transformation	Description / Interpretation
Logit TOC	Response	Logit	Logit transformation of the total organic carbon (TOC) proportion in the sample. Regression model predicts changes in terms of orders of magnitude. Logit transformations are common for measures that saturate.
Stratum	Explanatory	None	Categorical variable accounting for differences between study strata.
Year:Season	Explanatory	None	Categorical variable accounting for differences between sampling sessions that occurred once within each season within each year (see **Table 3** for sampling efforts).
Stratum:Logit SandTexture	Explanatory	Logit	Logit transformation of sediment texture (proportion 0.063 to 2.0mm sand). Sediment texture predicts total organic carbon in a parabolic function (inverted-U) indicating an optimal sediment texture for TOC.
Stratum:Logit SandTexture^2	Explanatory	Logit and square	
Stratum:ShoreDist	Explanatory	Square root	Square root transformed distance to the natural shoreline within each stratum. Square root distance predicts total organic carbon separately within each study stratum.
MarshDist	Explanatory	Square root	Square root transformed distance to the nearest seasonal marsh. Based on spring and summer marsh lines from the TRIM dataset. Square root distance to the natural shoreline predicts total organic carbon within all study stratum.

Table 10 Estimated Percent Change in Total Available Macrofauna Biomass between Existing and With Project conditions during the Winter Period with only Wave Height Changes

Area	Estimate	Lower CI	Upper CI
Canoe Passage	13.1%	-51.0%	115.2%
Intertidal Zone	5.9%	-39.6%	69.9%
All Areas Combined	6.7%	-39.6%	73.1%

Note: Percent change takes into consideration the change in total abundance (g) by expanding the estimated abundance (mg/m^2) by the total area. Availability due to the tidal cycle was not considered. Estimates are provided for the LSA as well as for Canoe Passage and the Intertidal Zone (see **Figure 3**).

Table 11 Estimated Percent Change in Total Macrofauna Biomass between Existing and With Project conditions during the Winter Period with only Water Column Salinity Changes

Area	Estimate	Lower CI	Upper CI
Canoe Passage	8.3%	-49.1%	118.7%
Intertidal Zone	7.2%	-42.1%	86.5%
All Areas Combined	6.3%	-41.1%	81.9%

Note: Percent change takes into consideration the change in total abundance (g) by expanding the estimated abundance (mg/m^2) by the total area. Availability due to the tidal cycle was not considered. Estimates are provided for the LSA as well as for Canoe Passage and the Intertidal Zone (see **Figure 3**).

Table 12 Total Available Macrofauna Abundance (g x hr) for Canoe Passage and the Intertidal Zone during the Overwintering Period

Season	Zone	Total Available Biomass (g x hr)	Ratio
Winter	Canoe Passage	7.7E+09	0.38
	Intertidal Zone	2.0E+10	1.00

APPENDIX 15-D

Assessment of Changes to Predation Risk to Shorebirds

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ROBERTS BANK TERMINAL 2

Appendix 15-D

Assessment of Changes to Predation Risk to Shorebirds

Prepared for:
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Prepared by:
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File: 302-042.02
March, 2014

EXECUTIVE SUMMARY

The Assessment of Changes of Predation Risk to Shorebirds Study was conducted as part of an environmental program for the proposed Roberts Bank Terminal 2 Project (Project or RBT2). The Project, part of Port Metro Vancouver's Container Capacity Improvement Program, is a proposed new three-berth marine container terminal located at Roberts Bank in Delta, B.C.

Port Metro Vancouver (PMV) has retained Hemmera to undertake environmental studies related to the Project. As part of these studies, Dr. Dick Dekker has conducted an assessment of the potential for Project-related effects to influence the predation risk to shorebirds.

Two field visits were conducted in August 2013 to collect data and make field observations on the current site conditions. The use of the study area by shorebirds and avian predators (e.g., falcons) was documented and their interactions were noted. Data and observations collected during these field visits, detailed Project design schematics made available by PMV, and available information on predation risk to shorebirds were used to assess the potential effects that the proposed Project may have on predation risk to shorebirds in the Roberts Bank area.

Based on site visits to the area and the comparative analysis of scientific literature on falcon/shorebird interactions for the region's intertidal zone, construction of RBT2 is not predicted to have a major negative impact on the predator/shorebird dynamics of coastal habitats in the study area.

TABLE OF CONTENTS

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1.0 INTRODUCTION

This section provides an overview of the study including project background and rationale for the study being conducted, study components, and major objectives.

1.1 PROJECT BACKGROUND

The Roberts Bank Terminal 2 Project (RBT2 or Project) is a proposed new three-berth marine terminal at Roberts Bank in Delta, B.C. that could provide 2.4 million TEUs (twenty-foot equivalent unit containers) of additional container capacity annually. The Project is part of Port Metro Vancouver's Container Capacity Improvement Program, a long-term strategy to deliver projects to meet anticipated growth in demand for container capacity to 2030.

Port Metro Vancouver (PMV), through its association with Hemmera, has retained the author of this report to undertake environmental studies to understand the possible effects of the Project on predation risk to shorebirds staging or wintering within the study area. The results of the assessment of potential changes of predation risk to shorebirds using the local intertidal mudflats during migration and wintering seasons are described in this report.

1.2 STUDY OVERVIEW

A review of available information and state of knowledge was completed to assess potential changes of predation risk to shorebirds within the general RBT2 area. Study findings for key components and major objectives are described, and a brief overview of the methodology is provided in **Table 1**.

Table 1 Predation Risk to Shorebirds Study Components and Major Objectives

Component	Major Objective	Brief Overview
1) Literature Review	• Establish current state of knowledge regarding predation risk to shorebirds in the Fraser River estuary.	• A review of available literature on falcon / shorebird interactions was conducted.
2) Field Visits	• Collect data and make field observations on the existing conditions in the study area to inform desk top review.	• Two field visits were conducted in August 2013.
3) Desktop Analysis	• Evaluate field data and review Project design drawings to assess Project-related changes of predation risk to shorebirds.	• Field data, Project design drawings, and professional knowledge of raptor / shorebird interactions were used to assess shorebird predation risk and site changes to safety within the study area.

A review of published literature concerning falcon-shorebird interactions and site visits, were the basis for determining current site safety conditions and assessing potential changes to the avian dynamics of the study area. Recent field research has shown that shorebirds select feeding and resting sites not only on the basis of food availability, but also on a site's safety from predators, primarily peregrine falcon (*Falco peregrinus*) and merlin (*Falco columbarius*) (Dekker 1998). Consequently, safety attributes may be as important as food availability in determining a site's overall quality. Roberts Bank is a foraging site for migrating and wintering shorebirds (Vermeer et al. 1994). Peregrine falcons are common and play a significant role in influencing shorebird feeding and roosting habits (Lank et al. 2003, Pomeroy et al. 2006, Ydenberg et al 2010, Dekker 2013). The construction of RBT2 could alter the level of predation risk to staging shorebirds in the intertidal zone near the site by confining shorebirds to areas that are safe from predation, but less rich in food resources, or alternately, by providing perching structures that favour falcons, allowing them to prey on shorebirds at close range. An elevated level of predation risk at certain sites has been shown to result in significantly higher kill rates of shorebirds (Dekker 2013). The primary factor correlated with increased predation danger is the distance a shorebird feeding or roosting site is to a visual obstruction (e.g., shoreline vegetation, a causeway, or a terminal) (Pomeroy et al. 2006). Safer sites are well away from obstacles that falcons might use to hide their approach and surprise their prey (Dekker and Ydenberg 2004).

This report investigates whether or not the construction of RBT2 will alter predation risk for shorebirds at Roberts Bank, and assesses modifications to the landscape that could result in changes in falcon hunting strategies and shorebird usage of areas proximal to the Project.

2.0 REVIEW OF AVAILABLE LITERATURE

The rich avian inventory of the Fraser River estuary (FRE) has been studied by ornithologists from Environment Canada (EC) over the last 25 years (Butler and Campbell 1987, Butler and Canning 1989, Butler and Vermeer 1994). The distribution and abundance of shorebirds frequenting the FRE continue to be monitored by the Canadian Wildlife Service (Drever et al. 2014). The intertidal mudflats on either side of the Roberts Bank terminals are important to migratory sandpipers and plovers on their way to and from sub-arctic nesting grounds (Fernandez et al. 2010). The most abundant shorebird species, the western sandpiper (*Calidris mauri*), has been estimated to exceed 100,000 birds per day at Roberts Bank during spring and late summer migrations (Drever et al. 2014). Wintering dunlin (*Calidris alpina*) reach peak numbers of about 50,000 (Butler and Campbell 1987, Shepherd and Lank 2004).

Peregrine falcons are a component of avian communities in many open wetland habitats (Palmer 1988, White et al. 2002), including the FRE. Near the middle of the twentieth century, falcons suffered a steep decline due to lethal and sub-lethal effects of industrial chemicals used in agriculture (Hickey and Anderson 1968, Hickey 1969), and local extirpation was observed along coastlines of North America (Palmer 1988). While little is known about falcon distribution along the Pacific coast of B.C. prior to the 1960s, it made a strong recovery in the 1980s after pesticides such as dichlorodiphenyltrichloroethane (DDT) were banned (Cade and Burnham 2003). From 1980 onward, intensive investigations of peregrines wintering in B.C. were conducted by Dekker (1995, 1998, 2003) and Dekker et al. (2012).

To mitigate risk associated with a more abundant predator community, shorebirds such as dunlin have responded to the return of the peregrine falcon with subtle changes in mass and wing measurements that increase their ability to escape predation (Ydenberg et al. 2010). Two further examples of response to increased predation pressures are dunlin reducing roosting on land when the intertidal zone is inundated by flooding tides (Dekker 1998, 2013) and dunlin shifting foraging locations away from areas of high predation risk (Zharikov et al. 2009). In the first instance, flocks of dunlins now remain air-borne for hours in an activity termed high-tide flight or over-ocean flocking (Dekker 1998, 2013). The objective of this anti-predator strategy is to avoid predation by falcons hunting in upland areas (Dekker and Ydenberg 2004). In the second instance, Zharikov et al. (2009) documented a shift in nocturnal feeding locations of dunlin between years in the presence of snowy owls. Areas of mudflats close to where owls were presumed to hunt were avoided by dunlin in the second year of the study when owl abundance in the area had increased. These physiological and behavioural adjustments are mechanisms used by shorebirds to mitigate predation risk. Increases in risk could change the way shorebirds utilise a site. Previously used sites with abundant resources might be abandoned if site-level falcon-shorebird predation rates are elevated.

3.0 METHODS

Descriptions for the study spatial and temporal scopes, and methodology are provided below.

3.1 STUDY AREA

The study area is at 49° 05' N, 123° 00' W, adjacent to and west of the Roberts Bank causeway (**Figure 1**). The area extends 3 km from Brunswick Point southeast along the mainland shore to the Roberts Bank causeway, and includes the intertidal zone, which at low tide is up to 4 km wide.

3.2 OBJECTIVES

The objectives of the study were to ascertain falcon presence and predatory pressure on the shorebird population within the study area, and assess whether the construction of RBT2 would change the site safety level of the intertidal mudflats adjacent to the RBT2 footprint.

3.3 STUDY METHODOLOGY

Field observations were conducted on two days in August 2013. The methods used in this study were observational and designed for minimal disturbance of resting or feeding birds. The intertidal mudflats were frequently scanned with 8x binoculars from a vehicle parked on the Tsawwassen Road Dike running parallel to the shoreline. Shorebirds were identified to species and their numbers estimated. The largest aggregations of one or more species were kept under surveillance. Alarm behaviour of the shorebirds, such as sudden flushing, often preceded the arrival of peregrines or merlins. Flying falcons were followed in the binoculars for as long as possible in the hope of seeing them attack shorebirds. In addition, prominent poles and trees along the water were monitored for perching falcons. This hands-off methodology is similar to the methods used in long-term field studies conducted at Boundary Bay between 1994 and 2013, which collectively have resulted in the largest published sample of peregrine attacks and their success rates on shorebirds ever assembled (Dekker 2013). Long-term experience gained in these earlier field studies was an invaluable asset in analysing the results obtained in this study.

In addition to the field observations, available RBT2 design drawings were studied to predict the potential effects that Project construction may have on the interaction between shorebirds and falcons frequenting the study area.

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Figure 1 Shorebird Predation Risk Study Area

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4.0 RESULTS

Under variable cloud cover, calm winds, and ambient temperatures of 20 to 23°C during the August 2013 surveys, the number of shorebirds in the area were estimated at 6,000 individuals, with the great majority being western sandpipers (*Calidris mauri*). About 300 black-bellied plovers (*Pluvialis squatarola*), a sub-arctic nesting shorebird known to winter on the B.C. west coast (Butler and Campbell 1987), were also observed feeding or resting on the intertidal mudflats.

Alerted by the abrupt rising of flocks of shorebirds, the observer noted 12 flying peregrine sightings. Some of these sightings included known or suspected duplicate views of the same individuals. For example, two first-year immature falcons interacting with each other, passed by several times low over the mudflats, and at least one adult falcon was also present in the study area. Adult peregrines are bluish-grey on back, wings, and tail, whereas the immatures are dorsally brown (White et al. 2002). Observations included several falcons harassing shorebirds in erratic pursuits. In one instance, an immature falcon succeeded in catching a small prey, probably a sandpiper, which was dropped again into the water when the falcon was harassed by another immature falcon.

A desktop assessment of the detailed engineering drawings of RBT2 construction plans indicates that the planned terminal and loading area will be approximately 5 km from the Brunswick shore, which is well away from and well outside the danger zone for feeding or roosting shorebirds (**Figure 2**). Moreover, the proposed widening of the causeway, from 60 m to 80 m, amounts to a relatively small loss of intertidal habitat compared to the approximately 24.5 km^2 of mudflats remaining in the RBT2 area.

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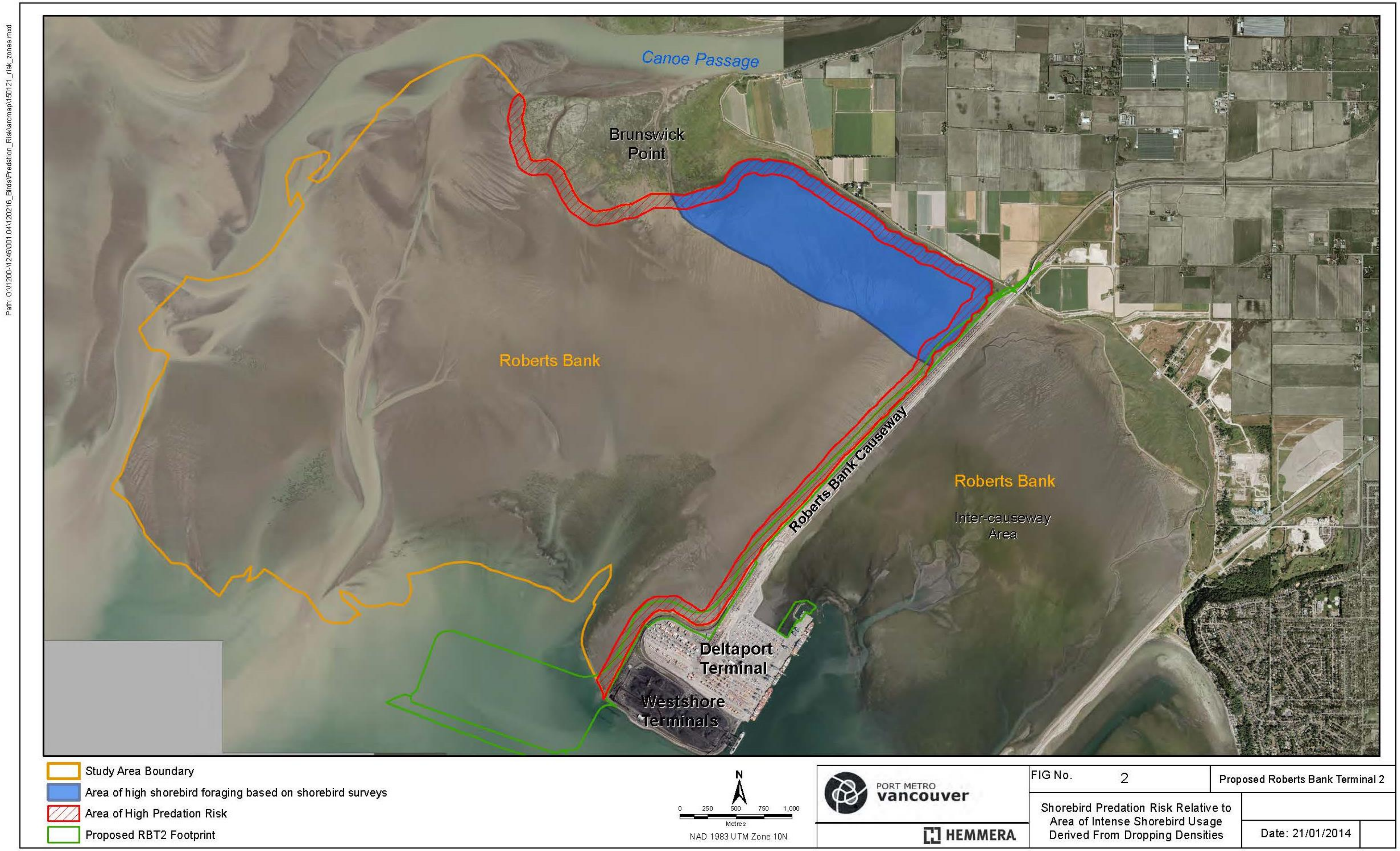
Figure 2 Areas of Highest Shorebird Predation Risk and High Shorebird Usage



Note: The polygon of high shorebird use was adapted from Hemmera 2014.

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5.0 DISCUSSION

The current study confirms that shorebirds and peregrine falcons were using the study area in what seemed to be typical numbers for the time period. There was no evidence that either the shorebirds or the falcons were attracted to, or disturbed by, the Roberts Bank causeway or existing terminals. Furthermore, based on a desk-top review of the detailed engineering drawings of RBT2 construction plans, shorebird use of the area adjacent to the proposed expanded Roberts Bank causeway (Hemmera 2014) and effects of the causeway on intertidal site-safety levels, are not expected to change much if at all. As is currently the case, predation risk for shorebirds feeding or resting 0 to 50 m from the edge of an expanded Roberts Bank causeway can be expected to remain higher than farther away (**Figure 2**), in particular if peregrines increase their use of the utility poles on the causeway as a convenient perch for still hunting. Scanning for vulnerable prey from high observation perches is a preferred and particularly successful hunting method of peregrine falcons worldwide (White et al. 2002). On Vancouver Island, Langara Island, and at Boundary Bay, peregrines have been observed to routinely launch foraging flights from high trees or utility poles, which give the attacking falcon a height and speed advantage over prey species on the ground or in water (Dekker 1995, 2003; Dekker and Bogaert 1997). Furthermore, prey-carrying falcons tend to use high perches as plucking posts because they allow a quick take-off when approached by kleptoparasitic bird species such as bald eagles (*Haliaeetus leucocephalus*) and other large raptors (Dekker 2003, Dekker et al. 2012).

An unknown effect of causeway expansion is whether or not flocks of shorebirds are attracted to the outer edge of the causeway as a convenient high-tide roosting site, specifically if the surface is kept free of vegetation and covered with stones. Similar use by roosting dunlin was documented for the breakwater jetties near the BC Ferries Terminal at Tsawwassen (Dekker 1998). Shorebird flocks roosting on such vulnerable spots can be expected to be targeted by falcons that can hide their attack behind the causeway.

6.0 CONCLUSION

Based on an objective interpretation of the above reported findings, professional judgement, and a desktop evaluation of the engineering drawings supplied by PMV, the proposed development of the RBT2 terminal is not predicted to have a major negative effect on shorebirds / falcon dynamics in the intertidal habitat of the study area. Shorebird predation risk under the proposed RBT2 scenario is not expected to differ greatly from current conditions.

7.0 CLOSURE

Major authors and reviewers of this technical data report are listed below, along with their signatures.

Report prepared by:
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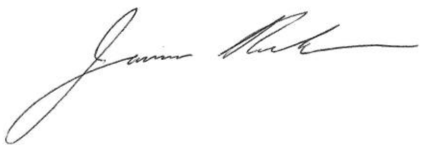
Report peer reviewed by:
Hemmera Envirochem Inc.



James Rourke, M.Sc. R.P.Bio.
Coastal Birds Discipline Lead

Report peer reviewed by:
Simon Fraser University

Ron Ydenberg, PhD.
Professor, Centre for Wildlife Ecology Director

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APPENDIX 15-E
Coastal Birds Supporting Figures

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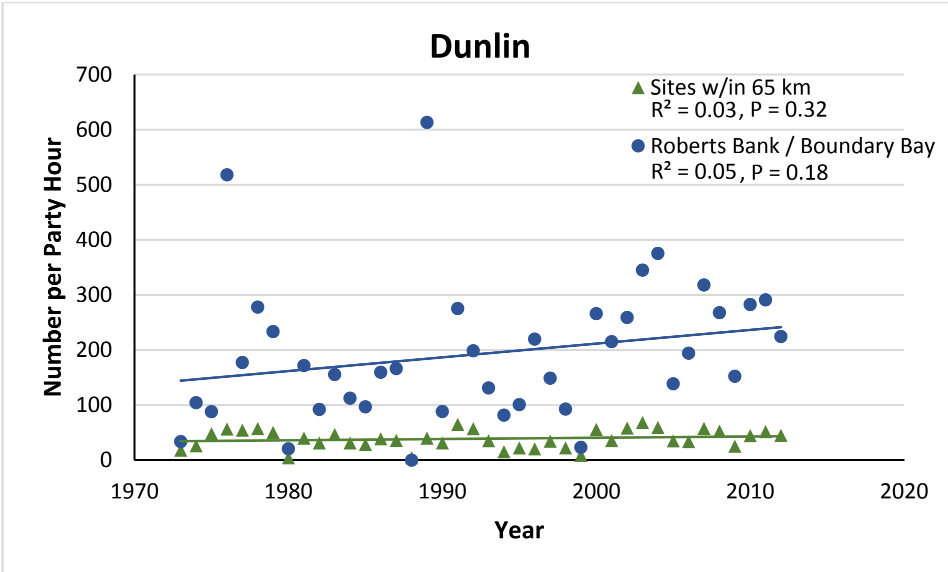
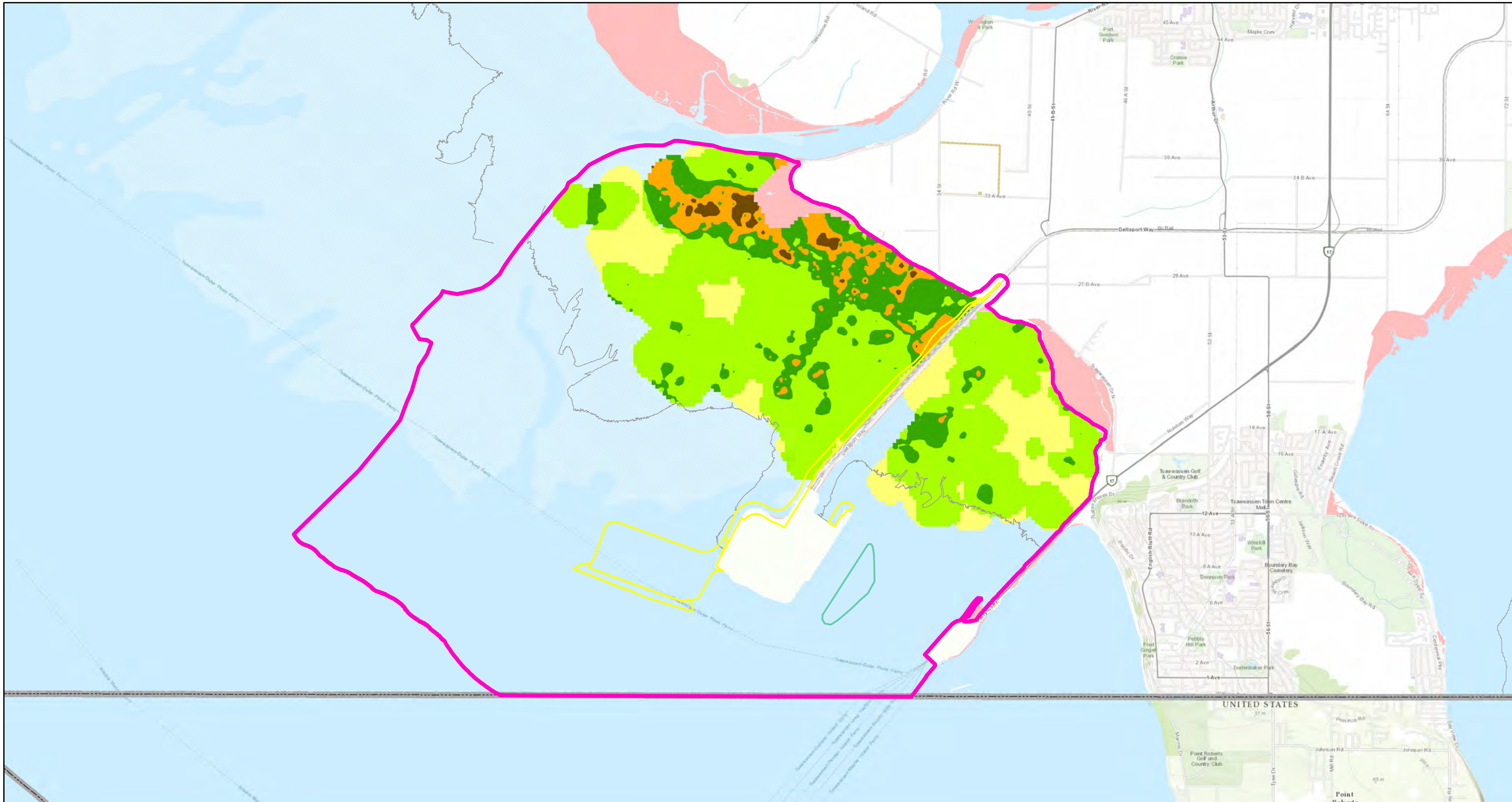
Appendix 15-E Coastal Birds Supporting Figures

List of Figures

Figure 15-E1 Number of Dunlin per Party Hour at Roberts Bank / Boundary Bay and at Sites within 65 km of Roberts Bank / Boundary Bay (n=7), from Christmas Bird Count Data. Number per Party Hour Reflects Species Abundance Adjusted for Survey Effort. Only Sites with Count Data from 1973 to 2012 were Included.





Legend

BOUNDARY OF PROJECT AREA	
INTERMEDIATE TRANSFER PIT	
COASTAL BIRDS LAA	
MARSH	
BATHYMETRY (1.3 m)	
U.S.A.-CANADA BORDER	

SHOREBIRD DROPPINGS (SMALLER THAN OR EQUAL TO A QUARTER) / 15 m^2

- 0
- 1 - 5
- 6 - 15
- 16 - 35
- > 35

0 1 2
Kilometres
1:50,000
NAD 1983 UTM Zone 10N

N

PORT METRO vancouver

ROBERTS BANK TERMINAL 2

WESTERN SANDPIPER AND DUNLIN USAGE DURING NORTHWARD MIGRATION WITHIN THE LAA (2012-2014)

DATE:	FIG No.
01/14/2015	15-E2

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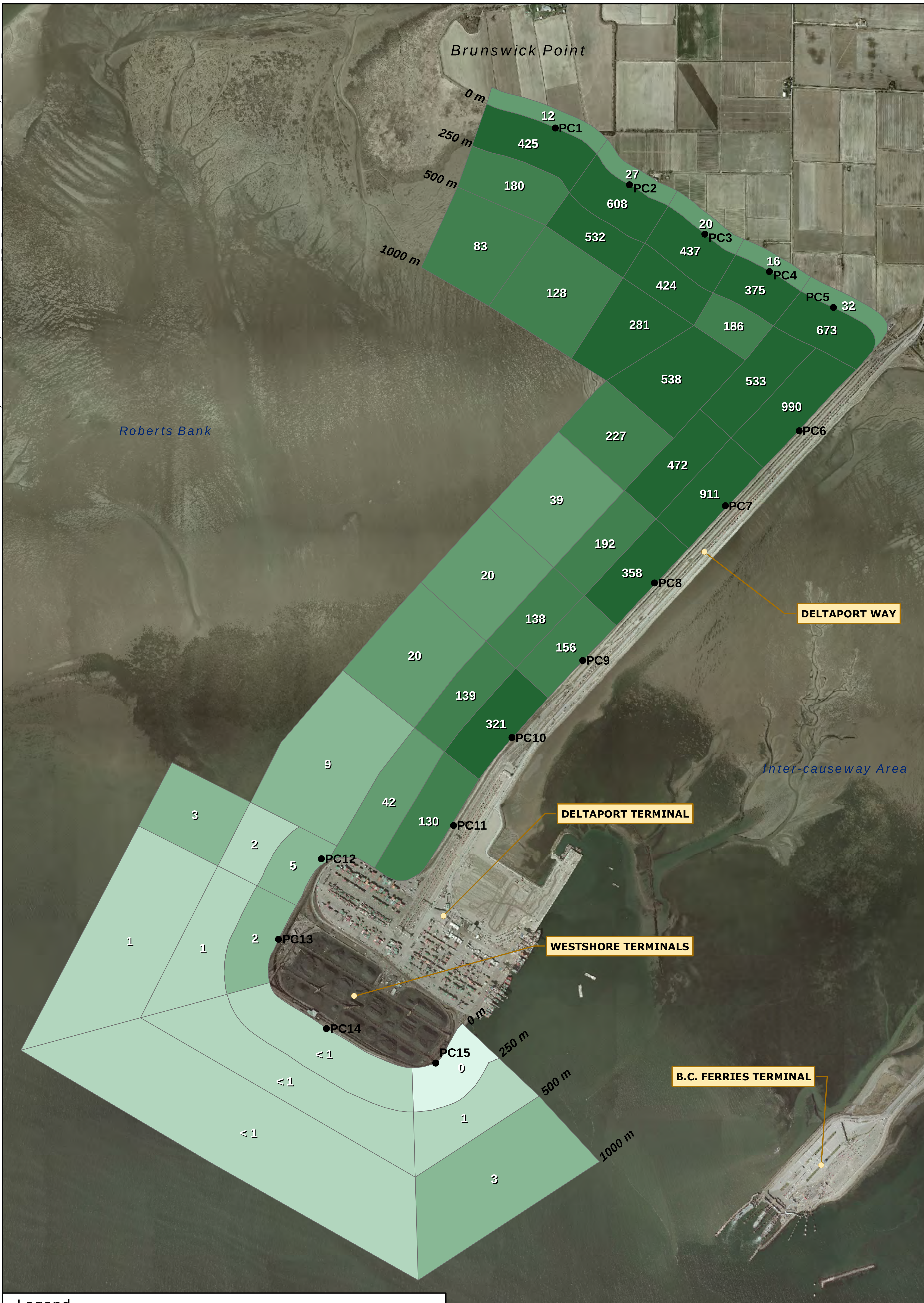


Legend

● POINT COUNT STATION

DENSITY (birds/25 ha)

- 0
- 0.01 - 2
- 2.01 - 10
- 10.01 - 50
- 50.01 - 250
- 250.01 - 1,250

N

0 500 1,000

Metres

500 m

25 ha

500 m

1:20,000

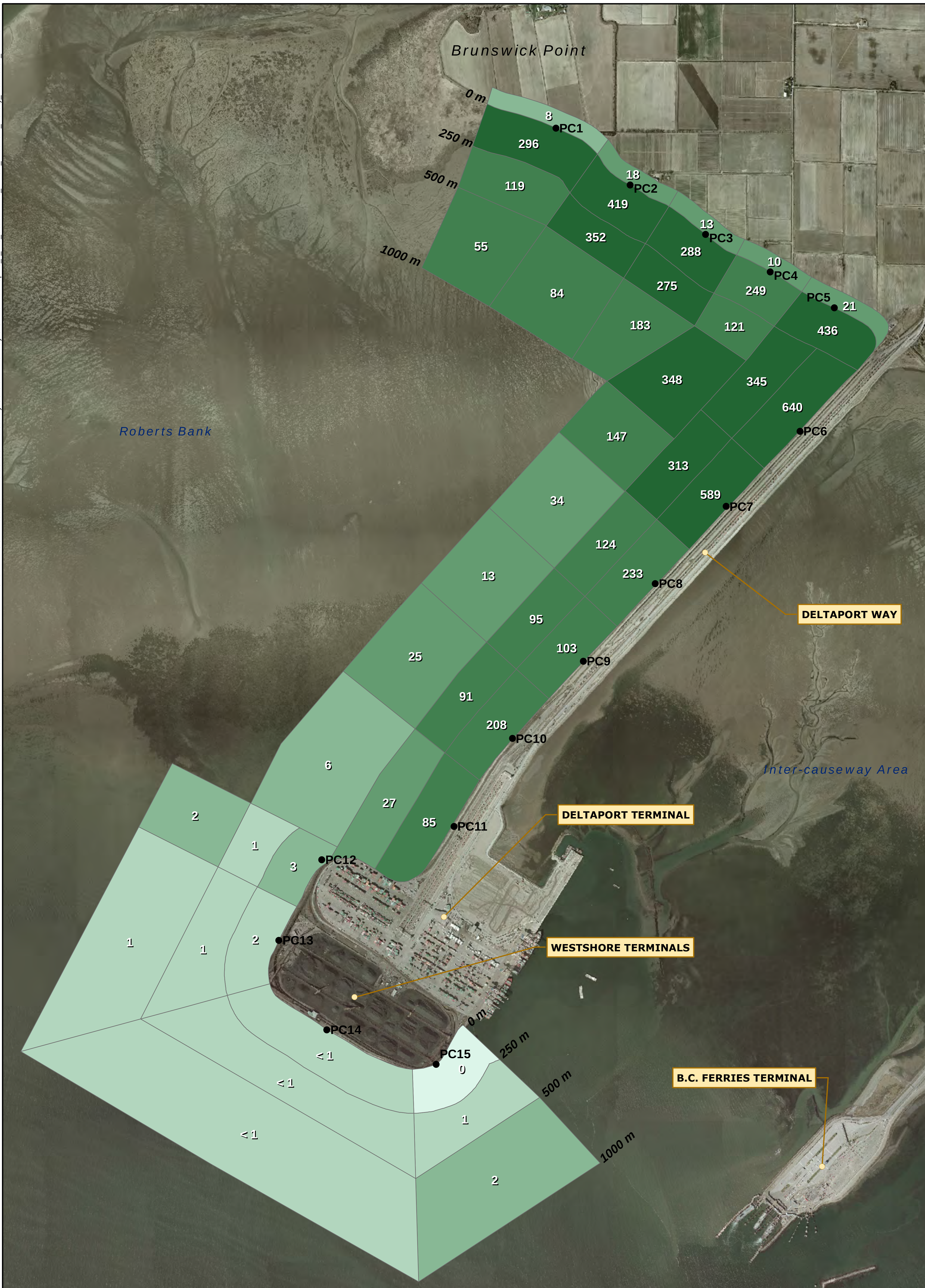
NAD 1983 UTM Zone 10N

PORT METRO vancouver

ROBERTS BANK TERMINAL 2

WINTER WATERFOWL DENSITY AND DISTRIBUTION (SEP 2012 – APR 2013)

DATE:	FIG No.
11/20/2014	15-E3



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● POINT COUNT STATION

DENSITY (birds/25 ha)

- 0
- 0.01 - 2
- 2.01 - 10
- 10.01 - 50
- 50.01 - 250
- 250.01 - 1,250

500 m × 500 m = 25 ha

N

0 500 1,000
Metres

1:20,000

NAD 1983 UTM Zone 10N

PORT METRO vancouver

ROBERTS BANK TERMINAL 2

ANNUAL WATERFOWL DENSITY AND DISTRIBUTION (MAY 2012 – MAY 2013)

DATE: 11/20/2014

FIG No. 15-E4

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Figure 15-E5 **Number of Waterfowl per Party Hour at Roberts Bank / Boundary Bay and at Sites within 65 Km of Roberts Bank / Boundary Bay (N=7), From Christmas Bird Count Data. Number per Party Hour Reflects Species Abundance Adjusted for Survey Effort. Only Sites with Count Data from 1973 to 2012 were Included.**

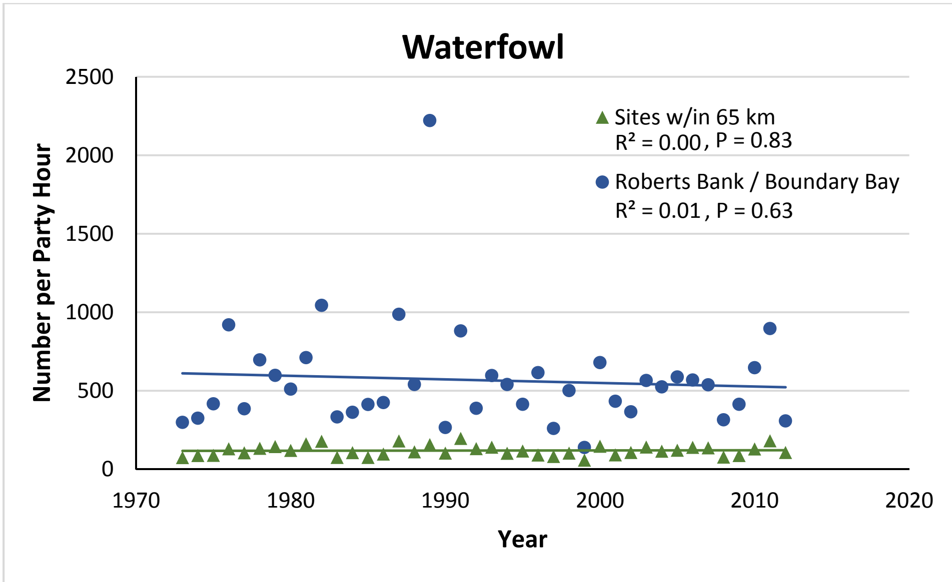
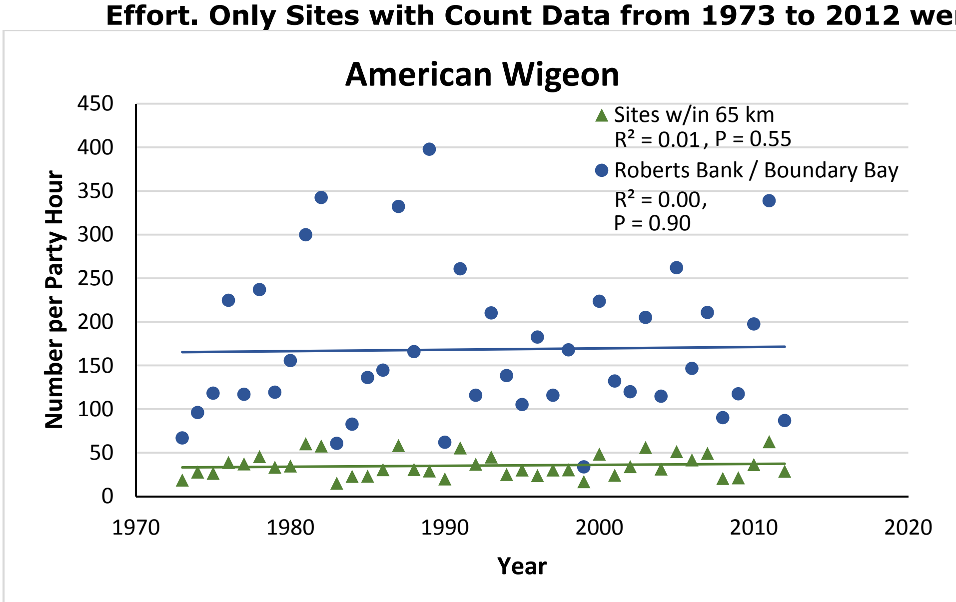


Figure 15-E6 **Number of American Wigeon per Party Hour at Roberts Bank / Boundary Bay and at Sites within 65 Km of Roberts Bank / Boundary Bay (N=7), From Christmas Bird Count Data. Number per Party Hour Reflects Species Abundance Adjusted for Survey Effort. Only Sites with Count Data from 1973 to 2012 were Included.**



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Legend

- ● POINT COUNT STATION

DENSITY (birds/25 ha)

- 0
- 0.01 - 2
- 2.01 - 10
- 10.01 - 50
- 50.01 - 250
- 250.01 - 1,250

500 m × 500 m = 25 ha

N

0 500 1,000
Metres

1:20,000

NAD 1983 UTM Zone 10N

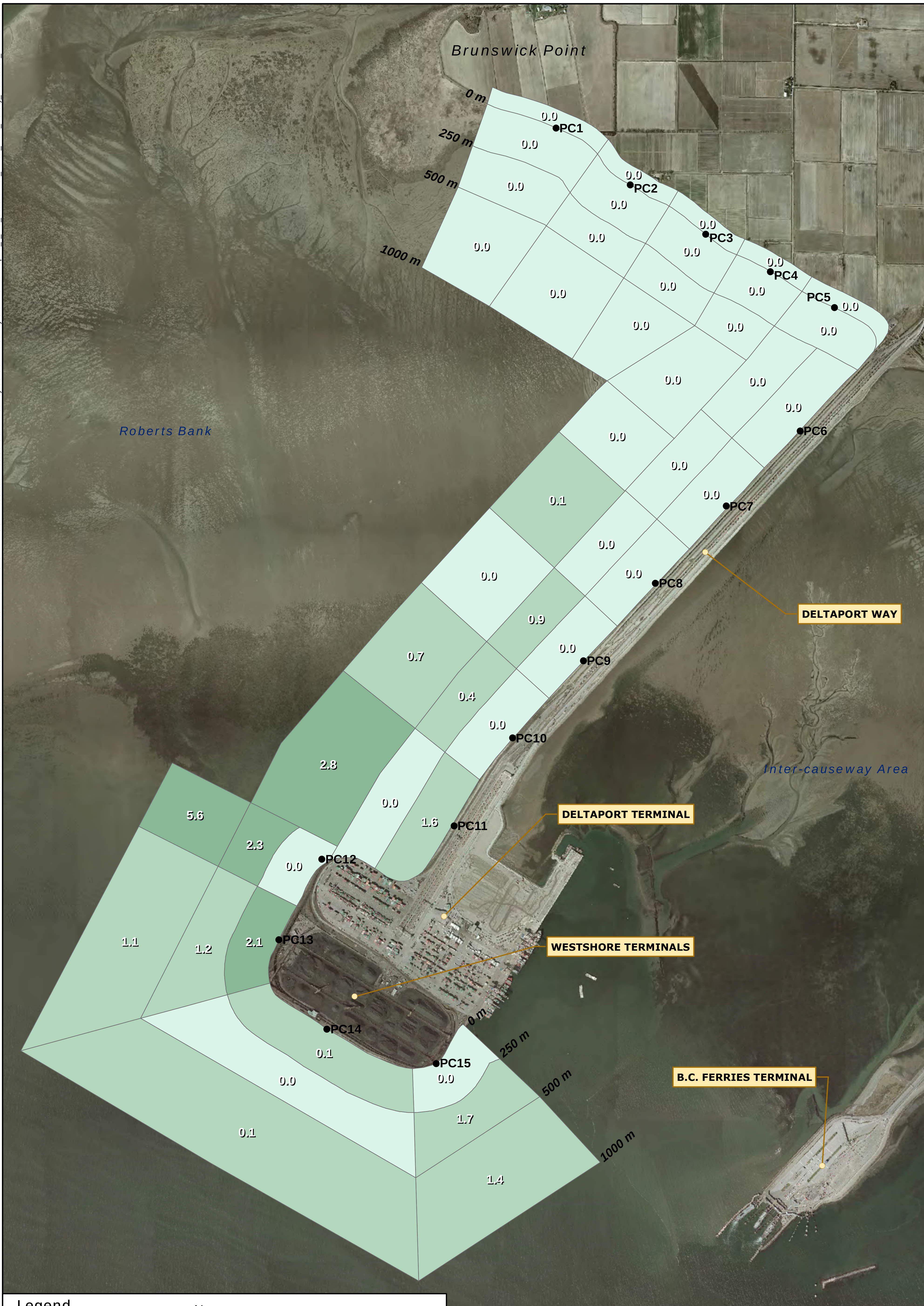
PORT METRO vancouver

ROBERTS BANK TERMINAL 2

FALL AMERICAN WIGEON DENSITY AND DISTRIBUTION (SEP 2012 – NOV 2012)

DATE:	FIG No.
11/20/2014	15-E7

Document Path: P:\282-315\302 - PMV\034-036 CCI\P0034 T2\T2 EA STUDY PROGRAM\Coastal Birds\General Bird Survey\General Bird Survey GIS - ECP\arcmap\15_x_EIS_CoastalBirds_Winter_Brant_Density_Distribution_141120.mxd



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● POINT COUNT STATION

DENSITY (birds/25 ha)

- 0
- 0.01 - 2
- 2.01 - 10
- 10.01 - 50
- 50.01 - 250
- 250.01 - 1,250

N

500 m × 500 m = 25 ha

0 500 1,000
Metres

1:20,000

NAD 1983 UTM Zone 10N

PORT METRO vancouver

ROBERTS BANK TERMINAL 2

WINTER BRANT DENSITY AND DISTRIBUTION (NOV 2012 – APR 2013)

DATE:	FIG No.
11/20/2014	15-E8

Figure 15-E9 Number of Brant per Party Hour at Roberts Bank / Boundary Bay and at Sites within 65 Km of Roberts Bank / Boundary Bay (N=7), From Christmas Bird Count Data. Number per Party Hour Reflects Species Abundance Adjusted for Survey Effort. Only Sites with Count Data from 1973 to 2012 were Included.

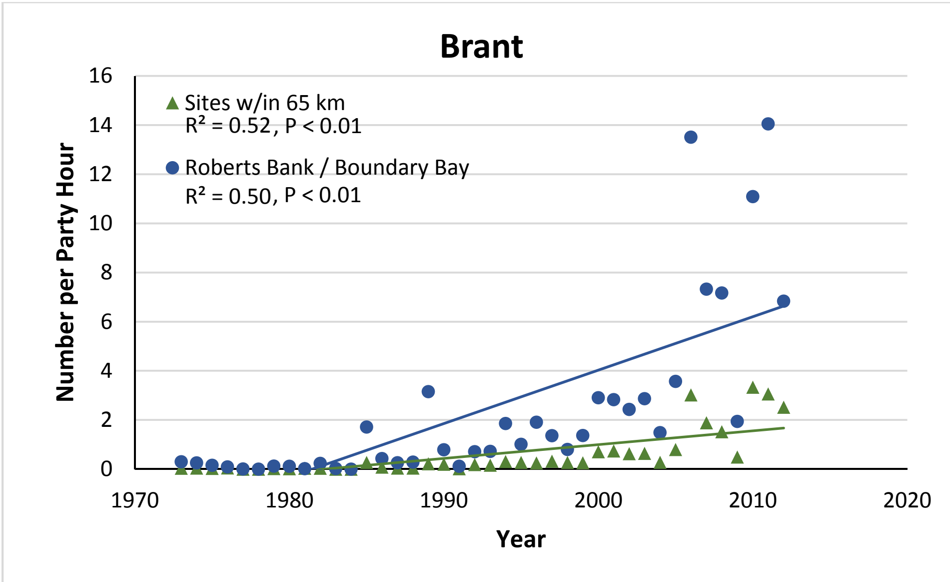
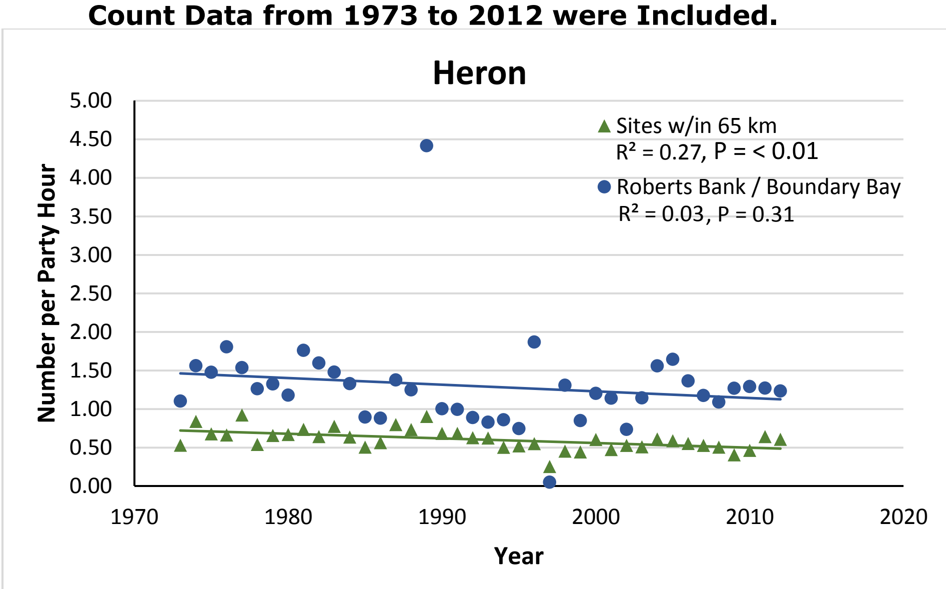


Figure 15-E10 Number of Herons per Party Hour at Roberts Bank / Boundary Bay and at Sites within 65 km of Roberts Bank / Boundary Bay (n=7), from Christmas Bird Count Data. Number per Party Hour Reflects Species Abundance Adjusted for Survey Effort. Only Sites with Count Data from 1973 to 2012 were Included.



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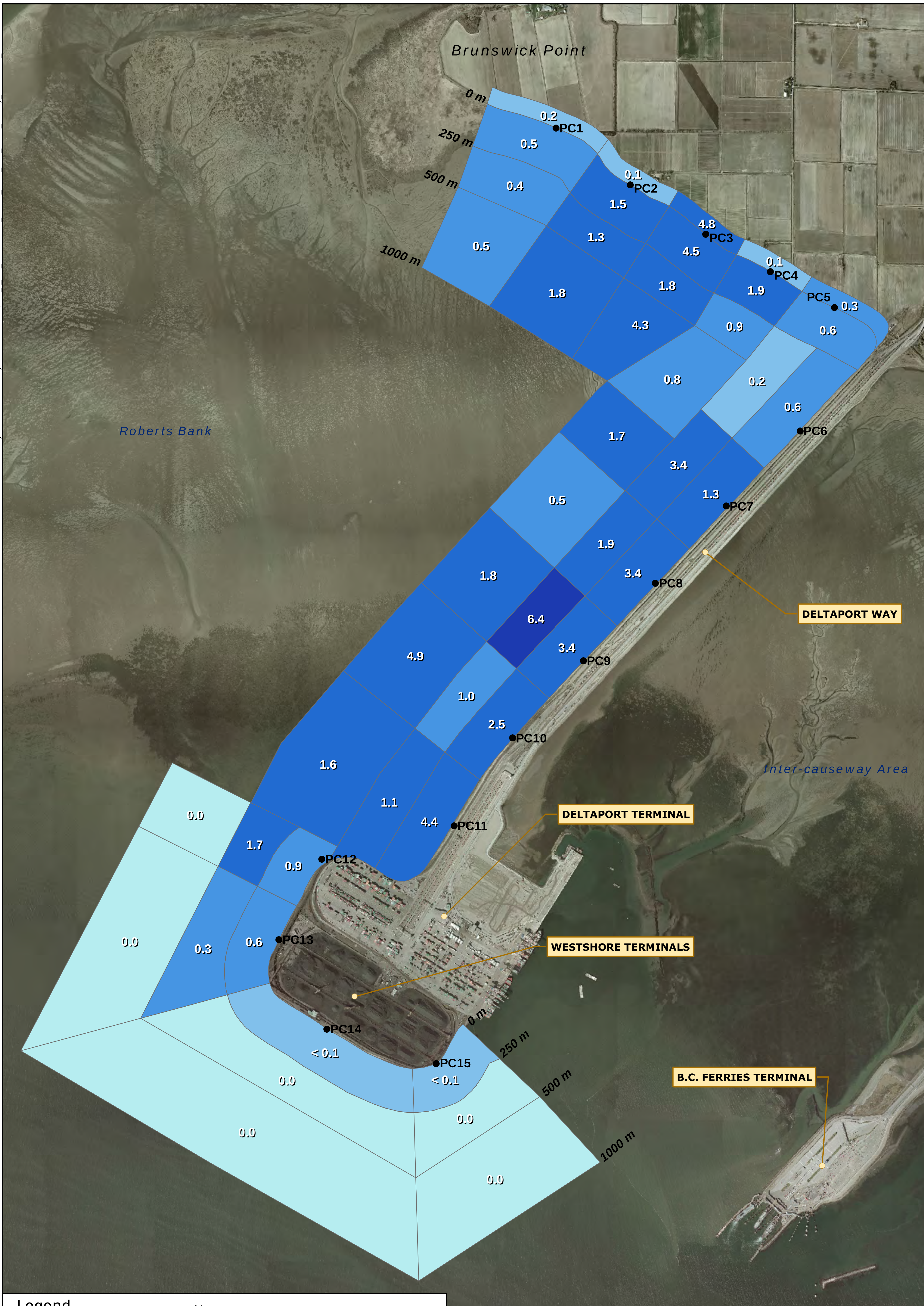

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Legend

● POINT COUNT STATION

DENSITY (birds/25 ha)
- 0
- 0.01 - 0.25
- 0.26 - 1
- 1.01 - 5
- 5.01 - 25
- 25.01 - 100

500 m × 500 m = 25 ha

N

0 — 500 — 1,000 Metres

1:20,000

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ROBERTS BANK TERMINAL 2

ANNUAL GREAT BLUE HERON DENSITY AND DISTRIBUTION (MAY 2012 – MAY 2013)

DATE:	FIG No.
11/20/2014	15-E11

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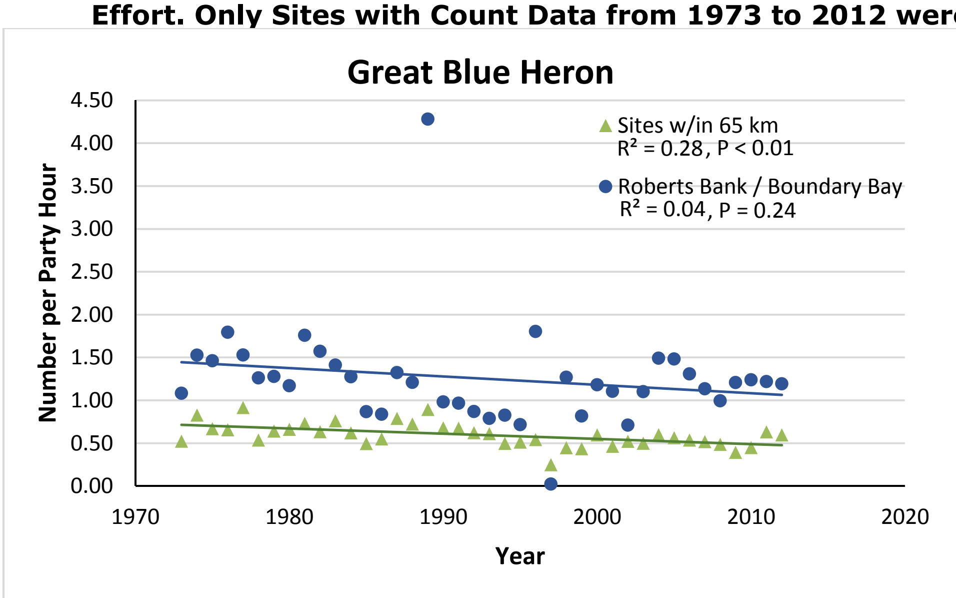
Figure 15-E12 Number of Great Blue Heron per Party Hour at Roberts Bank / Boundary Bay and at Sites within 65 Km of Roberts Bank / Boundary Bay (N=7), From Christmas Bird Count Data. Number per Party Hour Reflects Species Abundance Adjusted for Survey Effort. Only Sites with Count Data from 1973 to 2012 were Included.



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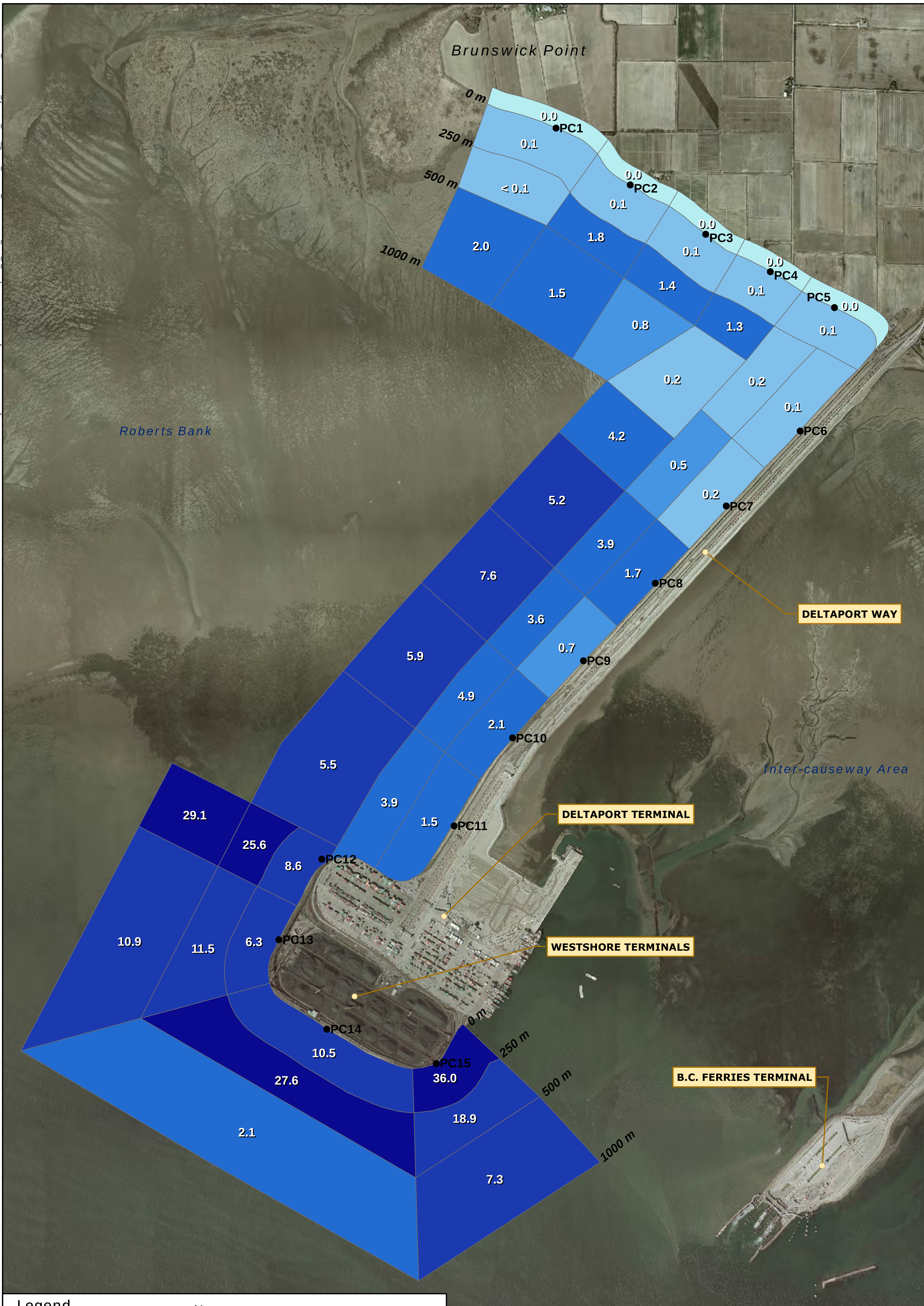

Legend

● POINT COUNT STATION

DENSITY (birds/25 ha)

- 0
- 0.01 - 0.25
- 0.26 - 1
- 1.01 - 5
- 5.01 - 25
- 25.01 - 100

500 m × 500 m = 25 ha

N

0 500 1,000 Metres

1:20,000

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ROBERTS BANK TERMINAL 2

ANNUAL DIVING BIRD DENSITY AND DISTRIBUTION (MAY 2012 – MAY 2013)

DATE:	FIG No.
11/20/2014	15-E13

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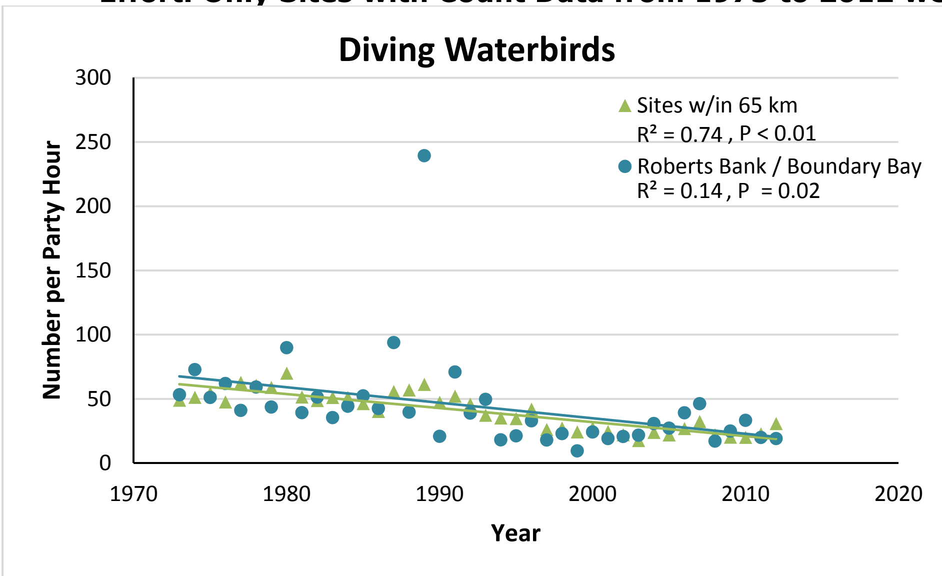
Figure 15-E14 Number of Diving Waterbirds per Party Hour at Roberts Bank / Boundary Bay and at Sites within 65 km of Roberts Bank / Boundary Bay (n=7), from Christmas Bird Count Data. Number per Party Hour Reflects Species Abundance Adjusted for Survey Effort. Only Sites with Count Data from 1973 to 2012 were Included.



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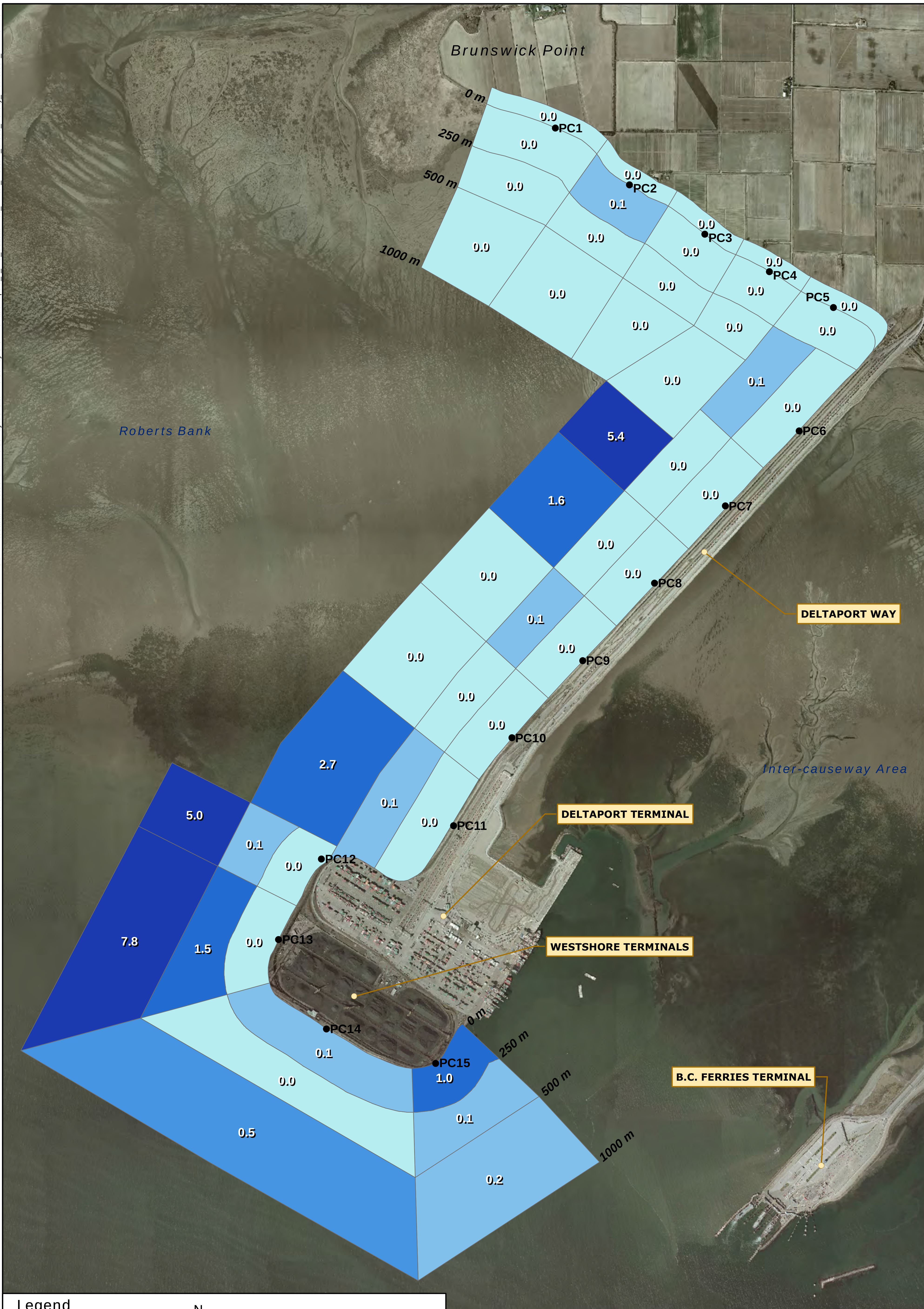

Legend

● POINT COUNT STATION

DENSITY (birds/25 ha)

- 0
- 0.01 - 0.25
- 0.26 - 1
- 1.01 - 5
- 5.01 - 25
- 25.01 - 100

N

0 500 1,000 Metres

500 m × 500 m = 25 ha

1:20,000

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ROBERTS BANK TERMINAL 2

WINTER WESTERN GREBE DENSITY AND DISTRIBUTION (OCT 2012 – APR 2013)

DATE:	FIG No.
11/20/2014	15-E15

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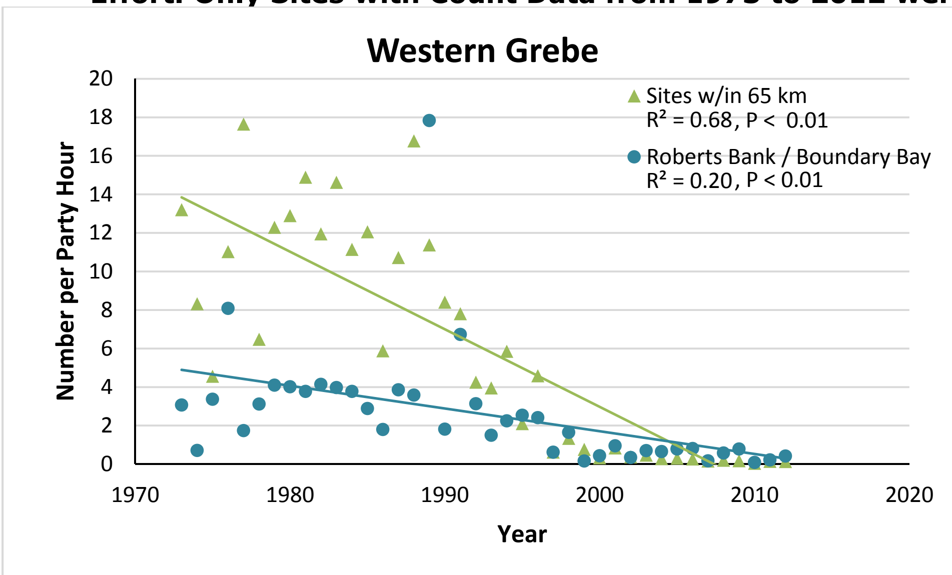
Figure 15-E16 Number of Western Grebe per Party Hour at Roberts Bank / Boundary Bay and at Sites within 65 Km of Roberts Bank / Boundary Bay (N=7), From Christmas Bird Count Data. Number per Party Hour Reflects Species Abundance Adjusted for Survey Effort. Only Sites with Count Data from 1973 to 2012 were Included.



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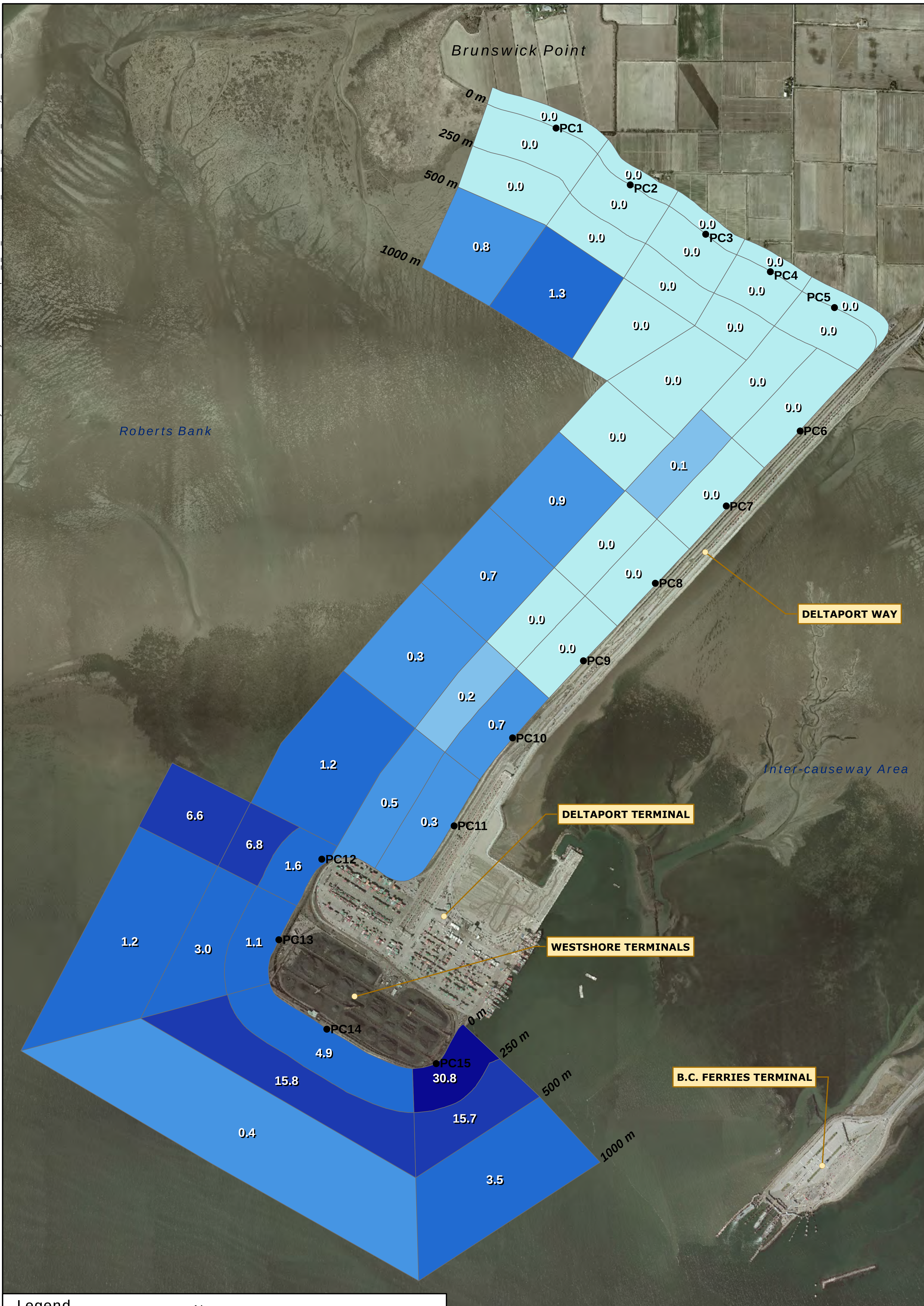

Legend

● POINT COUNT STATION

DENSITY (birds/25 ha)

- 0
- 0.01 - 0.25
- 0.26 - 1
- 1.01 - 5
- 5.01 - 25
- 25.01 - 100

N

500 m — 25 ha — 500 m

0 500 1,000
Metres

1:20,000

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ROBERTS BANK TERMINAL 2

ANNUAL SURF SCOTER DENSITY AND DISTRIBUTION (MAY 2012 – MAY 2013)

DATE:	FIG No.
11/20/2014	15-E17

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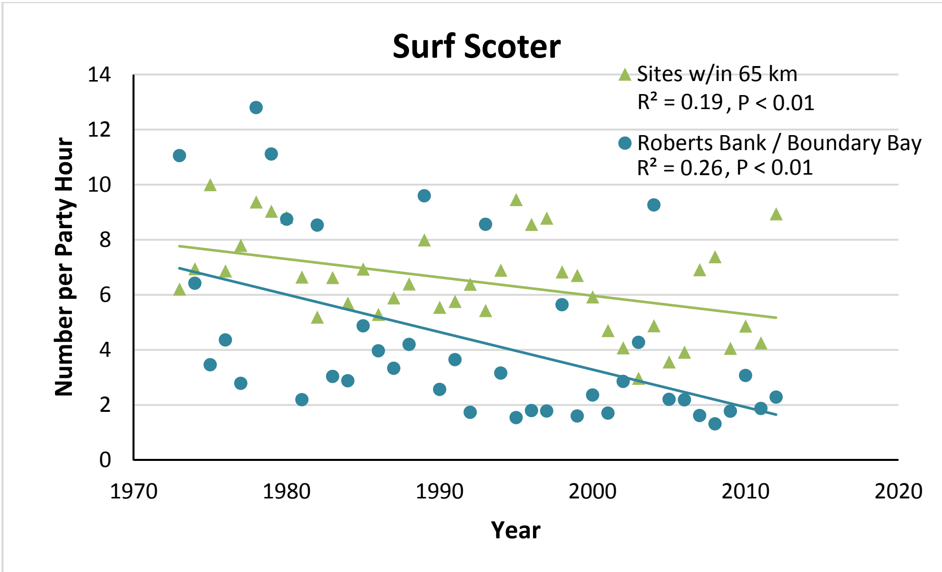
Figure 15-E18 Number of Surf Scoter per Party Hour at Roberts Bank / Boundary Bay and at Sites within 65 Km of Roberts Bank / Boundary Bay (N=7), From Christmas Bird Count Data. Number per Party Hour Reflects Species Abundance Adjusted for Survey Effort. Only Sites with Count Data from 1973 to 2012 were Included.



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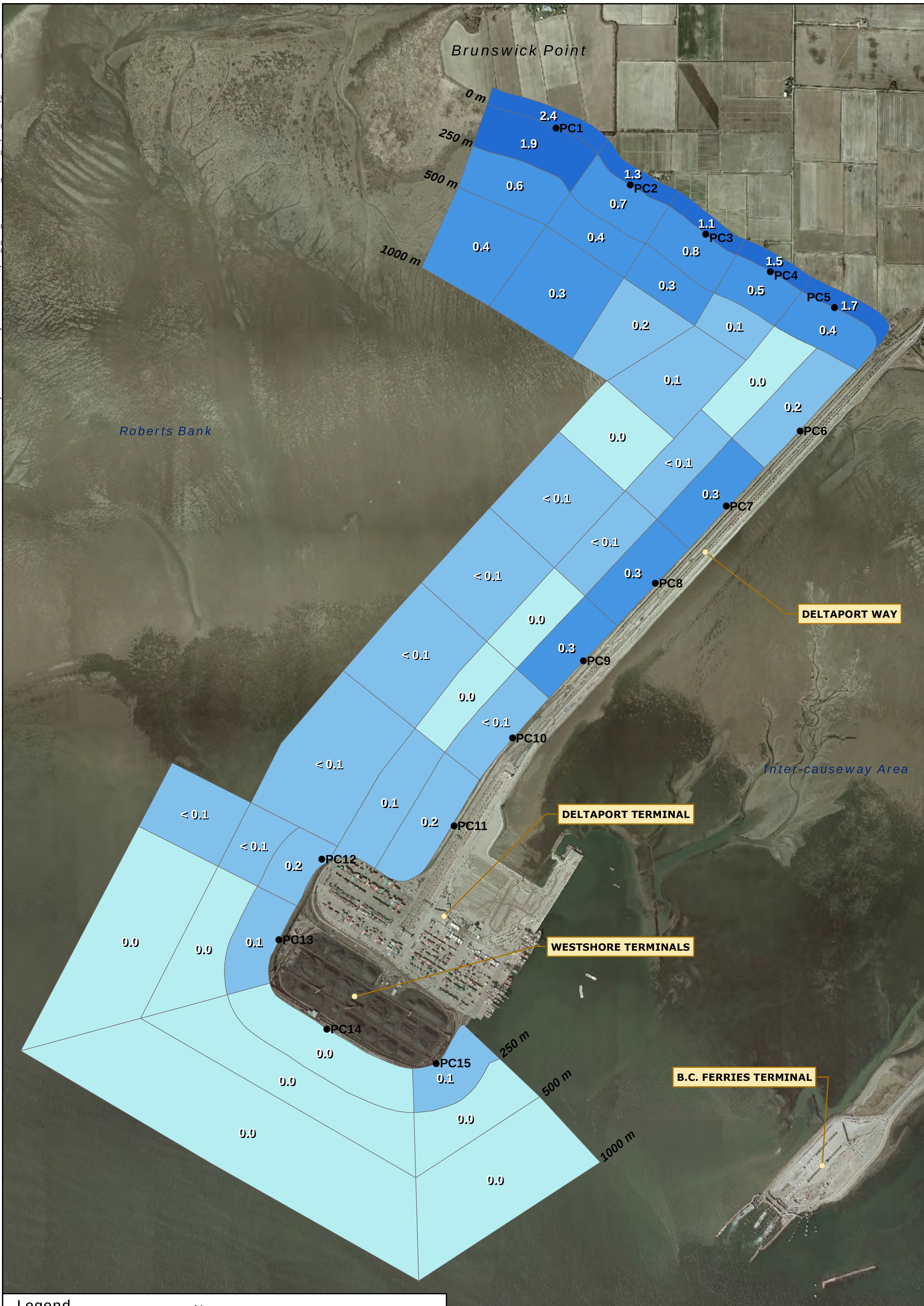

Legend

● POINT COUNT STATION

DENSITY (birds/25 ha)

- 0
- 0.01 - 0.25
- 0.26 - 1
- 1.01 - 5
- 5.01 - 25
- 25.01 - 100

N

0 500 1,000
Metres

500 m | 25 ha | 500 m

1:20,000

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ROBERTS BANK TERMINAL 2

ANNUAL RAPTOR DENSITY AND DISTRIBUTION (MAY 2012 – MAY 2013)

DATE: 11/20/2014

FIG No. 15-E19

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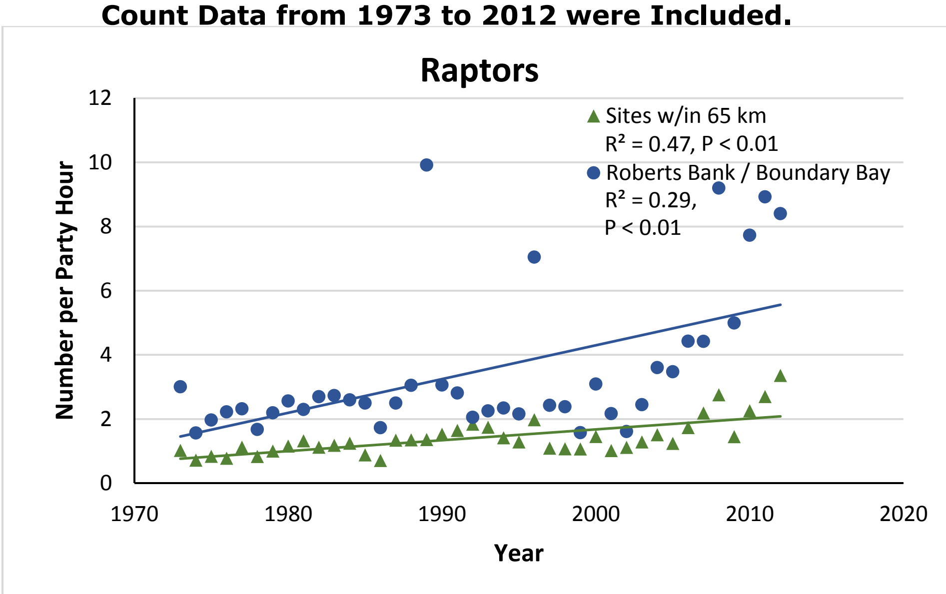
Figure 15-E20 Number of Raptors per Party Hour at Roberts Bank / Boundary Bay and at Sites within 65 km of Roberts Bank / Boundary Bay (n=7), from Christmas Bird Count Data. Number per Party Hour Reflects Species Abundance Adjusted for Survey Effort. Only Sites with Count Data from 1973 to 2012 were Included.



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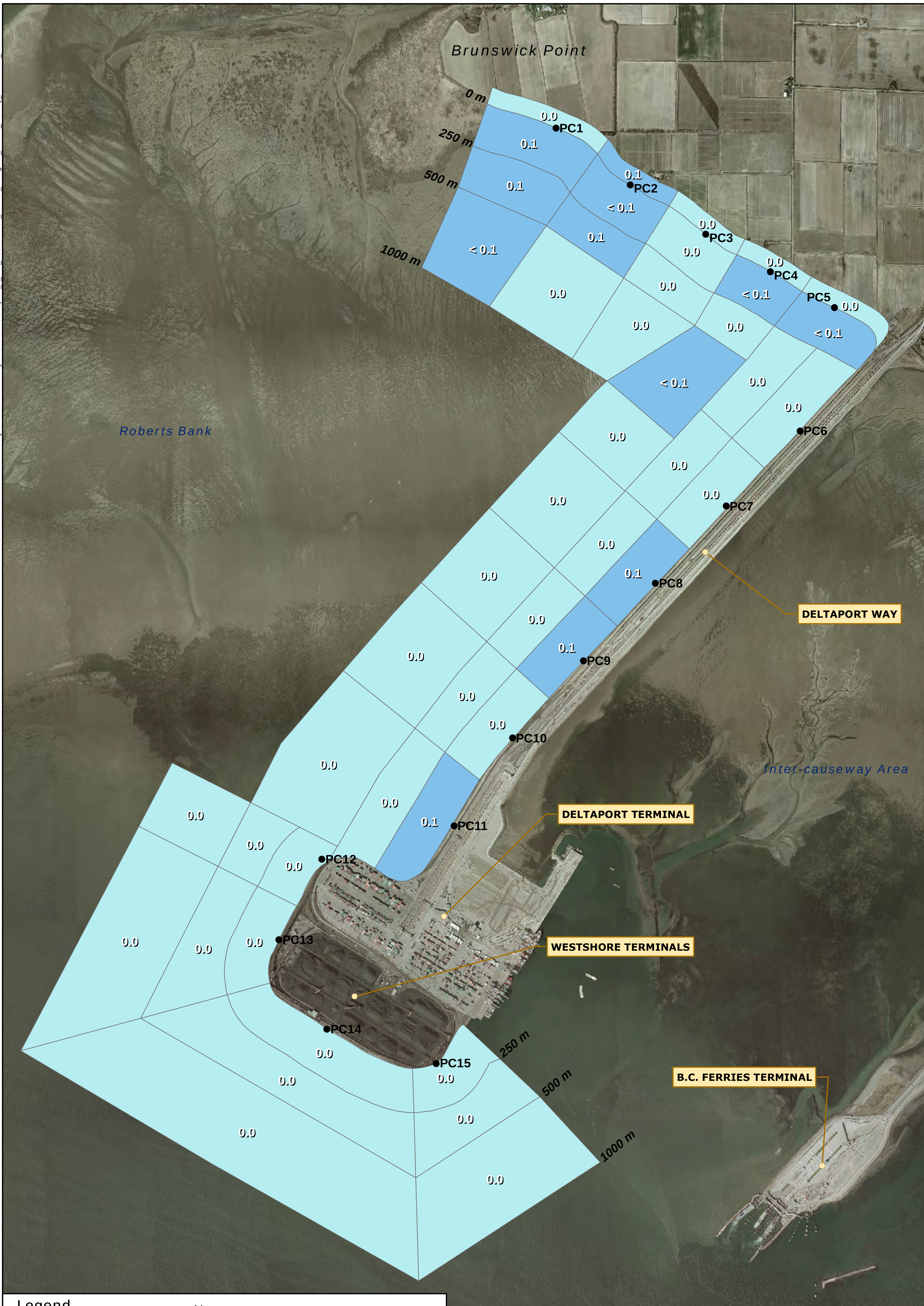

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Legend

● POINT COUNT STATION

DENSITY (birds/25 ha)

- 0
- 0.01 - 0.25
- 0.26 - 1
- 1.01 - 5
- 5.01 - 25
- 25.01 - 100

25 ha (500 m × 500 m)

N

0 500 1,000 Metres

1:20,000

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ROBERTS BANK TERMINAL 2

ANNUAL PEREGRINE FALCON DENSITY AND DISTRIBUTION (MAY 2012 – MAY 2013)

DATE:	FIG No.
11/20/2014	15-E21

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Figure 15-E22 Number of Peregrine Falcon per Party Hour at Roberts Bank / Boundary Bay and at Sites within 65 Km of Roberts Bank / Boundary Bay (N=7), From Christmas Bird Count Data. Number per Party Hour Reflects Species Abundance Adjusted for Survey Effort. Only Sites with Count Data from 1973 to 2012 were Included.

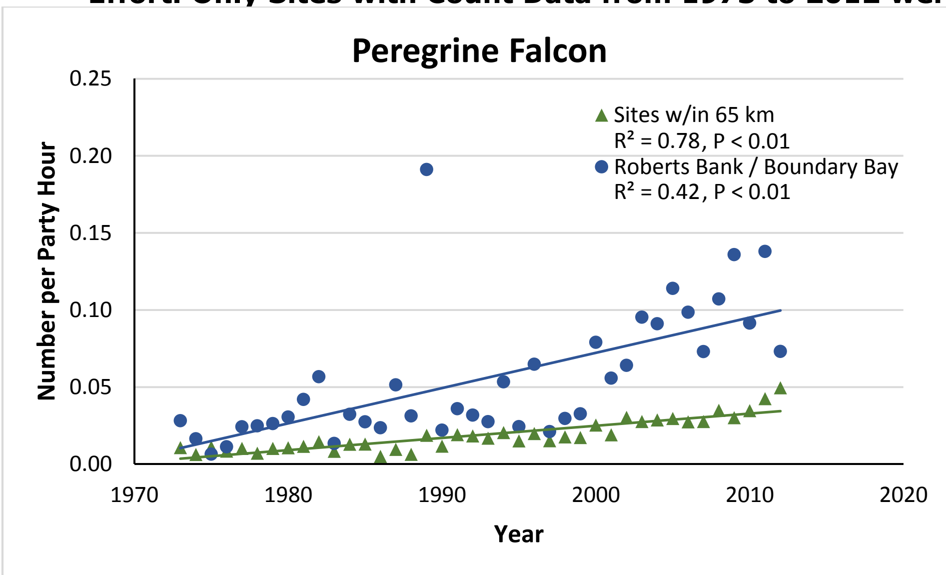
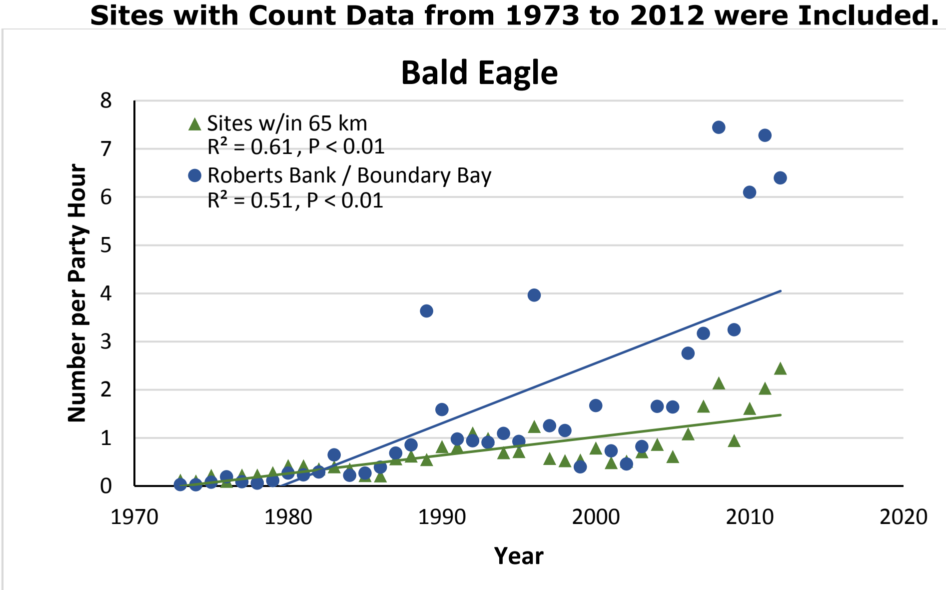


Figure 15-E23 Number of Bald Eagle per Party Hour at Roberts Bank / Boundary Bay and at Sites within 65 Km of Roberts Bank / Boundary Bay (N=7), From Christmas Bird Count Data. Number per Party Hour Reflects Species Abundance Adjusted for Survey Effort. Only Sites with Count Data from 1973 to 2012 were Included.



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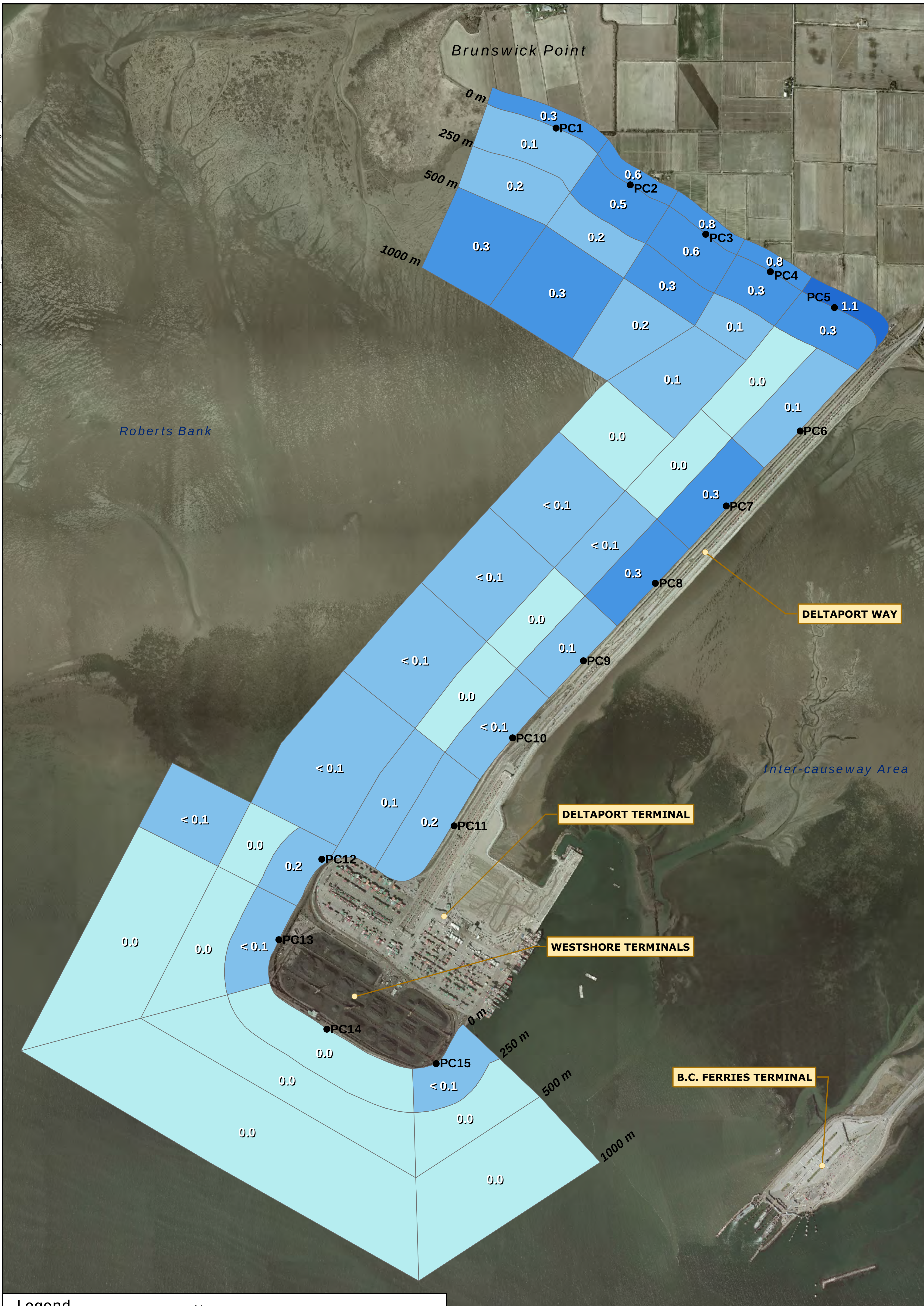

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Legend

● POINT COUNT STATION

DENSITY (birds/25 ha)

- 0
- 0.01 - 0.25
- 0.26 - 1
- 1.01 - 5
- 5.01 - 25
- 25.01 - 100

N

0 500 1,000
Metres

500 m × 500 m = 25 ha

1:20,000

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ROBERTS BANK TERMINAL 2

ANNUAL BALD EAGLE DENSITY AND DISTRIBUTION (MAY 2012 – MAY 2013)

DATE:	FIG No.
11/20/2014	15-E24

Legend

- POINT COUNT STATION

DENSITY (birds/25 ha)

- 0
- 0.01 - 2
- 2.01 - 10
- 10.01 - 50
- 50.01 - 250
- 250.01 - 1,250

N

0 500 1,000
Metres

500 m
25 ha
500 m

1:20,000

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ROBERTS BANK TERMINAL 2

ANNUAL GULL AND TERN DENSITY AND DISTRIBUTION (MAY 2012 – MAY 2013)

DATE:	FIG No.
11/20/2014	15-E25

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Figure 15-E26 Number of Gulls and Terns per Party Hour at Roberts Bank / Boundary Bay and at Sites within 65 km of Roberts Bank / Boundary Bay (n=7), from Christmas Bird Count Data. Number per Party Hour Reflects Species Abundance Adjusted for Survey Effort. Only Sites with Count Data from 1973 to 2012 were Included.

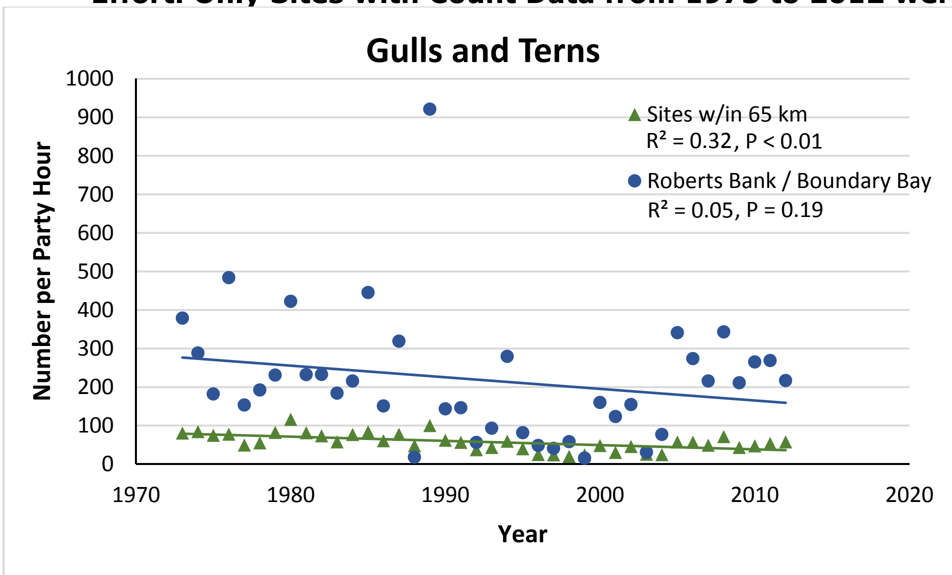
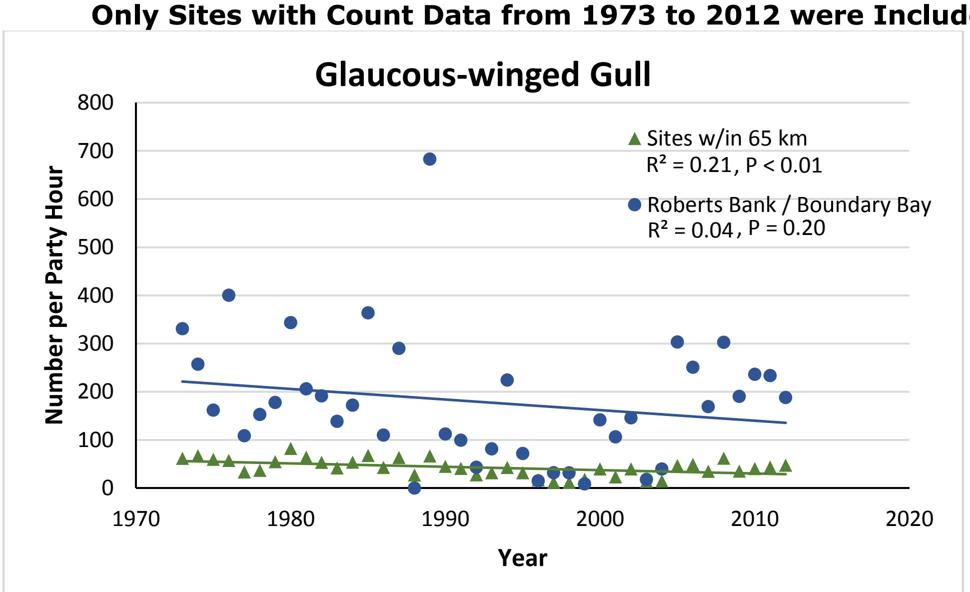


Figure 15-E27 Number of Glaucous-winged Gull per Party Hour at Roberts Bank / Boundary Bay and at Sites within 65 Km of Roberts Bank / Boundary Bay (N=7), From Christmas Bird Count Data. Number per Party Hour Reflects Species Abundance Adjusted for Survey Effort. Only Sites with Count Data from 1973 to 2012 were Included.



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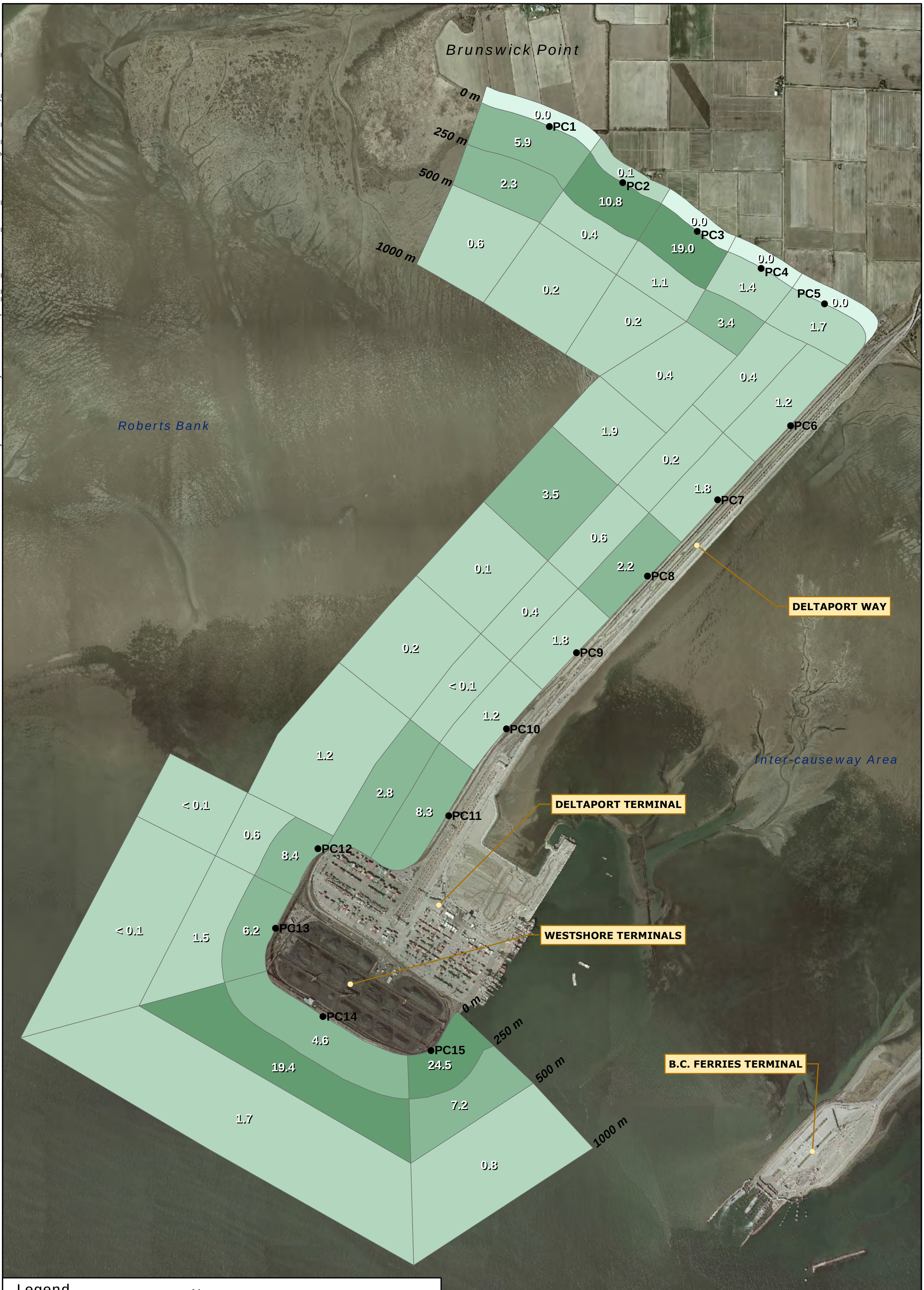

ROBERTS BANK TERMINAL 2

ANNUAL GLAUCOUS-WINGED GULL DENSITY AND DISTRIBUTION (MAY 2012 – MAY 2013)

DATE:	FIG No.
11/20/2014	15-E28

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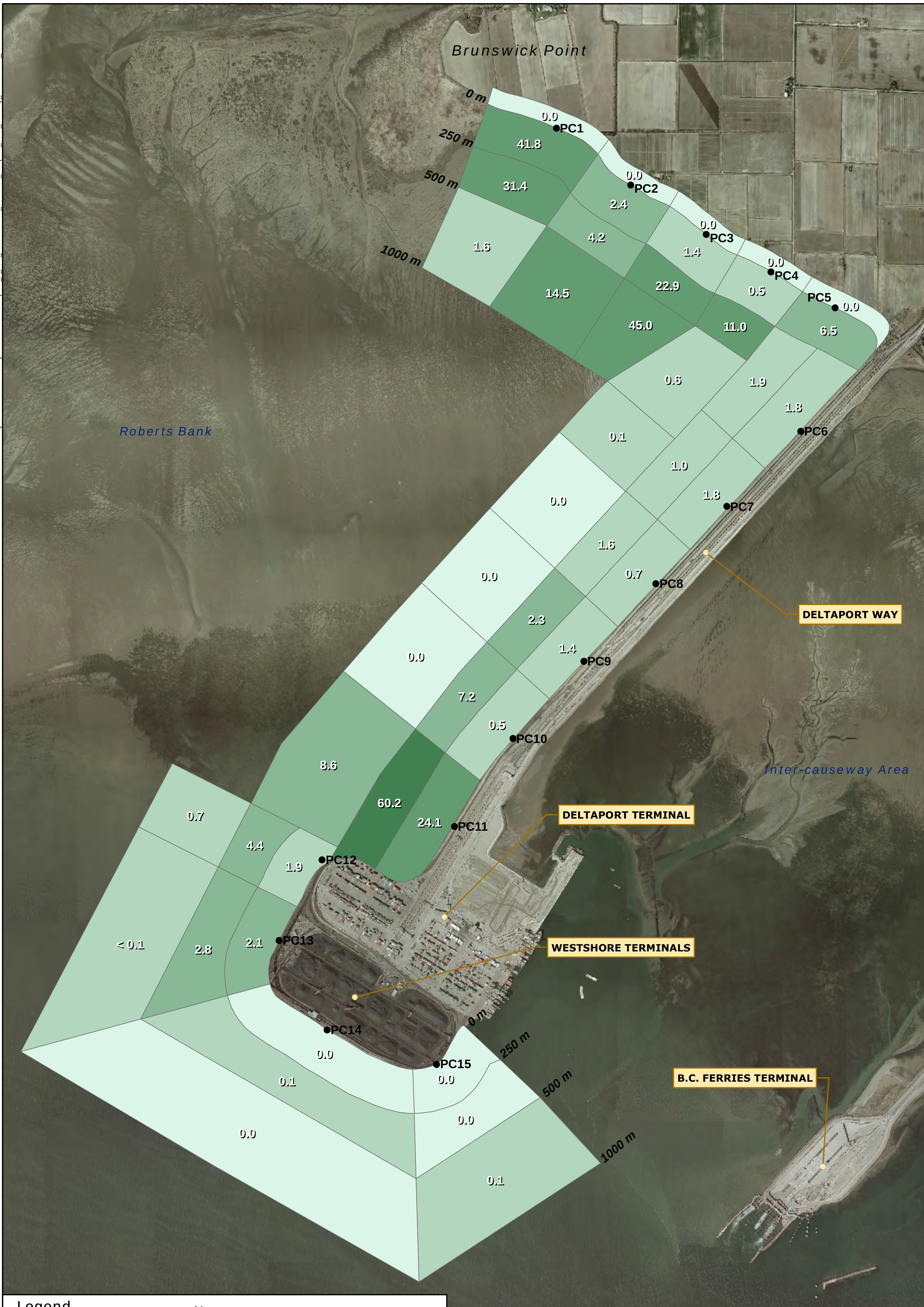

Legend

- ● POINT COUNT STATION

DENSITY (birds/25 ha)

- 0
- 0.01 - 2
- 2.01 - 10
- 10.01 - 50
- 50.01 - 250
- 250.01 - 1,250

500 m × 500 m = 25 ha

N

0 — 500 — 1,000 Metres

1:20,000

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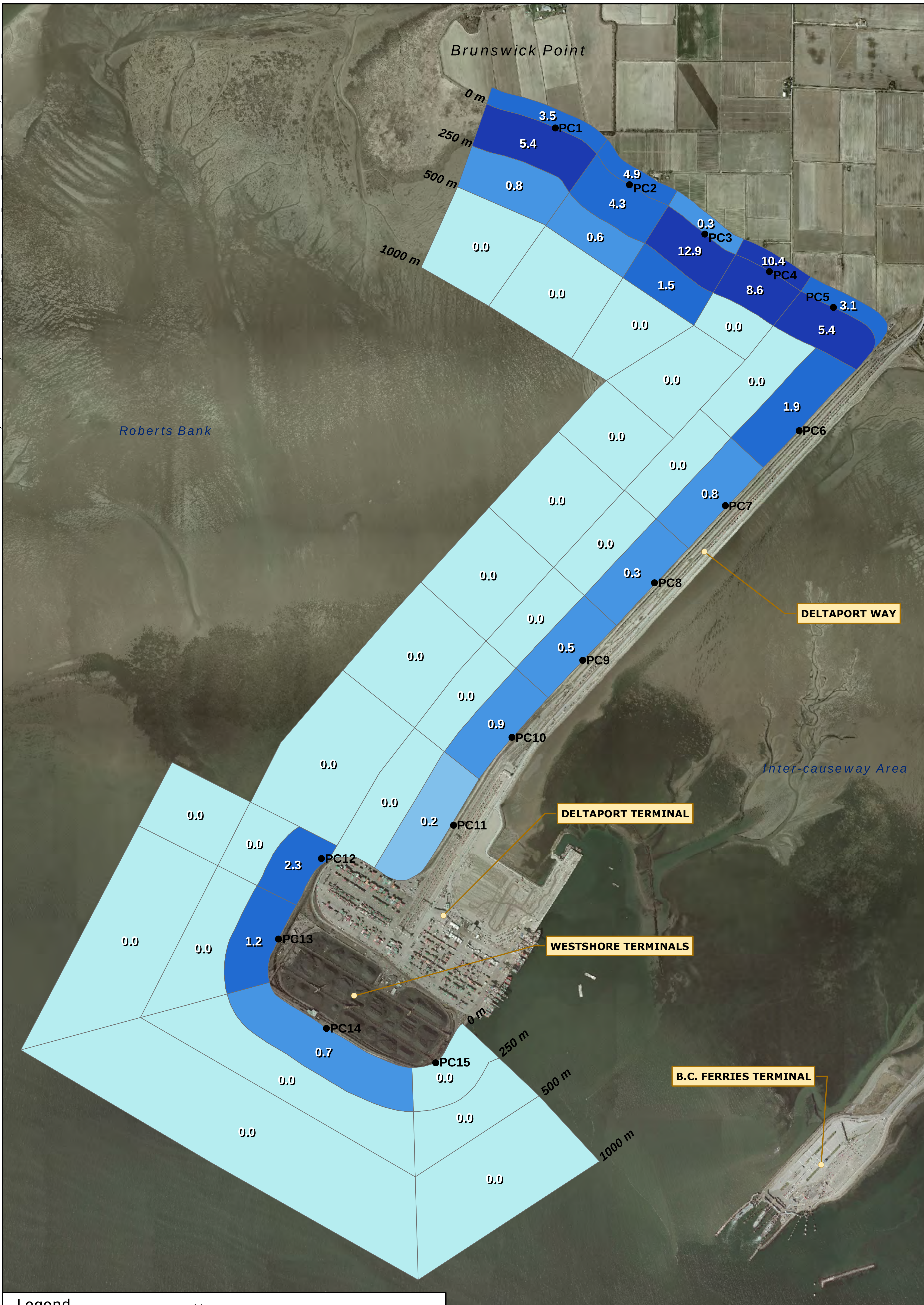
ROBERTS BANK TERMINAL 2

SUMMER CASPIAN TERN DENSITY AND DISTRIBUTION (MAY – AUG 2012, MAY 2013)

DATE:	FIG No.
11/20/2014	15-E29



Legend

● POINT COUNT STATION

DENSITY (birds/25 ha)

- 0
- 0.01 - 0.25
- 0.26 - 1
- 1.01 - 5
- 5.01 - 25
- 25.01 - 100

N

0 500 1,000
Metres

500 m × 500 m = 25 ha

1:20,000

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ROBERTS BANK TERMINAL 2

SUMMER BARN SWALLOW DENSITY AND DISTRIBUTION (APR – AUG 2012, APR – MAY 2013)

DATE:	FIG No.
11/20/2014	15-E30

APPENDIX 15-F

Rationale for Inclusion / Exclusion of Other Certain and Reasonably Foreseeable Projects and Activities in the Cumulative Effects Assessment of Coastal Birds

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Appendix 15-F Rationale for Inclusion/Exclusion of Other Certain and Reasonably Foreseeable Projects and Activities in the Cumulative Effects Assessment of Coastal Birds

The assessment included consideration of the potential for an interaction between a potential Project-related residual effect on coastal birds and the effects of other certain and reasonably foreseeable projects and activities on that VC. The rationale for exclusion of each certain and reasonably foreseeable project and activity identified in **Table 8-8 Project and Activity Inclusion List**, from the cumulative effects assessment is presented in **Table 15-F**.

Table 15-F Rationale for Inclusion/Exclusion of Other Certain and Reasonably Foreseeable Projects in the Cumulative Effects Assessment of Coastal Birds

Other Certain and Reasonably Foreseeable Project /Activity	Included (I) /Excluded (E)	Rationale for Inclusion / Exclusion
Projects		
BURNCO Aggregate Project, Gibsons, B.C.	I	Potential for permanent loss of subtidal habitats used by diving birds, but no potential for increased disturbance to diving birds from underwater and above-ground noise and visual disturbance as increases in the number of vessels is anticipated to be small compared to overall traffic (**Table 8-8**), and any cumulative change from noise would not be measurable.
Centerm Terminal Expansion, Vancouver, B.C.	E	Potential for increased disturbance to diving birds from underwater and above-ground noise and visual disturbance from vessel traffic within the Strait of Georgia; however, the number of vessels is anticipated to be small compared to overall traffic (**Table 8-8**), and any cumulative change would not be measurable.
Fraser Surrey Docks Direct Coal Transfer Facility, Surrey, B.C.	I	Potential for increased disturbance to diving birds from underwater and above-ground noise and visual disturbance associated with barge and vessel traffic.
Gateway Pacific Terminal at Cherry Point and associated BNSF Railway Company Rail Facilities Project, Blaine, Washington	I	Potential for permanent loss of subtidal habitats used by diving birds. Potential for increased disturbance to diving birds from underwater and above-ground noise and visual disturbance associated with barge and bulk carrier traffic.
Gateway Program - North Fraser Perimeter Road Project, Coquitlam, B.C.	E	Not relevant to this cumulative effects assessment since project is not expected to disturb diving birds or affect subtidal habitat used by diving birds.

Other Certain and Reasonably Foreseeable Project /Activity	Included (I) /Excluded (E)	Rationale for Inclusion / Exclusion
George Massey Tunnel Replacement Project, Richmond and Delta, B.C.	E	Not relevant to coastal birds effects assessment since project is not expected to disturb diving birds or affect marine subtidal habitat used by diving birds.
Kinder Morgan Pipeline Expansion Project, Strathcona County, Alberta to Burnaby, B.C.	I	Potential for permanent loss of subtidal habitats used by diving birds. Potential for increased disturbance to diving birds from underwater and above-ground noise and visual disturbance associated with tanker traffic within the Strait of Georgia.
Lehigh Hanson Aggregate Facility, Richmond, B.C.	E	Not relevant to this cumulative effects assessment since project is not expected to affect subtidal habitat used by diving birds, and project is expected to have a negligible contribution to future underwater and above-ground noise levels.
Lions Gate Wastewater Treatment Plant Project, District of North Vancouver, B.C.	E	Not relevant to this cumulative effects assessment since project is not expected to disturb diving birds or affect subtidal habitat used by diving birds.
North Shore Trade Area Project - Western Lower Level Route Extension, West Vancouver, B.C.	E	Not relevant to this cumulative effects assessment since project is not expected to disturb diving birds or affect subtidal habitat used by diving birds.
Pattullo Bridge Replacement Project, New Westminster and Surrey, B.C.	E	Not relevant to coastal birds effects assessment since project is not expected to disturb diving birds or affect marine subtidal habitat used by diving birds.
Southlands Development, Delta, B.C.	E	Potentially relevant to coastal birds cumulative effects assessment since project is land-based and diving birds utilise upland areas, but disturbance-related effects on diving birds are expected to be negligible due to the low likelihood of interaction in the vicinity of the project.
Vancouver Airport Fuel Delivery Project, Richmond, B.C.	I	Potential for permanent loss of subtidal habitats used by diving birds. Potential for increased disturbance to diving birds from underwater and above-ground noise and visual disturbance associated with tanker and barge traffic.
Woodfibre LNG Project, Squamish, B.C.	E	No potential for increased disturbance to diving birds from underwater and above-ground noise and visual disturbance as increases in the numbers of vessels is anticipated to be small compared to overall traffic (**Table 8-8**), and any cumulative change would not be measurable.

Other Certain and Reasonably Foreseeable Project /Activity	Included (I) /Excluded (E)	Rationale for Inclusion / Exclusion
Activities		
Incremental Road Traffic associated with RBT2	E	Potentially relevant to this cumulative effects assessment since activity is land-based and diving birds utilise upland areas, but disturbance-related effects from this activity on diving birds are expected to be negligible due to the low likelihood of interaction in the vicinity of the road corridor.
Incremental Rail Traffic associated with RBT2	E	Potentially relevant to this cumulative effects assessment since activity is land-based and diving birds utilise upland areas, but disturbance-related effects from this activity on diving birds are expected to be negligible due to the low likelihood of interaction in the vicinity of the rail corridor.
Incremental Ship Traffic associated with RBT2	I	Potential for increased disturbance to diving birds from above-ground and underwater noise and visual disturbance associated with container vessels.