APPENDIX AIR10-C

Technical Data Reports Containing Habitat Maps at Local and Regional Scales

TDR CB-1 - Shorebird Abundance and Foraging Use in the Fraser River Estuary during Migration TDR

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ROBERTS BANK TERMINAL 2

TECHNICAL DATA REPORT

Coastal Waterbirds

Shorebird Abundance and Foraging Use in the Fraser River Estuary during Migration

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Technical Report/Technical Data Report Disclaimer

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

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

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

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

EXECUTIVE SUMMARY

The Shorebird Abundance and Foraging Use in the Fraser River Estuary (FRE) during Migration Study was conducted as part of an environmental program for the proposed Roberts Bank Terminal 2 Project (Project or RBT2), and focused on collecting information to develop an understanding of existing conditions in the study area. 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.

The objectives of the study were to: 1) determine the importance of shorebird habitat adjacent to the proposed Project relative to the FRE and relative to migrating shorebird populations; 2) assess the quality of shorebird habitat adjacent to the proposed Project relative to other areas in the FRE; 3) define relationships between environmental/ecological variables and foraging use across the estuary and adjacent to the proposed Project; and 4) assess the influence of artificial light on shorebird presence at night.

Field studies were carried out during northward and southward shorebird migrations in 2012 and 2013. The effects of artificial light on shorebirds were assessed by conducting nocturnal surveys adjacent to the proposed Project during the 2014 northward migration. As determined by other studies, this study found that large proportions of Pacific dunlin (*Calidris alpina pacifica*) and western sandpiper (*Calidris mauri*) populations use the FRE during migration. During northward migration, the intertidal area between the Roberts Bank causeway and Brunswick Point (hereafter, BP) consistently supported approximately half (i.e., 45 to 51%) of the shorebird use observed across the estuary. During southward migration of adult western sandpipers, the proportion of use in this area varied dramatically between the two study years. During southward migration of juvenile western sandpipers proportions of use at BP relative to the estuary as a whole averaged almost one third (i.e., 27 to 32%). The Inter-causeway Area supported <5% of foraging use for the estuary during all migrations. The highest quality habitat, as inferred by density of shorebirds and their droppings, was predominantly in the BP area and the eastern half of Boundary Bay.

Relationships between environmental variables and shorebird (i.e., dropping) densities varied across the estuary and between northward and southward migrations; therefore, six separate models were used to analyse these relationships (i.e., across three areas and two migration periods). Foraging use decreased with distance to shore in almost all models, but often declined in areas within 200 m from shore. These results are attributed to reduced habitat availability in areas further from shore due to relatively prolonged tidal inundation, and high risks of predation in areas close to vegetative cover (i.e., areas adjacent to shore). During northward migration, areas with freshwater inputs (e.g., BP and Westham Island) supported substantially higher foraging use than other areas; however, salinity was not significantly related to use in the BP area. Foraging use at BP was greatest at salinities of 10-12 partial salinity units (psu), indicating potentially optimal conditions at low-intermediate salinity levels relative to those occurring

across the estuary. The relationship between salinity and foraging use was reversed during the southward migration and higher foraging use occurred in more saline areas (e.g., Boundary Bay). Organic content of sediments were also significantly related to droppings in most regions of the estuary during the southward migration with higher foraging use observed in areas with relatively high organic content. Salinity and organic content in sediments are positively related to invertebrate density. Thus, modeling results suggest that shorebird foraging is more focused on invertebrate prey during the southward migration as compared to the northward migration. Biofilm is the other major component of western sandpiper and other shorebird diets and appears to be a more important driver of foraging use during the northward migration.

In accordance with results from previous research, artificial light was not significantly related to the likelihood of shorebird presence at night.

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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 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 data report describes the results of the Shorebird Abundance and Use of the Fraser River Estuary (FRE) during Migration Study.

1.2 PROJECT OVERVIEW

A review of existing information and state of knowledge was completed for shorebird abundance and habitat use in the FRE during migration to identify key data gaps and areas of uncertainty within the general RBT2 area. This technical data 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 1-1**.

Table 1-1 Shorebird Abundance and Foraging Use in the Fraser River Estuary during Migration Study - Components and Major Objectives

Component	Major Objective	Brief Overview
1) Shorebird Foraging Use	• Assess the importance of intertidal mudflats to migrating shorebirds in areas close to the Project and other areas across the FRE by determining the proportion of use in all areas. • Assess relative habitat quality of intertidal mudflats to migrating shorebirds in areas close to the Project and other areas across the FRE by determining the concentration of use within and across areas. • Identify factors that influence shorebird use of the FRE by defining the relationships between environmental/ecological variables and foraging use across intertidal mudflats.	• Measure foraging use during northward and southward migrations of western sandpiper by counting shorebird droppings across FRE intertidal mudflats. • Determine the proportion of use in each area by comparing dropping abundance across areas within the FRE. • Assess the relative quality of habitat within areas of the FRE by mapping shorebird dropping densities at a resolution of 50 m^2. • Compare the relative quality of habitat across areas by determining mean dropping density for each area. • Identify factors significantly related to use and define those relationships by using statistical models to regress environmental variables against dropping densities.

Component	Major Objective	Brief Overview
2) Shorebird Abundance	• Assess the importance of intertidal mudflats to migrating shorebirds in areas close to the Project and other areas across the FRE by determining the proportion of abundances across areas and the FRE relative to population sizes. • Assess the relative quality of intertidal mudflats to migrating shorebirds in areas close to the Project and other areas across the FRE by determining the density of shorebirds in all areas.	• Record species specific shorebird abundances simultaneously across the FRE, during northward and southward western sandpiper migrations. • Compare abundances across areas to determine the proportion of each species in each study area. • Estimate the total number of shorebirds migrating through the FRE to determine the proportion of shorebird populations using the estuary. • Compare shorebird densities across FRE study areas to assess relative habitat quality.
3) Influence of Artificial Light	• Determine if/how artificial influences shorebird use of intertidal habitat.	• Conduct nocturnal surveys within the Brunswick Point survey area to document shorebird use. • Determine shorebird abundance, light measurements, and other variables (e.g., weather, sediment characteristics) at survey locations. • Model data to determine factors influencing nocturnal shorebird usage of intertidal mudflats.

The objectives of the study were to: 1) determine the importance of shorebird habitat adjacent to the proposed Project relative to the FRE and relative to the shorebird populations that migrate through the estuary; 2) assess the quality of shorebird habitat adjacent to the proposed Project relative to other areas in the FRE; 3) define relationships between environmental/ecological variables and foraging use across the estuary and adjacent to the proposed Project; and 4) assess the influence of artificial light on shorebird presence.

Shorebird densities and droppings were used as habitat quality indicators (Fretwell and Lucas 1970) and proportional abundance was used to assess the importance of each study area within the estuary. Areas of high and low use were mapped to develop a more thorough understanding of shorebird distribution and habitat use at Roberts Bank and surrounding sites.

2.0 REVIEW OF EXISTING LITERATURE AND DATA

The expansive mudflat, marsh, and agricultural areas of the FRE have been designated a 'Wetland of International Importance' (Ramsar Convention 2013), 'Important Bird Area' (IBA Canada 2012), and 'Site of Hemispheric Importance' for shorebirds (Western Hemisphere Shorebird Reserve Network 2005). The estuary is valuable to globally important populations of western sandpipers (*Calidris mauri*) and Pacific dunlin (*Calidris alpina pacifica*) during spring migration (Butler and Vermeer 1994, Western Hemisphere Shorebird Reserve Network 2005, Fernández, Buchanan, et al. 2010).

Shorebirds are abundant in the FRE throughout most of the year, but especially during migration (Butler and Vermeer 1994, Sutherland et al. 2000). Western sandpipers are the most abundant shorebird species during migration followed by dunlin. During northward migration, 100,000s of western sandpipers and dunlin stopover in the FRE to replenish energy and fat reserves along with 1,000s of black-bellied plovers (*Pluvialis squatarola squatarola*) and least sandpipers (*Calidris minutilla*) as well as smaller numbers of many other shorebird species (Butler and Vermeer 1994).

Northward migration of western sandpipers occurs between mid-April and mid-May (Butler et al. 1987), while the southward migration spans from July (mostly adults) to August and September (mostly juveniles) (Butler et al. 1987, Ydenberg et al. 2004). During migrations, shorebirds continually move through the estuary and only a portion of the birds that stopover in the estuary are present on any given day. The length of time that individual western sandpipers stopover in the FRE during northward migration was recently estimated at 2.2 to 3.6 days (Iverson et al. 1996, Butler et al. 2002, Ydenberg et al. 2004). Length of stay during southward migration has not been documented for the FRE, but is assumed to be similar based on estimates of 2.7 days at Sidney Island, B.C. (Ydenberg et al. 2004). The northward migration of dunlin occurs between early April and early May, while the southward migration of adults and juveniles occurs primarily during October and November (Page 1974, Ruiz et al. 1989). Length of stay for dunlin during the northward migration ranges from 2 to 11 days, shortening towards the end of the migration (Warnock et al. 2004).

During northward migration, an average of 600,000 western sandpipers and 200,000 dunlin use habitat at Brunswick Point, north of the Roberts Bank causeway (based on surveys between 1991 and 2013: Drever et al. 2014). These are important numbers considering that population estimates for western sandpipers and Pacific dunlin are 3.5 million and 550,000, respectively (Fernández, Buchanan, et al. 2010, Fernández, Warnock, et al. 2010, Andres et al. 2012). Western sandpiper densities at Brunswick Point are highest during the northward migration period (Butler and Vermeer 1994, Butler et al. 2002), but their distribution and density in the FRE are not as well documented during southward migration. Currently available census data do not describe the distribution or density of dunlin or black-bellied plovers across the estuary during migration.

During migration, sandpipers primarily use mudflats and sandflats (hereafter, collectively referred to as 'mudflats') as foraging habitat but can supplement their diet by foraging in adjacent agricultural fields. Detailed studies of factors related to the spatial distribution of foraging use in mudflats during migration are lacking.

Nocturnal habitat use by sandpipers is not as well understood as diurnal use. In the FRE, the intertidal habitat is predominantly exposed during daylight hours during northward and southward migrations, but western sandpipers and other shorebirds also forage at night (Mouritsen 1994, Evans Ogden et al. 2005, Zharikov et al. 2009). Zharikov et al. (2009) examined the potential influence of light on the distribution of over-wintering dunlin in mudflat habitat at Roberts Bank and did not find a significant relationship between light and habitat use. Other research suggests that artificial and natural light (i.e., moonlight) improve visual foraging efficiency for shorebirds (Santos et al. 2010, Dwyer et al. 2013). Tactile foraging is the most common foraging mode observed in low-light conditions (Mouritsen 1994) and is thought to require more time and energy than visual foraging. The effect of artificial light on nocturnal predation of shorebirds is unknown, but increased foraging efficiency could be counteracted by increasing predator activity or hunting efficiency in well-lit areas (Clarke 1983).

3.0 METHODS

3.1 STUDY AREA

The study area was comprised of three 'study sites', referred to as Sturgeon Bank, Roberts Bank, and Boundary Bay (**Figure 3-1**). These three study sites encompass most of the FRE's intertidal mudflats and host the highest concentrations of shorebirds (Butler and Cannings 1989, Butler and Vermeer 1994, Butler et al. 2002). The intertidal habitat of the Sturgeon Bank study area was bound by Iona Jetty to the north and the South Arm of the Fraser River to the south. Roberts Bank was bound to the north by the South Arm of the Fraser River and to the south by the BC Ferries Causeway at Tsawwassen, with additional surveys conducted in the South Arm Marshes located east of Westham Island. The Boundary Bay study area was bound by Point Roberts to the west and the outflow of Serpentine River to the east.

Each study site was further delineated into 'survey areas', defining sections of mudflat that could be surveyed by a single observer during a single survey day. Sturgeon Bank and Roberts Bank were each comprised of three survey areas while Boundary Bay was comprised of five (**Figure 3-1**).

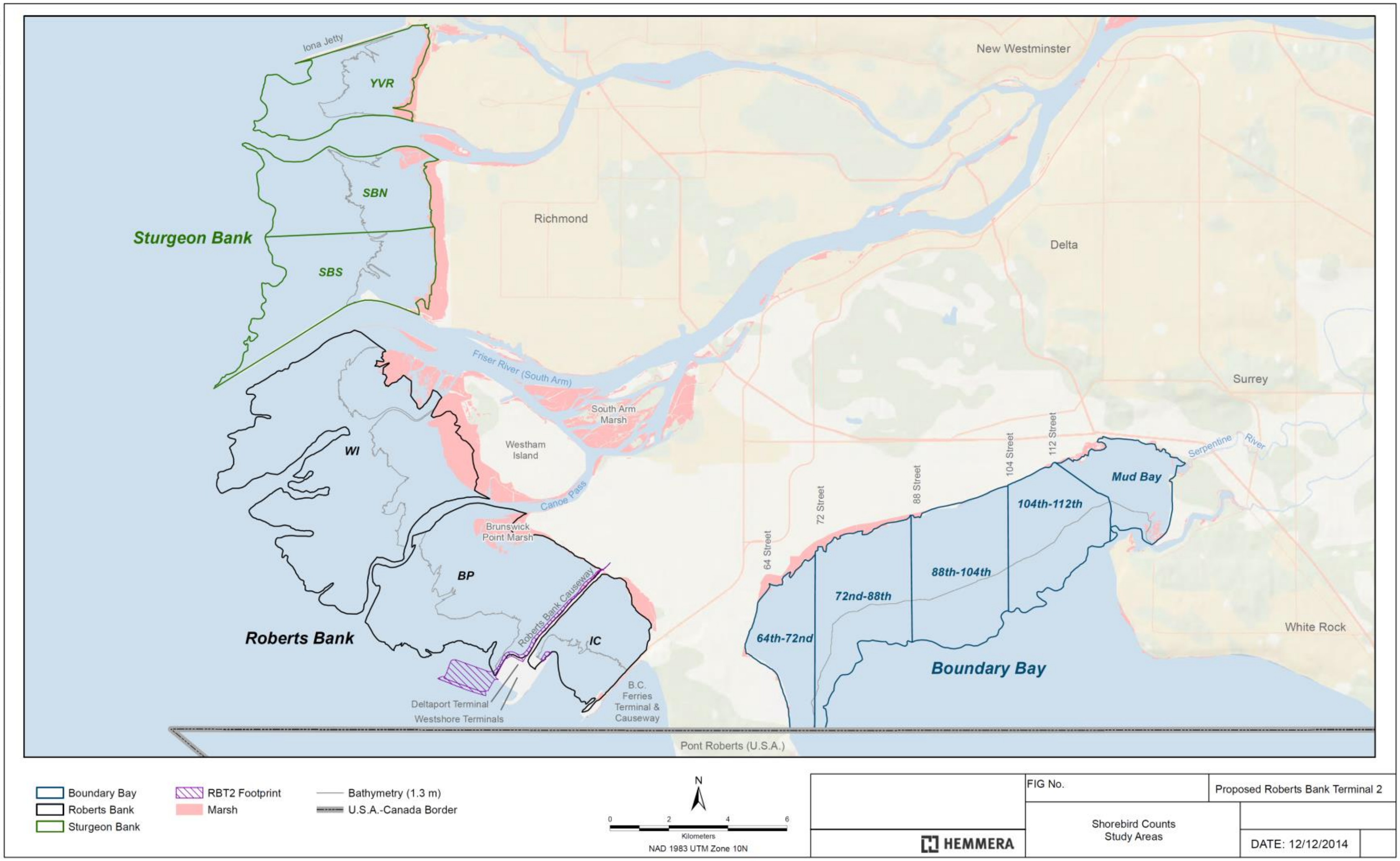
Field surveys were conducted within the intertidal areas exposed during low tide, which averaged 1.3 m during northward and southward migrations. The area of intertidal habitat exposed during 1.3 m tides is illustrated in **Figure 3-1** and presented by survey area in **Table 3-1**.

Table 3-1 Intertidal Area Exposed and Percentage of the Total Study Area in Survey Areas at the Average Low Tide (1.3 m) during Migratory Periods

Survey Area	YVR	SBN	SBS	WI	BP	IC	64-72	72-88	88-104	104-112	Mud Bay
Area (km^2)	6.94	7.08	7.59	15.88	17.99	6.51	8.42	9.83	9.23	6.11	7.32
Proportion of study area (%)	6.7	6.9	7.4	15.4	17.5	6.3	8.2	9.6	9.0	5.9	7.1

Notes: Survey area abbreviations: Vancouver International Airport (YVR), Sturgeon Bank North (SBN), Sturgeon Bank South (SBS), Westham Island (WI), Brunswick Point (BP), and Inter-causeway (IC).

Figure 3-1 Study Area Showing the Sturgeon Bank (Green), Roberts Bank (Black), and Boundary Bay (Blue) Study Sites, and Respective Survey Areas



Notes: Study areas are bound by the 0 m bathymetry chart datum. The gray line shows the 1.3 m bathymetry contour, and outlines the extent of intertidal area exposed on the average low tide during northward and southward migrations. Study site abbreviations: Vancouver International Airport (YVR), Sturgeon Bank North (SBN), Sturgeon Bank South (SBS), Westham Island (WI), Brunswick Point (BP), and Inter-causeway Area (IC). In Boundary Bay, study site names refer to the streets giving access to the dyke.

3.2 TEMPORAL SCOPE

Abundance and foraging use of the FRE by shorebirds are expected to show appreciable variation between northward and southward migration, as well as inter-annual variation. In consideration of such temporal variability, field studies were conducted during northward and southward migratory periods in 2012 and 2013 (**Table 3-2**).

Table 3-2 Survey Dates for Each Study Component

Year	Migration Direction	Study Component		
		Foraging Use	Abundance	Artificial Light
2012	Northward	Apr 17 – May 07	-	-
	Southward	Jul 02 – Sep 18	Jul 01 – Sep 26	-
2013	Northward	Apr 15 – May 07	Apr 06 – May 06	-
	Southward	Jul 14 – Sep 09	Jul 13 – Sep 09	-
2014	Northward	-	-	Apr 23 – Apr 29

Field studies in 2012 encompassed the full extent of migration periods. Given that the average length of stay for an individual western sandpiper is two to four days, surveys assessing shorebird abundance and foraging use were generally conducted every second day during northward migration and every third day during the more prolonged southward migration. Tidal conditions required adjustments of these schedules in some cases.

During the northward 2013 migration, abundance surveys were conducted on consecutive days around peak migration because tidal conditions meet the standardized criteria for surveys during the anticipated peak. During the 2013 southward migration, abundance surveys were conducted once every six days (instead of every three days) in areas with relatively few shorebirds (e.g., Inter-causeway Area and Vancouver International Airport (YVR)).

Nocturnal surveys to assess the influence of artificial light on shorebirds were conducted in 2014. The surveys were conducted near the western sandpiper northward migration peak and coincided with night-time low tides below 3.0 m.

3.3 Study Methods

3.3.1 Shorebird Foraging Use Surveys

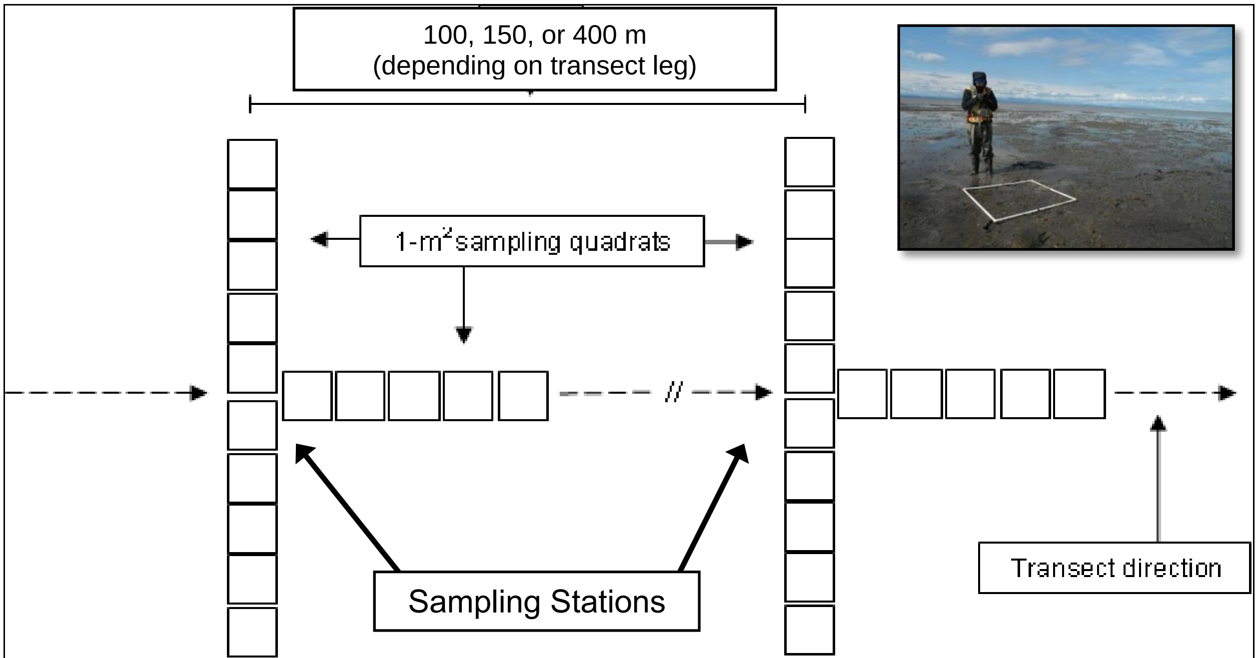
3.3.1.1 Overview

Shorebird foraging use of the FRE was assessed using methods developed by the Centre for Wildlife Ecology (CWE) of Simon Fraser University and described in Pomeroy (2005), which involve counting dropping (i.e., fecal) densities at sampling stations along transects. Dropping densities provide a sensitive and convenient measure of the intensity of spatial usage because they are produced frequently (i.e., 0.48 droppings/minute for western sandpipers) by foraging shorebirds and are washed away during high tide periods (Pomeroy 2005). Droppings in the upper intertidal zone may not be completely cleared during lower high tides; however, 'old' droppings can be identified by their discolored and aged appearance.

Shorebird droppings can be distinguished from those of gulls, ducks, and other larger bird species as they are typically smaller than the size of a Canadian quarter (<2.5 cm diameter). In addition, field observations found that dunlin droppings can be smaller or larger than the size of a Canadian dime, while western sandpiper droppings are generally dime-sized or smaller (Pomeroy 2005) and black bellied plover droppings are typically larger than a dime. While overlap in droppings size across species prevents definitive assignment to species, for qualitative assessments of differences in size class distributions, droppings were recorded in two categories, dime-sized or smaller, and dime to quarter size.

Droppings were counted using the procedure illustrated in **Figure 3-2**. Fifteen quadrats (each 1-m^2) were counted at each sampling station: ten quadrats perpendicular to the transect bearing (i.e., five to either side) and five along the transect bearing. To allow shorebirds time to feed and deposit droppings on the mudflats, sampling began 1.5 to 2.5 hours prior to the lowest tide. Dropping surveys were not conducted after periods of rainfall that reduced dropping presence.

Figure 3-2 Sampling Design at each Station to Assess Shorebird Usage of the Intertidal Mudflats.

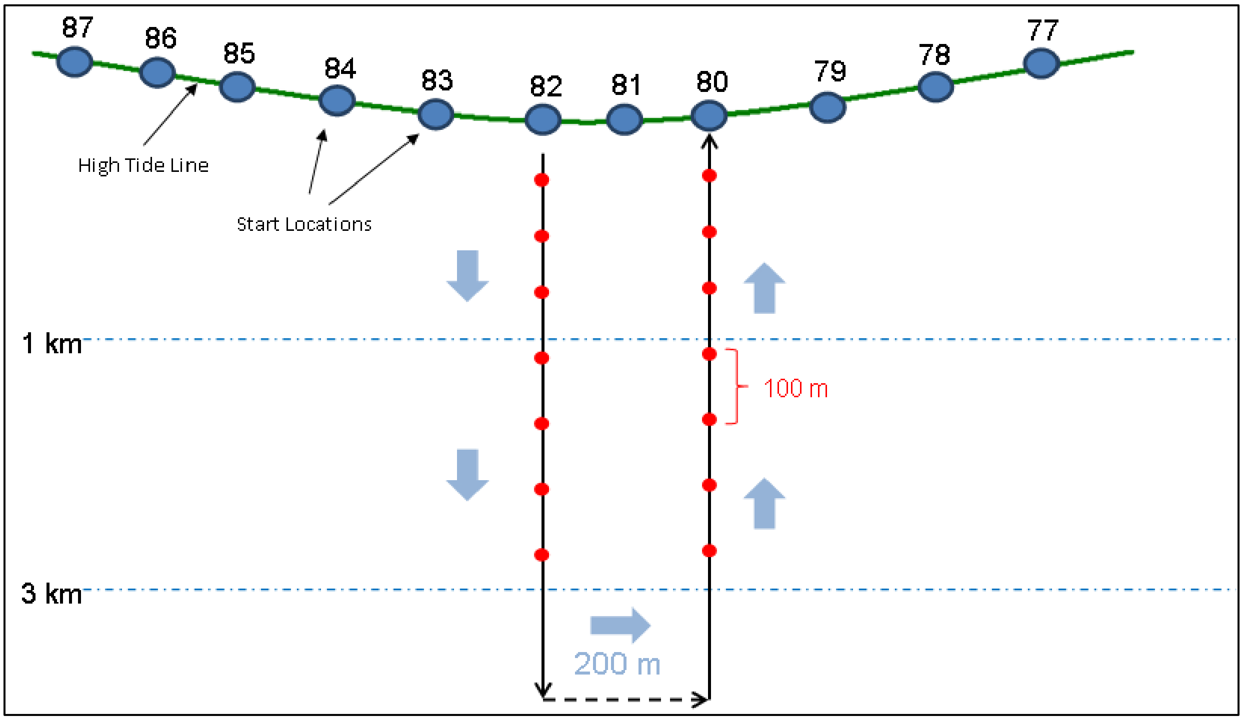


Notes: Inset photograph shows a biologist inspecting a 1-m^2 quadrat for shorebird droppings

3.3.1.2 2012 Northward Migration

During the 2012 northward migration, four dropping transects were surveyed at each study site (i.e., Sturgeon Bank, Roberts Bank, and Boundary Bay) on each survey day. Potential starting points of transects were located 100 m apart along the marsh and mudflat edge and numbered in ArcGIS 10.1 software (**Figure 3-3**). Start point(s) for each transect on each survey day were randomly selected from four groups of adjacent start points at each study site. The stratified allocation of transects provided approximately even coverage of all areas of the mudflats.

Figure 3-3 Transect Layout during the 2012 Northward Western Sandpiper Migration

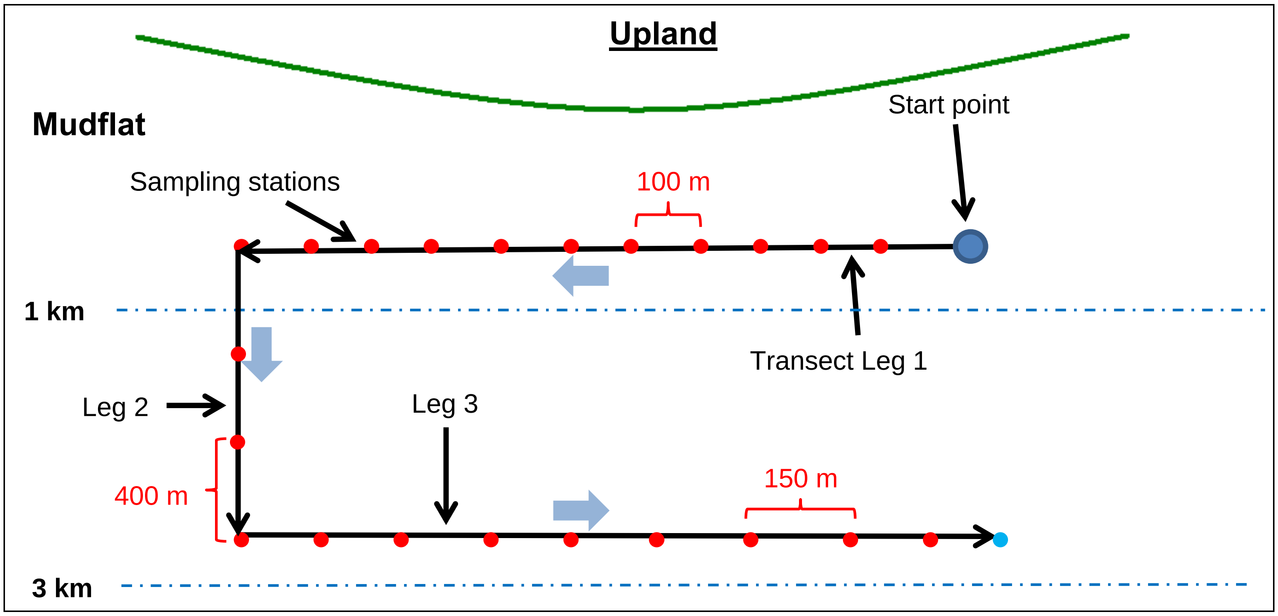


Surveyors walked along a pre-determined transect bearing perpendicular to shore, and extending from the edge of the intertidal mudflats to up to 3 km from shore. Sampling stations were located every 100 m (**Figure 3-3**). Upon reaching 3 km or the low tide line (whichever came first), the surveyors moved 200 m to the left and conducted a second parallel transect back to the shore. This pattern of shifting 200 m down the shoreline was repeated until the rising tide made mudflats inaccessible, or after six to seven hours of survey time. This ‘staple-shaped’ transect was used at all sites, as it made efficient use of field time

3.3.1.3 2012 Southward Migration

During the 2012 northward migration, shorebird usage was most concentrated in the upper intertidal zone (i.e., within 1 km from the marsh edge). To ensure adequate spatial resolution in this high-use area, southward migration sampling effort was stratified, with 60% of sample stations allocated within 1 km of shore, and 40% from 1 to 3 km of shore. Dropping counts were conducted every 100 m within the 0 to 1 km zone, every 150 m within the 1 to 3 km zone, and every 400 m along the perpendicular transect (**Figure 3-4**).

Figure 3-4 Staple Transect Design Used during the 2012 Southward Western Sandpiper Migration



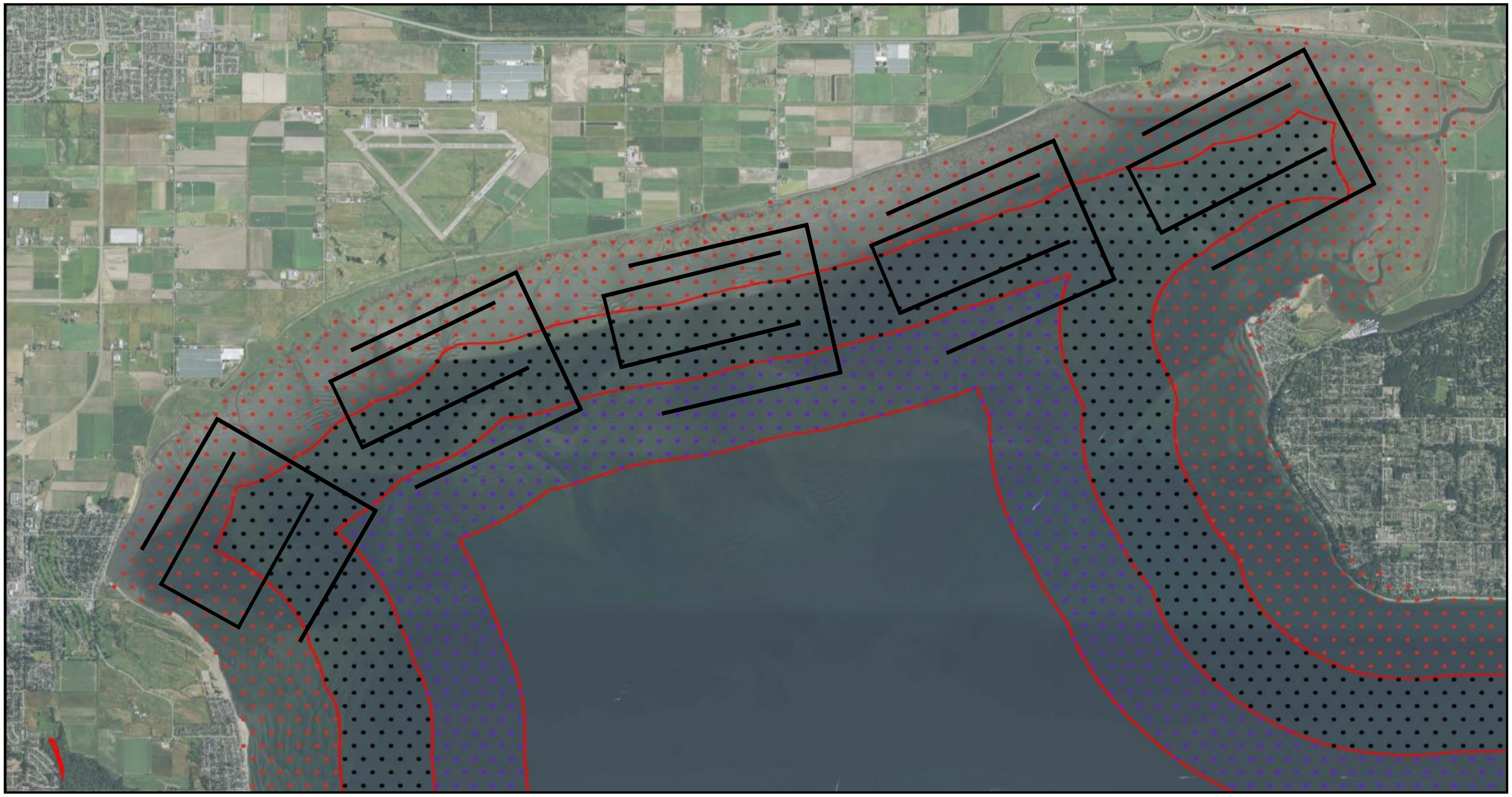
Approximately 10 staple transects were distributed across each study site. Five small staple transects with a comparatively short second leg were allocated within five larger staple transects (**Figure 3-5**). A grid of evenly dispersed potential transect start points was created using ArcGIS 10.1 software. Random start points were selected to allow for approximately even allocation of transects and maximum coverage of the mudflats at each site. Each day, two transects were surveyed at each site by a two-member field crew. Dropping counts were conducted along the transect by the first crew member and along a parallel transect at a distance of 100 m by the second crew member. On average, 10 transects were completed at each site every two weeks. At the beginning of each two-week sampling period, the start location of previous transects was randomly shifted 100 to 300 m to create 10 new transects.

A semi-random procedure was used to assign transects to survey days because tides restricted the area of mudflats exposed, thereby influencing which transects could be surveyed on any given day. If surveyors encountered the tide line prior to reaching the third leg of a transect they shifted their transect 50 to 100 m toward shore, conducting the leg roughly parallel to the tide line.

3.3.1.4 2013 Northward and Southward Migration

Sampling efforts in 2013 were stratified as in the 2012 southward migration with 60% of points within 1 km of shore and 40% from 1 and 3 km from shore. Sampling stations were spaced 100 m apart on transects within 1 km from shore, 150 m at 1 km to 3 km from shore, and 400 m apart on transects perpendicular to shore (**Figure 3-4**).

Figure 3-5 Example of Staple Transect Design at Boundary Bay, Delta, B.C.



Notes: Dots represent the grid of potential start points for transects. Black lines represent transects. Red lines are 1, 2, and 3 km from shore.

3.3.1.5 Quality Control and Assurance

Data were recorded on Android smartphones using Pendragon Forms software (Pendragon Forms VI 2012). Electronic records were uploaded directly into an electronic database that was examined for irregularities by data custodians trained in data management. An independent review of the raw dropping data was also conducted by staff involved in the field efforts, which included sorting of the data to identify anomalous records, as well as reviewing of the spatial data and habitat information to ensure all records were recorded within appropriate areas and habitat. Finally, summary statistics were reviewed by field coordinators to verify that the distribution of droppings reflected the general patterns of use observed in the field. Any data inconsistencies were examined and corrected.

3.3.1.6 Data Analysis

Preliminary analyses of droppings data found that separating droppings into the two size classes did not significantly improve models; therefore, all droppings smaller than a quarter were analyzed together.

Inverse distance weighted (IDW) interpolation was used to generate spatially smoothed illustrations of dropping densities within each migratory period of western sandpipers (i.e., adult southward, juvenile southward, and combined northward). The IDW interpolation approximated dropping densities at a resolution of 50 m^2 areas across the FRE intertidal zone using weighted by distance averages of the 12 nearest survey stations (i.e., the standardized number used in IDW interpolation across RBT2 studies). Since samples were most often collected within 50 m of one another, the distance within which twelve sites were sampled was generally 300 m or less. To limit the extent of interpolation into unsampled areas while allowing for the majority of areas to conform to the standard of averaging across twelve survey sites, 300 m was set as a maximum distance limit for interpolation. When fewer than twelve sites were present within 300 m, only sites within that distance were averaged for interpolation. Based on banding data collected from 2,750 western sandpipers captured during southward migrations since 1978, droppings from surveys conducted on August 2 and earlier were attributed to adults and droppings from August 3 and later were attributed to juveniles (Ydenberg et al. 2004). Dropping data collected during northward migration could not be differentiated by age.

Bar plots of mean dropping densities within survey areas in 2012 and 2013 were produced for northward, southward adult, and southward juvenile migrations to illustrate differences in intensity of use across survey areas in each year and migration. The average number of droppings in each survey area was estimated for each migration period and year by multiplying the mean density of droppings by the area of mudflats available to shorebirds on the average low tide (1.3 m). Proportions of droppings in each survey area were derived from these estimates, and illustrated with pie charts for each migration and year.

Shorebird dropping density records were zero-inflated (i.e., a large proportion of survey stations had no droppings). Consequently, differences in dropping densities could not be assessed with standard statistical analyses. Instead, models that specifically account for zero-inflated data were used to assess the relationship between dropping densities and factors with potential influence on foraging use, hereafter described as predictor variables. Zero-inflated models have two components, one component that calculates the probability of non-dependant (i.e., false) zeroes using a binomial regression, and a second component that models the dependent (i.e., true) zeroes with the non-zeroes using either a Poisson or a negative binomial distribution. False zeroes are records the model considers to be misrepresented as zeroes (e.g., a droppings survey in which a zero was recorded because random sampling missed droppings or droppings were less concentrated than one per 15 m^2), whereas true zeroes are records the model considers to represent complete absence of the study subject. The component of the model that accounts for false zero records is hereafter referred to as the `zero model`. Results relevant for the interpretation of relationships between predictor and dependent variables are derived from the component of the model that evaluates the true zero and non-zero records, hereafter referred to as the `count model`. Zero-inflated models with a negative binomial (ZINB) distribution were used due to over-dispersion of the droppings data (Zuur et al. 2009, 2012).

Predictor variables for shorebird dropping densities (**Table 3-3**) were chosen from a suite of environmental and spatial parameters related to shorebird distributions in previous studies (Yates et al. 1993, Zharikov et al. 2009). Prior to modelling, predictor variables were assessed for potential collinearity using variance inflation factors (VIF). All variables had VIF values less than two indicating no important collinearity, so each variable was included in the models. Some variables which have been previously related to shorebird prey abundance and distributions (e.g., sediment particle size) were excluded *a priori* because of known collinearities

Modelling of the relationships between dropping densities and Salinity, Total Organic Carbon (TOC), and Distance from Shore helped explain the factors influencing the distribution of foraging use across the FRE mudflats. Inclusion of Year, Shorebird Abundance, and Low Tide Height helped account for variation in the data unrelated to environmental factors and increase the power to detect significant relationships. Spatial covariance was found to be present and was therefore specified and included in all models.

Relationships between predictor variables and dropping densities were not consistent across the FRE and, consequently, could not be defined with a single model. Instead, six models were developed based on two migration periods (i.e., northward and southward migration) and three regions of the estuary. Separate models were developed for each migration period to account for the shift in select environmental characteristics (e.g., salinity and vegetation) between spring and summer. Models were developed for Sturgeon Bank and Westham Island (YVR, SBN, SBS, WI), Boundary Bay and Inter-causeway (IC, 64^{th} to 112^{th} streets), and Brunswick Point. Separate models were developed for the first two regions based on differences in sediment grain size and sources of baseline organic matter described by stable isotope signatures (Hemmera 2014*a*). A separate model was developed for the Brunswick Point survey area to specifically define the relationships between habitat characteristics and habitat use by shorebirds within the area most likely to experience changes as a result of the proposed RBT2 project.

Mud Bay was excluded from modeling analyses due to distinct salinity and organic matter sources from the rest of Boundary Bay, as well as missing data from the 2013 southward migration. Parameter estimates were determined for predictor variables in each model along with estimates of uncertainty (standard error). Measures of uncertainty were used to determine a probability value for the significance of each predictor variable's relationships to dropping densities. Likelihood ratio comparisons using chi-squared statistics were also used to determine the significance of relationships between predictor variables and dropping densities in the count model.

Table 3-3 Variables with Potential Influence over Shorebird Dropping Densities and Methods Employed for their Determination

Variable	Potential Influence on Dropping Densities	Method of Determination
Salinity	Influences abundance and composition of biofilm and invertebrate shorebird prey	Estimated using inverse distance weighted (IDW) interpolation from 50th percentile salinity data modeled by Northwest Hydrological Consultants*
% Total Organic Carbon in Sediments (TOC)	Describes the organic content of sediments which can influence the abundance and composition of shorebird prey	Estimated from IDW interpolation of TOC data from sediment samples collected from locations throughout the FRE
Distance to Shore	Related to tidal elevation which influences the proportion of time that sites are inundated and available to shorebirds as well as prey composition and abundance. Also related to predation danger from birds of prey (i.e., higher risk close to shore).	Determined using the marsh edge, the Roberts Bank and BC Ferries Terminal causeways and the Iona Jetty as the shoreline
Year	Inter-annual variation in use	Droppings data collected in either 2012 or 2013
Shorebird Abundance	Number of birds in the estuary on the day of the survey	Shorebird abundances observed during abundance surveys, or interpolated from abundance surveys conducted on subsequent and previous days
Low Tide Height	Available foraging area on the day of survey	Lowest tide during the tidal cycle in which each survey was conducted
Spatial Covariance	Locations that are close together are often similar due to proximity and, therefore, do not always represent independent samples.	The spatial variance structure was defined in the model within each area to account for the relatedness of samples across a gradient of proximities.

Notes: *Salinity was estimated from models using 50th percentile data from the month of April and August, 2012 for the northward and southward migrations, respectively. 2012 was an extreme freshet year resulting in higher than normal inputs of freshwater.

3.3.2 Shorebird Abundance Surveys

3.3.2.1 Overview

Abundance surveys were conducted by trained field staff to document the number and relative distribution of shorebirds across the FRE during migratory periods. Focal species were shorebirds and birds of prey that could influence shorebird distributions (e.g., peregrine falcon (*Falco peregrinus*), merlin (*Falco columbarius*), owls, eagles, and other raptors). Emphasis was also placed on recording great blue herons (*Ardea herodius fannini*) as they are of conservation concern (IBA Canada 2012).

Intertidal mudflats were surveyed on rising tides that concentrate birds, thus facilitating species identification and accurate estimates of flock sizes. Surveys were not conducted when ≥15 mm of rain was forecast for the survey period or if rainfall reduced visibility to 500 m. Surveys were cancelled and rescheduled if high winds (≥50 kph) were present at any of the survey areas. To minimize multiple counts of moving flocks, surveys were conducted simultaneously across survey areas where possible; however, this could not be done for all areas. At Boundary Bay, tides do not flood intertidal habitat until they reach a height of 3.8 to 4.0 m, while at Brunswick Point and the Inter-causeway Area, intertidal areas are flooded at a lower height of 3.6 to 3.8 m, and at Westham Island and Sturgeon Bank inundation occurs at 3.4 to 3.5 m. Consequently, surveys at Boundary Bay were conducted later relative to those at Roberts and Sturgeon banks. To document the possible movement of shorebirds between early-flooding and late-flooding sites, observers were stationed at the north end of Brunswick Point and the southwest end of Boundary Bay.

Field staff arrived at start locations 30 minutes prior to the survey start time to record site conditions, weather, raptor presence and behaviour, and to conduct a preliminary assessment of bird abundance and species composition. Small flocks (<50 birds) were enumerated by counting individual birds, while the size of large flocks was estimated by tallying the number of blocks of 10, 100, or 500 birds needed to encompass the entire flock (Bird Studies Canada 2011, US Geological Survey 2012). Due to survey distance (e.g., 500 m in many cases), and the occasional need to survey large flocks while in flight, there was significant potential to misidentify small sandpipers (e.g., western and least sandpipers); therefore, records of these species were grouped together as 'peep' sandpipers (i.e., a term commonly used to collectively refer to the smallest North American sandpipers). Peep sandpiper records are primarily representative of western sandpipers as previous studies have shown that ≤5% of small shorebirds captured within the FRE are semipalmated (*Calidris pusilla*) or least sandpipers (Lissimore et al. 1999). Shorebird flocks were only recorded as present in a survey area if they were observed foraging. Surveyors also documented flock movements between survey areas to account for flocks present within two or more survey areas in a single survey event.

3.3.2.2 Roberts Bank and Sturgeon Bank

Dykes at Sturgeon Bank and Westham Island were too far (>500 m) from mudflats to provide suitable vantage points for surveys. During tide heights appropriate for intertidal surveys at Sturgeon Bank and Westham Island, the tideline at Brunswick Point and the Inter-causeway Area was also too far from the dyke (>1000 m) for surveys. To conduct simultaneous counts and minimize the likelihood of double-counting, surveys at these sites were conducted on foot by observers traversing the intertidal mudflats. To maximize their ability to detect shorebirds, field staff maintained similar distances between the marsh edge and tide line. Surveys began at a tide height of 2.7 m when the tide line was generally less than 1 km from shore (marsh edges), allowing field staff to maintain distances equal to or less than 500 m from flocks. A single surveyor covered the intertidal area exposed at 2.7 m within each survey area at Sturgeon Bank (**Appendix A: Figure 1)** and Roberts Bank **(Appendix A: Figure 2)**. Surveyors used a combination of the naked eye, binoculars, and a spotting scope (Vortex Viper HD 20-60 x 80) to view and count birds (**Appendix C: Plate 8**). If surveyors observed flocks within their survey area, they approached closer to obtain more accurate counts; however, surveyors prioritized complete coverage of survey areas over obtaining exact bird counts, as rising tides generally limited the survey time to 0.75 to 1.5 hrs. Survey area boundaries were marked with reference locations loaded into handheld GPS units carried by the surveyor.

3.3.2.3 Boundary Bay

The dyke that separates Mud Bay and Boundary Bay from agricultural fields provides unobstructed vantage points over intertidal mudflats at a close distance (generally <100 m); therefore, surveys in these areas were conducted from the dyke. Since the intertidal flats of Mud Bay flood before Boundary Bay on rising tides, surveys began in Mud Bay as soon as birds were sufficiently close for accurate identification and abundance estimation (i.e., typically a tide height of 3.1 m and a distance of 700 to 800 m to the tide line).

Survey areas within Boundary Bay were divided by roads running perpendicular to the dyke (see **Appendix A: Figure 3**). Two field staff surveyed from Mud Bay to 72nd Street in a car, stopping to survey the intertidal every 400 to 500 m (**Appendix C: Plate 9**). The driver was a short distance surveyor (i.e., using the naked eye and binoculars) while the passenger was a long distance surveyor (i.e., using a spotting scope with a window mount). The most westerly survey area (i.e., 64th to 72nd Street) was covered by a separate surveyor who traversed the dyke on foot equipped with binoculars and a spotting scope. In addition to surveying the mudflats every 400 to 500 m, this surveyor recorded birds moving to and from Roberts Bank to account for flock movements and minimize double counts. The length of time available for surveys was controlled by the speed of the rising tide (i.e., 1.5 to 2 hrs).

3.3.2.4 South Arm Marshes

In 2013, mudflats in the South Arm Marshes (**Appendix A: Figure 4**) were surveyed by boat three times during the northward migration and five times during the southward migration. During southward migration, two surveys were conducted during the adult western sandpiper migration period and three during the juvenile migration period.

3.3.2.5 Quality Control and Assurance

All field staff attended an office-based orientation to review field and data collection protocols, and completed shorebird counting calibration exercises to reduce observer bias. Field staff reviewed strategies for counting large shorebird flocks and tested the accuracy of their flock size estimates with photographs of shorebird flocks of different sizes and densities (Bird Studies Canada 2011). Bird Studies Canada and the Canadian Wildlife Service set a precedent of obtaining accuracy to within 20% for shorebird surveys. Thus, observers repeated desktop training exercises and adjusted counting techniques as necessary until they attained or exceeded 20% accuracy. During the northward and southward migrations of 2013, additional quality assurance counts were conducted in the field to test for accuracy and consistency. Observers counted several flocks of various sizes, photographs were taken to determine true flock sizes, and true flock sizes were compared to each observer`s estimates. Mean observer accuracy was 0.96 and 1.00 during the northward and southward migration quality assurance counts respectively; however, accuracy was not within the 20% standard for all observers (**Appendix A: Figure 5**). To account for sub-standard accuracy of some observers (i.e., 5 of 36) and variable accuracy across observers, counts were adjusted using season and observer-specific correction factors. Specifically, dunlin and peep sandpiper counts from the field were multiplied by the inverse of each observer`s average count accuracy during quality assurance counts. Survey records of other species were assumed to be accurate as they were most often obtained by counting individuals one at a time. The accuracy of flock size estimates during quality assurance counts were examined at the level of individual counts as well. Summary statistics and a frequency distribution plot of count and observer accuracy were produced for reference (**Appendix A: Figure 6**).

Data recorded on field forms were reviewed after each survey to verify anomalous records, confirm that flock movements were properly accounted for, and ensure that multiple records of the same flock did not occur. Quality assurance measures to ensure data were entered and processed accurately included: 1) randomised checking of entered data against hardcopy forms; 2) sorting and searching of the electronic database to identify and address potential missing records, double entries, and anomalous results; and 3) cross-checking of summary figures via independent calculations.

3.3.2.6 Data Analysis

Estimates of Total Numbers of Shorebirds using the Estuary during Migrations

To determine the importance of the FRE for shorebirds during migration, abundances and published estimates of the average length of stay at migratory stopover sites were used to estimate the total number of western sandpipers and dunlin that use the estuary during migrations (i.e., cumulative abundance). Stopover durations of black-bellied plovers are unknown so estimates of their cumulative abundance could not be determined.

Western sandpipers spend between two and four days at stopover sites during northward and southward migrations (Ydenberg et al. 2004). The total number of western sandpipers migrating through the estuary was, therefore, estimated by summing abundances of peep sandpipers from every third day of each migration. For the northward migration, peep sandpiper abundances were summed from every third day between April 20 and May 8, 2013. Appropriate conditions for rising tide surveys only occurred at night from April 28 to May 2, 2013 so abundance surveys were conducted during this time. Instead, abundance data collected by the Canadian Wildlife Service (CWS) during falling tides at Brunswick Point on those dates were used as a conservative estimate of FRE abundance. Abundance surveys conducted during 2012 encompassed the entire southward migration of western sandpipers, whereas surveys in 2013 only encompassed the peaks of the juvenile and adult migration. Consequently, only data from 2012 were used to estimate the cumulative abundance of western sandpipers during the southward migration. Surveys conducted every three days from July 4 to August 2, and from August 3 to September 26, 2012 were summed for estimates of cumulative abundance for adult and juvenile western sandpipers, respectively (Ydenberg et al. 2004).

Length of stay for dunlin during the northward migration can be as long as 11 days in April, but shortens to five or less by May (Warnock et al. 2004). Because surveys were primarily conducted in April, surveys with the highest counts that were conducted 9 to 11 days apart were summed to estimate cumulative abundance (i.e., April 11, 25, and May 4, 2013). Surveys were not conducted during the dunlin's southward migration, so no estimates of cumulative abundance were determined for that period.

Shorebird Abundances and Densities across the FRE

To assess the importance and quality of habitat in survey areas adjacent to the RBT2 project location (BP, IC), abundances and densities in these areas were compared to those in other parts of the study area during the 2012 and 2013 southward migration, as well as the 2013 northward migration. Survey data from 2012 and 2013 southward migrations were analyzed separately because survey efforts were expanded in 2013 and included additional survey areas relative to 2012. Within the southward migrations, abundances and densities of juvenile and adult western sandpipers were examined separately as well, to account for variable distributions and greater abundances during the juvenile migration. Comparisons were made for black-bellied plovers and peep sandpipers during all migrations, and for dunlin during the 2013 northward migration (**Table 3-4**).

In order to gauge the relative importance of habitat for shorebirds across the study area, the proportions of shorebirds observed in each survey area were determined. Additionally, statistical comparisons were conducted to assess the importance of survey areas adjacent to the proposed Project location relative to rest of the estuary. Specifically, abundances of shorebirds within the Brunswick Point and Inter-causeway survey areas were compared to total abundances from areas influenced by flow from the Fraser River at Sturgeon Bank and Westham Island (counts summed from YVR, SBN, SBS, WI) and from more marine areas with relatively low freshwater inputs in Boundary Bay (counts summed across 64-112th streets and Mud Bay). These two regions were defined for comparison based on a range of characteristics that had potential to influence the abundance and community of shorebirds: location, organic content (%TOC), average sediment grain size, salinity, and sources of baseline organic nutrients.

To assess the relative quality of habitat for shorebirds across the study area, average densities were determined for each survey area. Densities were calculated by dividing the average abundance of birds by the area exposed on the average winter low tide (1.3 m: **Figure 3-1; Table 3-1**). In order to describe habitat quality and make comparisons across the study area at as high a resolution as possible, statistical analyses compared shorebird densities in the Brunswick Point and Inter-causeway survey areas to densities reported within each survey area.

Comparisons of shorebird density and abundance during the 2013 northward migration were made for each of three periods in which abundance surveys were conducted: early shorebird migration (April 6 to 11; n = 3); anticipated peak western sandpiper migration (April 20 to 27; n = 7); and late shorebird migration (May 3 to 6; n = 3). Considering a typical length-of-stay of three days, survey frequency of three days or less, and a high fidelity to survey areas (Butler et al. 2002), surveys should provide near complete records of peep sandpipers that used the FRE during the early, late, and anticipated peak migration. Thus, average abundances and densities of peep sandpipers from surveys were considered to be true averages rather than a sample and were compared directly (i.e., without statistical analyses) between survey areas adjacent to the Project and other areas in the FRE.

During April 20 through 27, surveys were conducted on seven of eight days and offer an almost complete record of distributions and densities of all shorebirds. Mean abundances and densities of all shorebird species were, therefore, compared directly for that period. There is no evidence of site fidelity at migratory stopover sites for dunlin or black-bellied plovers, and hence these data may provide an incomplete record (i.e., sample) of abundances and densities during the early and late migration periods. Furthermore, due to dunlin’s duration of stay exceeding survey frequency during the early (April 6 to 11) and late (May 3 to 6) periods of the northward migration, surveys were not considered independent samples and statistical analyses could not be used to compare densities or abundances. The same constraints were assumed to be true for black-bellied plovers. Nevertheless, means and standard deviations of dunlin and black-bellied plover abundances and densities are presented for the early and late northward migration and qualitative comparisons are made.

Movements of peep sandpipers and other shorebirds stopping-over in the FRE during the southward migration may be wider ranging than observed in western sandpipers during the northward migration. This uncertainty requires that survey data from southward migrations be taken as a sample of potentially more broadly varying densities and abundances in the days between surveys. In these cases where surveys were conducted with a frequency matching or exceeding the length of stay of western sandpipers, statistical analyses were employed to determine the significance of differences between mean abundances and densities.

Analyses comparing abundances and densities of birds across areas of the FRE during the southward migration were conducted with ANOVA analyses blocked by survey date. Because the average migratory stopover duration of western sandpipers was generally matched with survey frequency (i.e., three days), each survey during the southward migration was considered a sample of an independent group of birds. ANOVA analyses require a normal distribution (i.e., bell-curve distribution) of data; therefore, analyses only considered abundance data from surveys conducted during and around the peak of migratory periods (**Table 3-4**) and all abundance and density data were log-transformed before analyses. Additionally, survey areas where a disproportionate number of zero records (i.e., surveys in which no shorebirds were detected) relative to a normal distribution were excluded from analyses. Specifically, survey areas with three zero records were always excluded and survey areas with two zero records and a relatively small number of samples (n < 9) were also excluded.

Table 3-4 Surveys Considered in Density and Abundance Comparisons across Survey Areas during Migratory Periods in the Fraser River Estuary

Migration	Species/Age Class	Survey Dates	Number of Surveys
2012 Southward	Adult Peep Sandpipers Juvenile Peep Sandpipers Black-bellied Plovers (BBPL)	Jul 7 – 31 Aug 18 – Sep 19 Aug 15 – Sep 10	7 11 10
2013 Northward	Early Migration*: Dunlin, BBPL Middle Migration: Dunlin, BBPL, Peep Sandpipers** Late Migration: Dunlin, BBPL, Peep Sandpipers	Apr 6-11 Apr 20-27 May 3-6	3 7 3
2013 Southward	Adult Peep Sandpipers Juvenile Peep Sandpipers BBPL	Jul 13 - 21 Aug 18 – Sep 5 Aug 18 – Sep 8	5 7 8

Notes: *Comparisons were not made for peep sandpipers due to minimal presence (<10 individuals); **The peak of the peep sandpiper migration began on April 27. Density and abundance comparisons for peep sandpipers were, therefore, made separately for early migration (April 20 to 26) and peak migration (April 27). In contrast, black-bellied plover and dunlin numbers were relatively consistent during this period and comparisons were made using all survey dates.

Abundance and density data were assessed for temporal autocorrelation across survey dates using a time series analysis within the modeling platform of JMP Ver. 12.0. Densities and abundances during and surrounding peak migration were not significantly temporally correlated. Following ANOVAs, pairwise comparisons between individual survey areas were conducted using significance levels adjusted for multiple comparisons (Tukey's all-pairs comparisons). Tukey's adjustments for multiple comparisons across numerous sites can reduce the power to detect differences among survey areas; however, exclusion of survey areas with multiple zero records limited comparisons amongst survey areas. Four to six survey areas were considered in most analyses.

Cumulative counts from all surveys were used to determine the proportion of shorebird species recorded in each survey area within each migratory period and year. Survey data collected on non-shorebird species were also summed for each survey area within each migratory period and year.

3.3.2.7 Comparison of Survey Techniques

During the southward migration of 2013, simultaneous shorebird abundance surveys were conducted at Boundary Bay from the dyke (as done during normal surveys at Boundary Bay) and by traversing the mudflats on three separate survey days. Abundance estimates from the two survey types were compared to test for an effect of survey methods used at Boundary Bay and other sites. Survey method effects were also tested by comparing the results of abundance surveys to results from dropping density surveys. More specifically, proportions of droppings observed within each survey area relative to the total droppings across the estuary were compared to the same proportion of total shorebird abundance records. Survey areas in which the proportions of droppings and abundances were similar (e.g., 40% of droppings and 42% of shorebird abundances) received values near one, while higher proportions of droppings and abundances yielded higher or lower values respectively. These comparisons were made for each migration in which abundance surveys were conducted: 2012 and 2013 southward migrations; and the 2013 northward migration.

3.3.3 Influence of Artificial Light Study

3.3.3.1 Overview

To assess the impacts of artificial light on foraging shorebird distribution, nocturnal surveys were conducted adjacent to and north of Roberts Bank terminals (i.e., Brunswick Point), which was the survey area with the highest level of artificial light. Nocturnal usage surveys were conducted with the assistance of night vision optics (Armasight NYX-14 GEN 2+ monocular) with 5x magnification lens (**Appendix C: Plate 1**). To limit the effect of tide height on sandpiper distributions, surveys were generally conducted at tide heights between 2.0 and 3.0 m. Surveys were not conducted if visibility was impeded within 100 m or on nights with ≥15 mm of rain or ≥50 kph winds forecasted for Delta, B.C. Forty-one surveys were conducted, limited by tidal conditions and equipment resources. Surveys were distributed randomly across Brunswick Point at sites devoid of tidal channels, depressions, or raised mud / mud banks to control for their influence on ability to accurately detect shorebird abundance (**Figure 3-6**). Prior to conducting surveys, sampling areas were checked for appropriate habitat (i.e., mudflat covering ≥75% of the survey area), and PVC markers were placed in the center of each area.

3.3.3.2 Survey Techniques

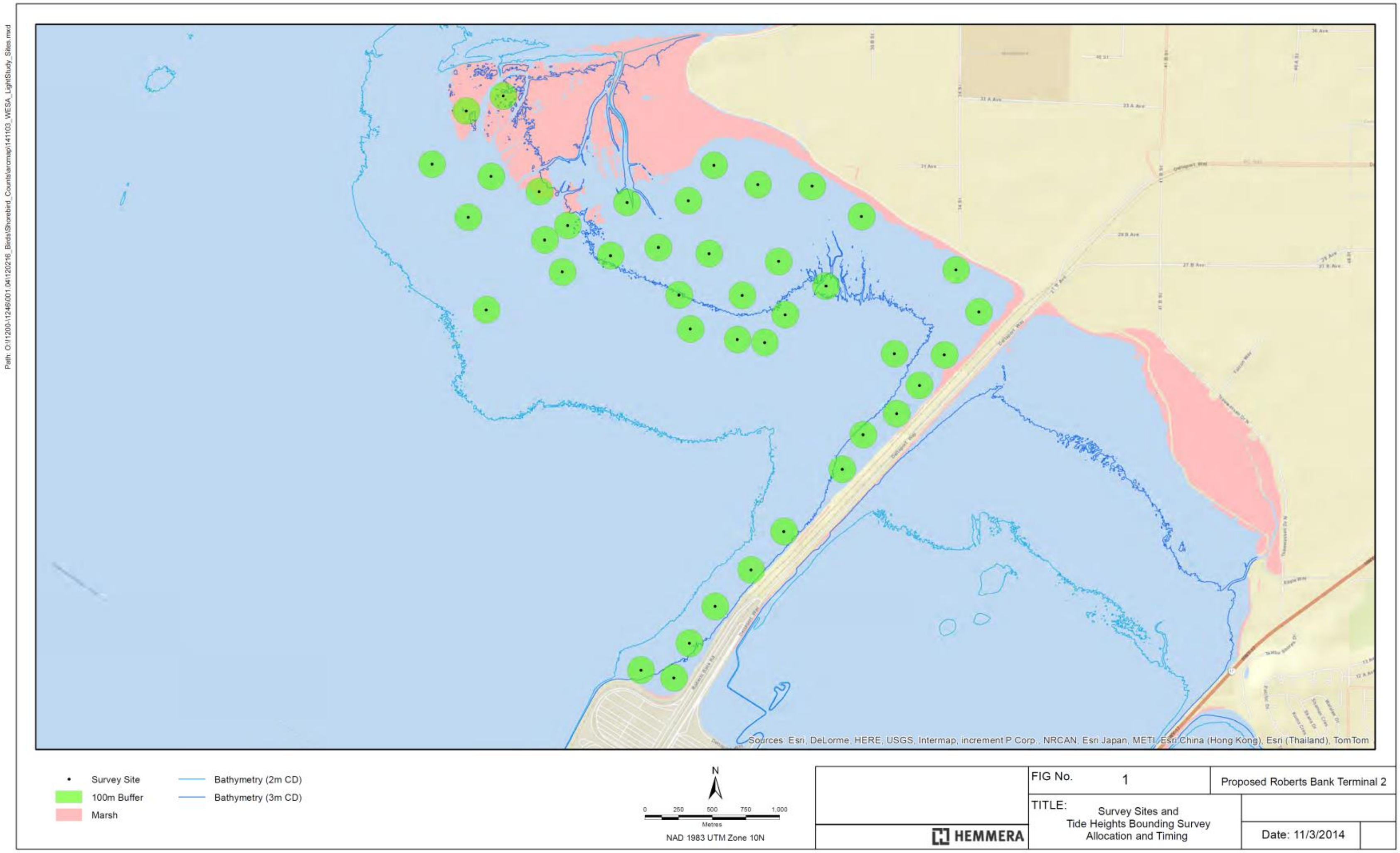
Each nocturnal usage sample consisted of a 20 minute survey of shorebird abundance within a 100 m radius circle. Observers recorded wind, temperature, precipitation, visibility, and cloud cover immediately before surveys, and conducted a preliminary scan of the sampling area at a distance of 125 m from its centre. Using handheld GPS units to measure distance, observers approached the centre of the sampling area to within 50 m, scanning every 25 m to ensure no birds were flushed without being counted. At a distance of 50 m from the centre, surveys were conducted to record all birds within 50 m of the observer. The 50 m distance was approximated using the field of view of the night vision equipment with reference to the PVC marker at the centre of each sampling area. After each 360 degree, 50 m scan, the observer moved 25 m in a counter-clockwise direction, circumnavigating the centre of the survey area at a distance of 50 m (**Figure 3-7**). The total number of shorebirds and maximum flock size encountered during each survey were recorded. Percent cover of vegetation and standing water (i.e., 1 to 5 cm in depth) was also estimated to the nearest 10%.

Following surveys, two light measurements were taken from the centre of sampling areas using an Extech LT300 light meter. A measurement of skylight was taken by facing the light sensor towards the sky at a distance of 50 cm from the ground and recording the range and average reading. A direct measurement of light from Roberts Bank terminals was also taken by facing the light sensor towards the terminals and recording the average and range of readings for the brightest part (as determined by the light readings).

3.3.3.3 Quality Control and Assurance

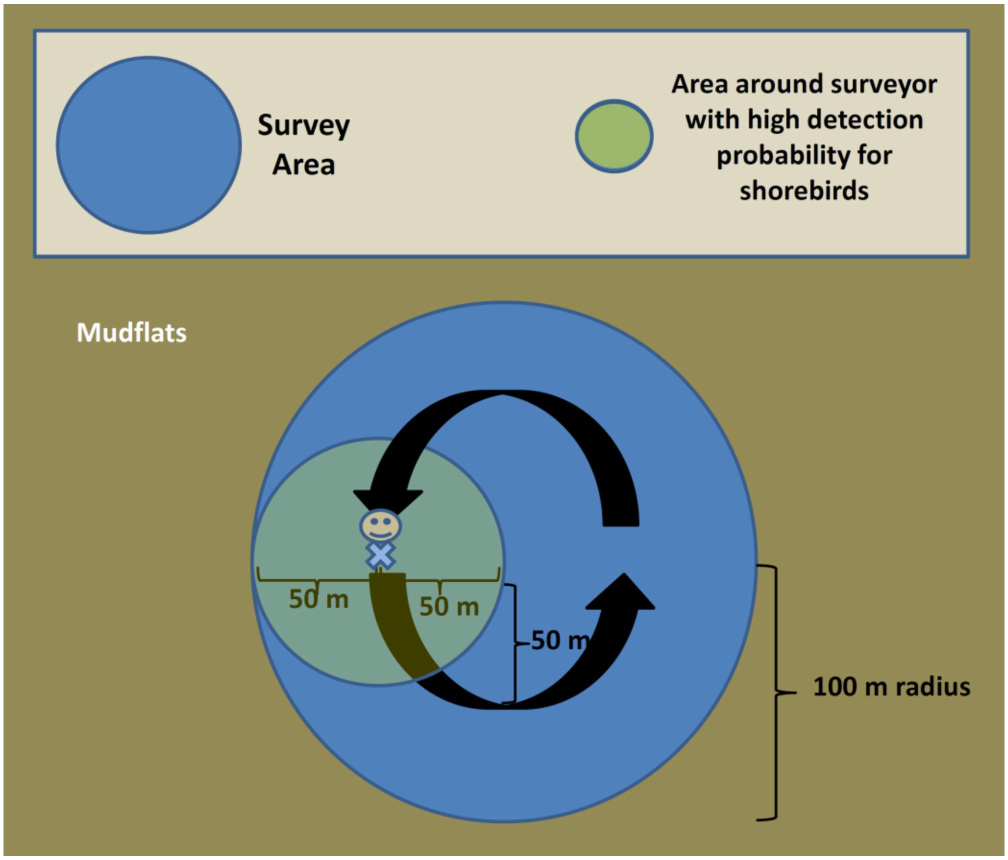
Quality control was enforced with an office orientation and training day. Additionally, each crew member conducted their first survey with oversight from either the field program leader or an experienced crew member to ensure survey methods were standardized across observers. Data forms were reviewed each night to ensure no fields were left blank. Data forms were reviewed the following day by the field program leader and any inconsistencies or anomalous records were discussed with crew members. Quality assurance measures to ensure data were entered and processed accurately were the same as described for the shorebird abundance data.

Figure 3-6 Sampling Areas for Nocturnal Surveys of Migrating Shorebirds to Assess Intertidal Habitat Use during the 2014 Northward Migration



Notes: Tides never fell below the 2.0 m tide line during the western sandpiper migration. Surveys were generally conducted at tide heights ≤3.0 m.

Figure 3-7 Diagram of Nocturnal Usage Survey Area and Method



3.3.3.4 Data Analysis

Nocturnal shorebird distributions were modelled using logistic regressions that describe the presence or absence of sandpipers in relation to predictor variables with anticipated or potential influence on shorebird distributions (**Table 3-5**). A presence/absence model was used because of the highly variable distributions of abundances observed during surveys as well as shorebirds' tendency to forage in flocks rather than independently (Zharikov et al. 2009). Prior to modeling, all variables were assessed for collinearity using a required criterion of variance inflation factors (VIF) ≤ 4 for inclusion in the model. Salinity, TOC, and Distance to Shore all exceeded this threshold; however, following removal of the variable with the highest VIF (Distance to Shore: 8.2), VIFs were all less than two allowing inclusion of all other variables in the model selection process. Model selection was conducted using a backwards, stepwise approach. Predictor variables with the weakest relationship to dropping densities were sequentially removed from a full model including all variables of *a priori* interest (**Table 3-5**) until removing variables no longer improved the strength of the model (i.e., the fit of the model to the data). Model strength was assessed with Akaike's Information Criteria (AIC), which is a likelihood criterion that compares models based on a combination of their description of the dependent variable and model parsimony, and selects models with fewer parameters over more complex models. The most supported model receives the lowest AIC value and establishes a standard value of 0 ΔAIC to which other models are compared. AIC values within 2 of the lowest AIC (i.e. ΔAIC ≤2) indicate models are competitive with the most supported model (Burnham and Anderson 2002). All models with ΔAIC ≤2 of the best supported model were analyzed with a general linear model, and probability values describing the significance of each predictor variable in the model were determined.

Following model selection, spatial autocorrelation of the data was tested using variogram analysis of the best fit model (i.e., winning model) residuals. No significant residual correlation was present indicating that variance in the data was unrelated to the distance between surveys.

Table 3-5 Variables with Potential Influence over Nocturnal Use of Intertidal Habitat by Shorebirds and Methods Employed for their Determination

Variable	Potential Influence on Abundance	Method of Determination
Light	Increased foraging and/or predation danger	Light meter sensitive to 0.01 lux measuring direct light from the brightest source from any direction.
Salinity	Influences abundance and composition of biofilm and invertebrate shorebird prey	Estimated using inverse distance weighted (IDW) interpolation from 50th percentile salinity data modeled by Northwest Hydrological Consultants*
% Total Organic Carbon in Sediments (TOC)	The organic content of sediments can influence the abundance and composition of shorebird prey	Estimated from IDW interpolation of TOC data from sediment samples collected from locations throughout the FRE
Surface Water	Potential influence on prey type and availability	Estimate of percent cover at survey stations (1 to 5 cm depth)
Distance to Shore	Related to tidal elevation which influences the proportion of time that sites are inundated and available to shorebirds as well as prey composition and abundance. Also related to predation danger from birds of prey (i.e., higher risk close to shore).	Determined using the marsh edge, the Roberts Bank and BC Ferries Terminal causeways and the Iona Jetty as the shoreline
Tide Height	Available foraging area at the time of survey	Tide height in the middle of each survey
Tide Line	Shorebird foraging is often concentrated at tideline.	Surveys categorized as at the tide line or not

Notes: *Salinity estimated from models using percentile data from the range predicted during April 2012 (an extreme freshet year).

4.0 RESULTS

This section presents the main findings of the study, and describes data gaps and potential biases. For ease of reference, results comparing habitat use across survey areas are color coded for Sturgeon Bank (green), Roberts Bank (gray), and Boundary Bay (blue).

4.1 SHOREBIRD FORAGING USE

Overall Dropping Densities across Migrations and Years

Across the estuary, dropping densities were greatest during the northward migration, intermediate during the southward migration of juvenile western sandpipers, and lowest during the southward adult migration (**Appendix A: Figure 7**). Mean dropping densities across the estuary were slightly greater in 2012 than 2013, but inter-annual variation was only 5 to 13% across the three migrations.

Dropping Densities and Estimated Proportions of Usage in Survey Areas

The proportions and densities of droppings in survey areas varied across migration periods, but were similar across years except during the southward adult migration (**Figure 4-1**, **Figure 4-2**, **Figure 4-3**, **Figure 4-4**, **Figure 4-5**, and **Figure 4-6**).

During the 2012 and 2013 northward migrations, shorebird dropping densities were greatest at Brunswick Point, followed by Westham Island (**Figure 4-1)**. In both years, these areas contained an estimated 75% of total droppings in the FRE (**Figure 4-2**). Dropping densities were similar across survey areas at Sturgeon Bank and Boundary Bay which contained 5 to 14% and 12 to 18% of total estimated droppings, respectively.

During southward adult migrations, proportions and densities of droppings within survey areas varied substantially across years. In 2012, mean dropping densities were highest within Boundary Bay where an estimated 67% of droppings occurred (**Figure 4-3** and **Figure 4-4**). In 2013, mean dropping densities were highest within Brunswick Point where an estimated 85% of droppings occurred (**Figure 4-3** and **Figure 4-4**).

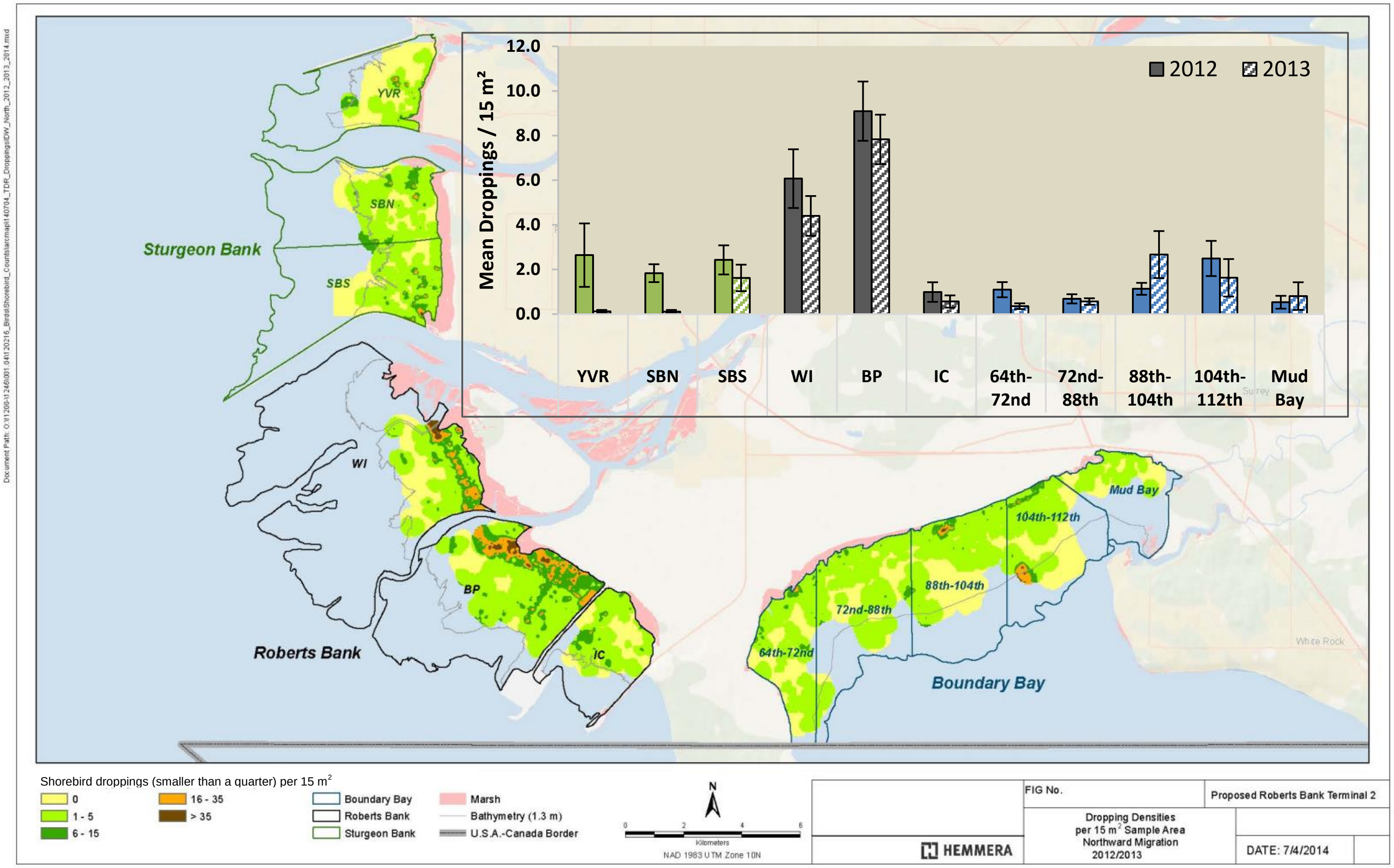
During southward juvenile migrations, proportions and densities of droppings were generally highest in Boundary Bay. In 2012, dropping densities were highest between 88th and 112th streets where an estimated 50% of droppings occurred (**Figure 4-4** and **Figure 4-5**). During the 2013 southward juvenile migration, survey areas in Boundary Bay hosted 67% of all droppings estimated to occur across the estuary; however, dropping densities at Brunswick Point were similar or greater than those densities occurring in Boundary Bay (**Figure 4-4** and **Figure 4-5**).

Droppings in the Inter-causeway Area occurred at low densities during all migrations and never comprised more than 2% of total FRE droppings estimates. Mean dropping densities in survey areas across migration periods and years are listed along with sample sizes, standard deviations, and standard errors in **Appendix B: Tables 5, 6,** and **7**. Estimates of the total number of droppings in each survey area on an average day are also presented for each migration and year in these tables.

Spatial Distribution of Droppings

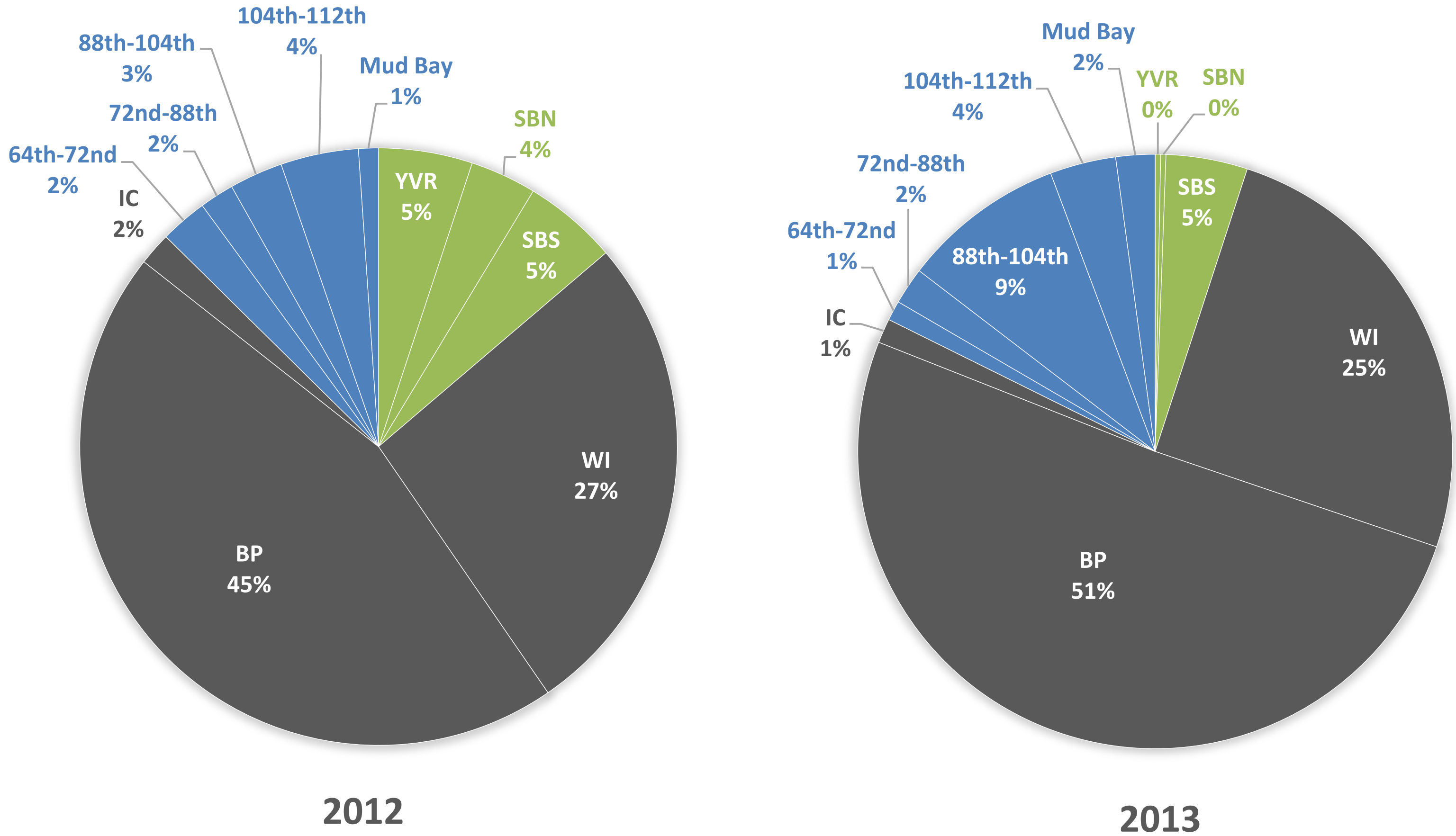
Foraging use during northward and southward migrations was primarily recorded within 1.5 km of the marsh edge (**Figure 4-1**, **Figure 4-3**, and **Figure 4-5**). During the southward migration, the highest concentrations of droppings (i.e., >15/m^2) were found between 100 to 500 m from shore. During the northward migration, similarly high dropping densities were located in these same areas, but high dropping densities were also observed further from shore, most notably at Westham Island and Brunswick Point. In areas with high dropping densities, foraging use generally declined within 200 m from shore.

Figure 4-1 Shorebird Dropping Densities across the Fraser River Estuary Mudflats and Mean Dropping Densities within Survey Areas: 2012 and 2013 Northward Migration



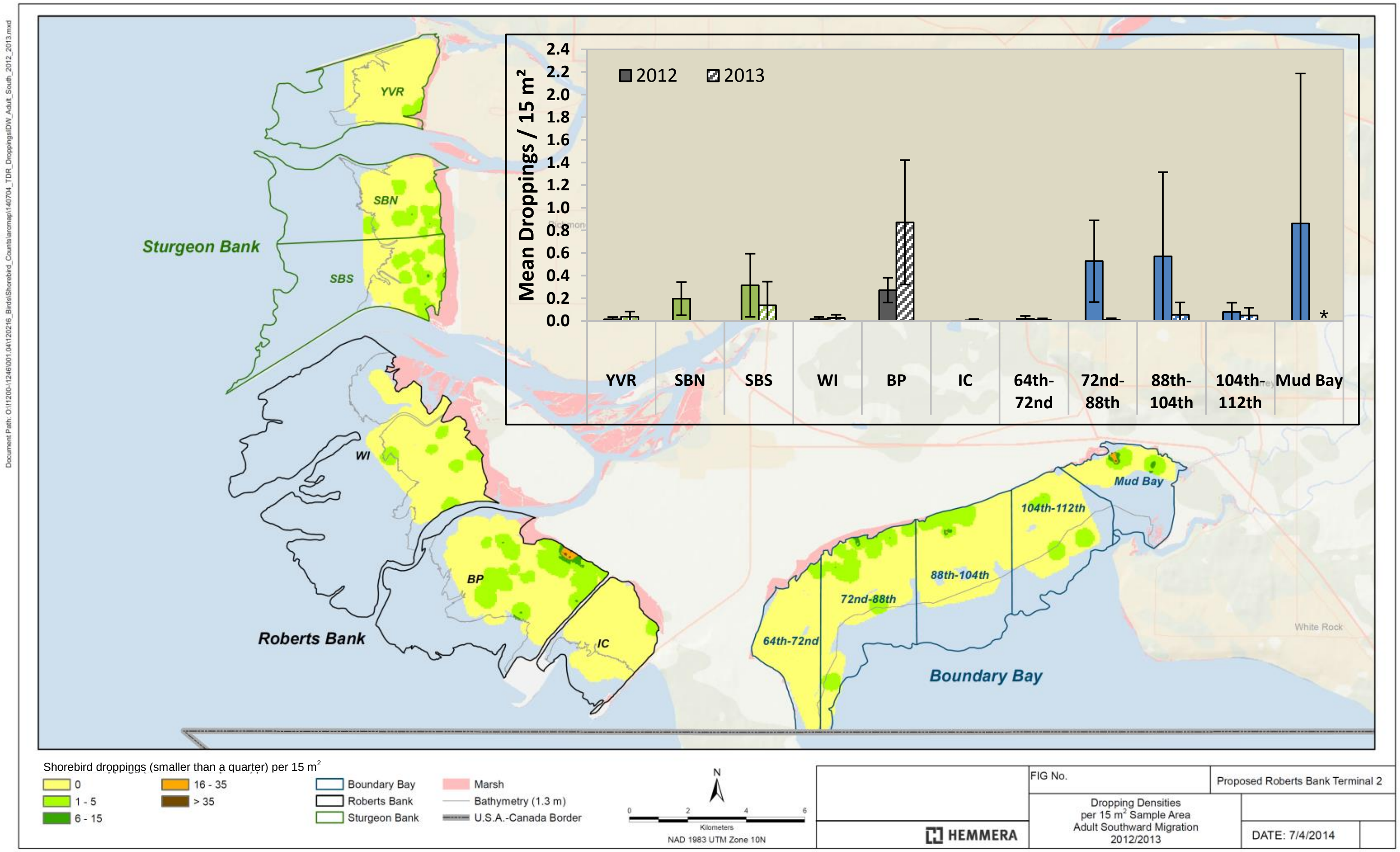
Notes: Dropping densities estimated across the estuary using inverse distance weighted (IDW) interpolation of survey data. Interpolation distance = 300 m. Bar plots and whiskers show mean dropping densities and two standard errors for each survey area. Survey area abbreviations: Vancouver International Airport (YVR), Sturgeon Bank North (SBN), Sturgeon Bank South (SBS), Westham Island (WI), Brunswick Point (BP), and Inter-causeway (IC). In Boundary Bay survey area names refer to the streets giving access to the dyke.

Figure 4-2 Proportions of Shorebird Foraging Use (Droppings) across Survey Areas of the Fraser River Estuary: 2012 and 2013 Northward Migration



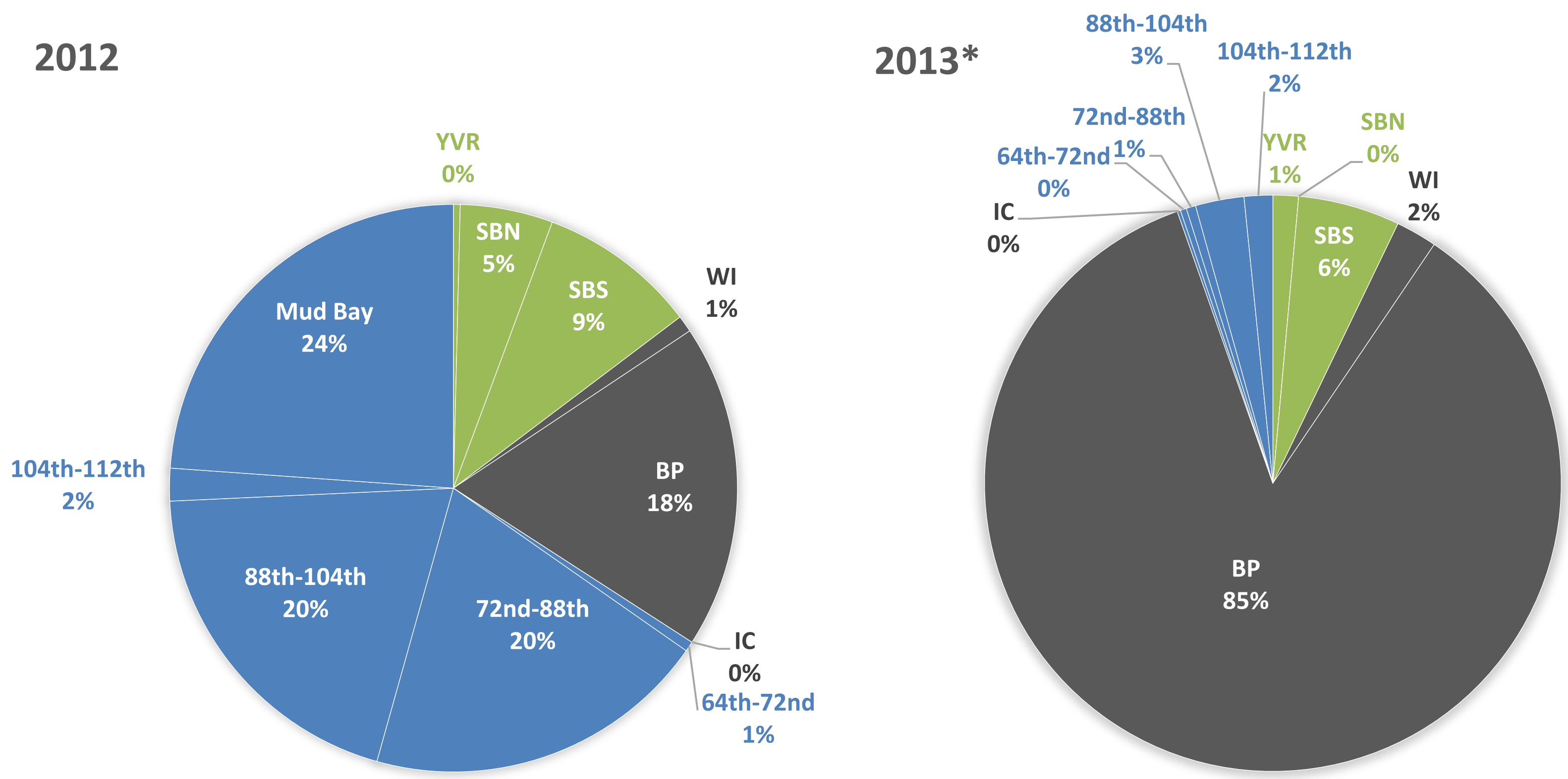
Notes: Proportions of droppings at Sturgeon Bank, Roberts Bank, and Boundary Bay are reported in green, gray, and blue respectively

Figure 4-3 Shorebird Dropping Densities across the Fraser River Estuary Mudflats and Mean Dropping Densities within Survey Areas: 2012 and 2013 Southward Adult Migration



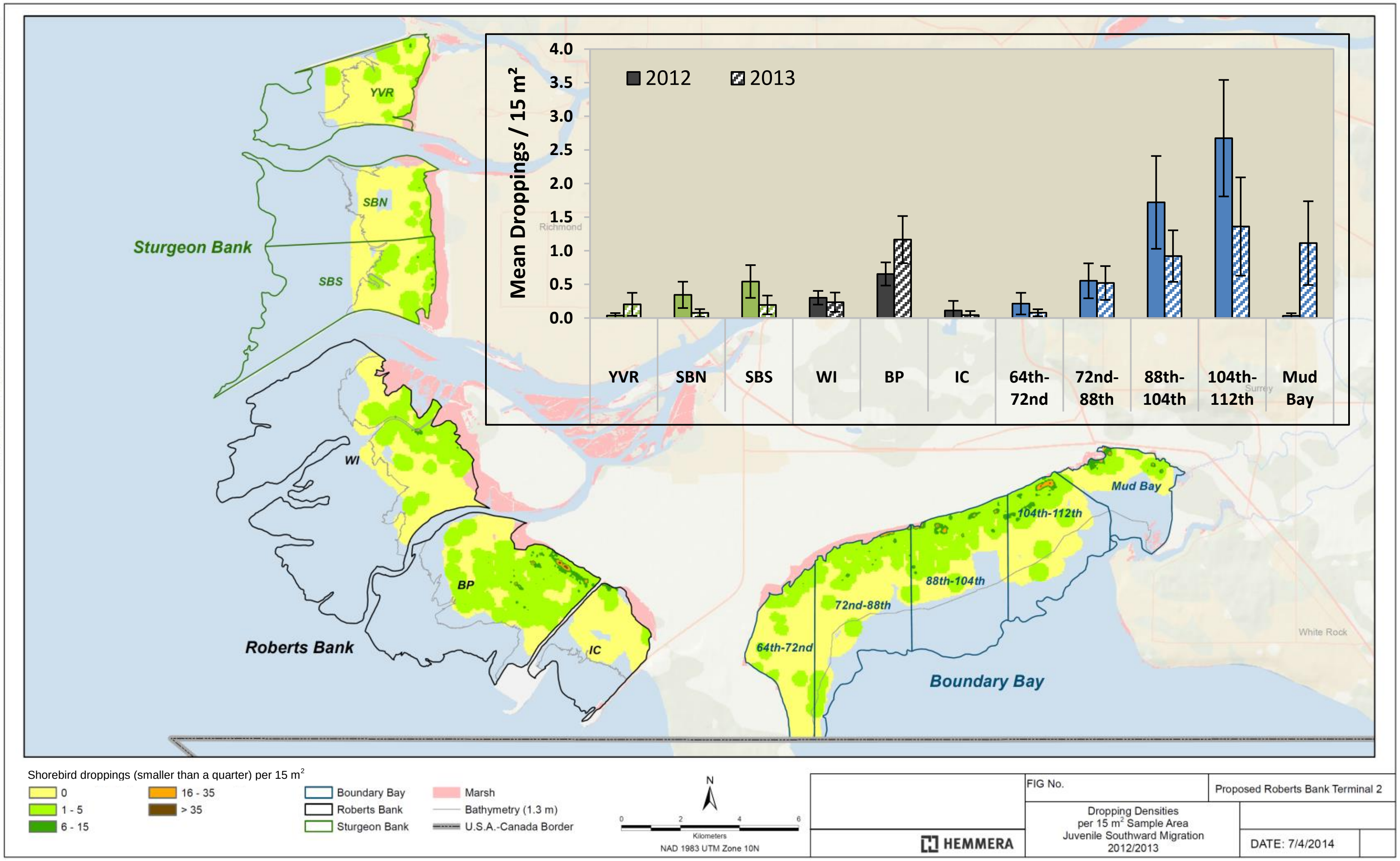
Notes: Dropping densities estimated across the estuary using inverse distance weighted (IDW) interpolation of survey data. Interpolation distance = 300 m. Bar plots and whiskers show mean dropping densities and two standard errors for each survey area. Survey area abbreviations: Vancouver International Airport (YVR), Sturgeon Bank North (SBN), Sturgeon Bank South (SBS), Westham Island (WI), Brunswick Point (BP), and Inter-causeway (IC). In Boundary Bay survey area names refer to the streets giving access to the dyke. *Surveys were not conducted at Mud Bay during the 2013 migration.

Figure 4-4 Proportions of Shorebird Foraging Use (Droppings) across Survey Areas in the Fraser River Estuary: 2012 and 2013 Southward Adult Migration



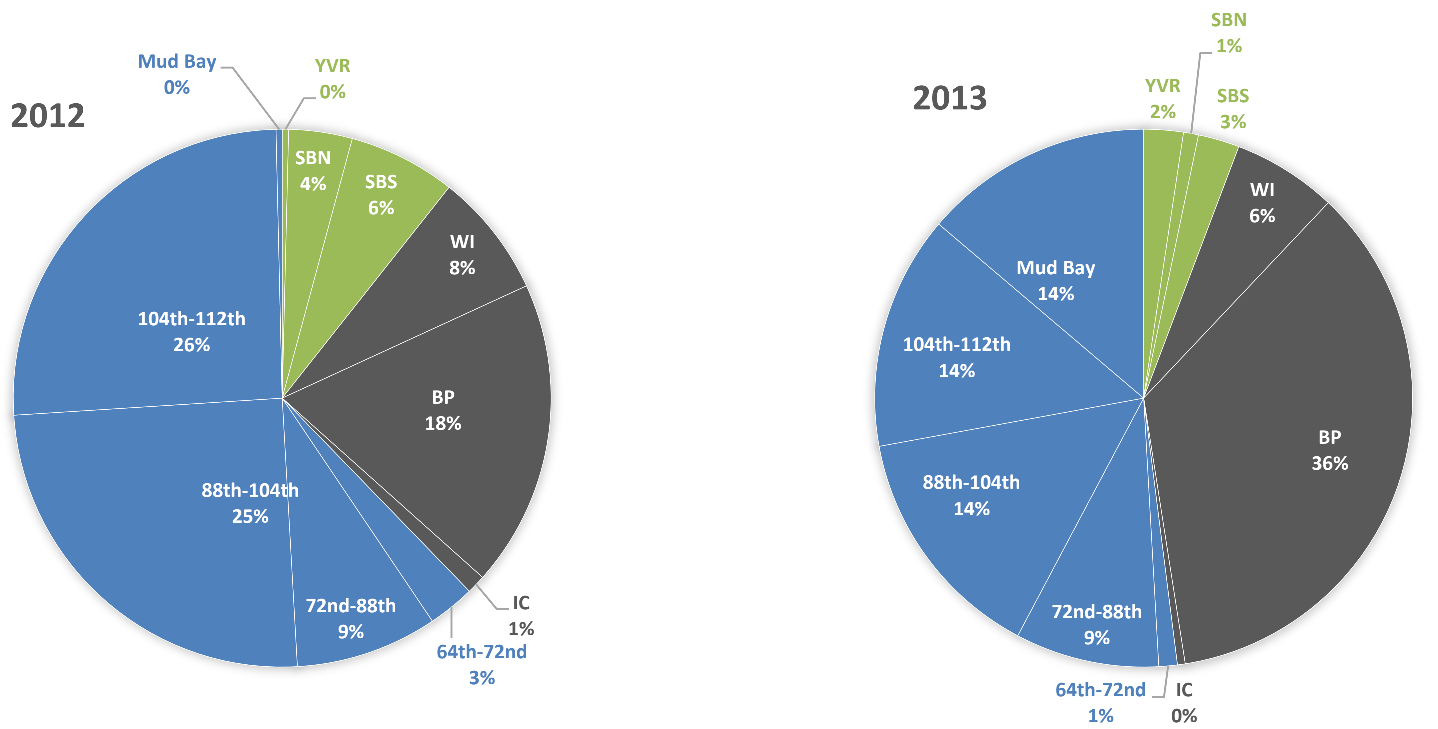
Notes: Proportions of droppings at Sturgeon Bank, Roberts Bank, and Boundary Bay are reported in green, gray, and blue respectively. *Mud Bay surveys during the 2013 adult migration were cancelled due to adverse weather. Had Mud Bay been included, proportions of use in other survey areas might have been substantially reduced.

Figure 4-5 Shorebird Dropping Densities across the Fraser River Estuary Mudflats and Mean Dropping Densities within Survey Areas: 2012 and 2013 Southward Juvenile Migration



Notes: Dropping densities estimated across the estuary using inverse distance weighted (IDW) interpolation of survey data. Interpolation distance = 300 m. Bar plots and whiskers show mean dropping densities and two standard errors for each survey area. Survey area abbreviations: Vancouver International Airport (YVR), Sturgeon Bank North (SBN), Sturgeon Bank South (SBS), Westham Island (WI), Brunswick Point (BP), and Inter-causeway (IC). In Boundary Bay survey area names refer to the streets giving access to the dyke.

Figure 4-6 Proportions of Shorebird Foraging Use (Droppings) across Survey Areas of the Fraser River Estuary: 2012 and 2013 Southward Juvenile Migration



Notes: Proportions of droppings at Sturgeon Bank, Roberts Bank, and Boundary Bay are reported in green, gray, and blue respectively.

Modeling Results

All relationships between predictor variables and dropping densities varied in their significance across models; however, some relationships were consistent across models developed for the northward or southward migrations (**Table 4-1)**. Probability values from parameter estimates and chi-square calculations were very similar, but chi-square analyses were generally lower **(Appendix B: Tables 8-13).**

During the northward migration, dropping densities did not differ between years or in relation to TOC, but increased significantly with shorebird abundances in all regions. Significant and positive Spatial Covariance during the northward migration shows that dropping densities were also more similar at survey stations in close proximity as compared to survey stations at greater distances. Across modelling regions, dropping densities either decreased with, or were unrelated to Salinity and Distance to Shore. In contrast, dropping densities either increased with, or were unrelated to Tide Height.

During the southward migration, dropping densities decreased with Distance to Shore and increased with Salinity. Dropping densities during the southward migration either increased or were unrelated to Shorebird Abundance, Low Tide Height, TOC, and Spatial Covariance. Year was the only variables for which opposite significant relationships were found in different models within the same migration.

Results of the zero model portion of the zero-inflated model are presented in **Appendix B: Tables 8-13**.

Table 4-1 Summary of Count Model Results: Relationships between Predictor Variables and Dropping Densities within Regions Defined for Modeling during the 2012 and 2013 Northward and Southward Migrations

Migration	**Northward (Spring)**			**Southward (Summer)**		
Modeling Region	**SB, WI**	**BP**	**BB, IC**	**SB, WI**	**BP**	**BB, IC**
Year	*ns*	*ns*	*ns*	-	+	-
Shorebird Abundance	+	+	+	*ns*	+	+
Distance to Shore	ns	-	-	-	-	-**
Low Tide Height	+	+**	*ns*	+*	+	*ns*
TOC	*ns*	*ns*	*ns*	*ns*	+	+
Salinity	-	*ns*	*NA*	+	+	*NA*
Spatial Covariance	+	+	+	*ns*	*ns*	+

Notes: "+" and "–" represent significantly positive and negative relationships; "*ns*" represents non-significant relationships; "*NA*" represents Not Applicable: Salinity within the BB, IC region does not vary to an extent that would influence shorebird prey (means of 30.5 to 31.5 partial salinity units (psu) and 30.0 to 30.6 psu across survey areas during the southward and northward migrations, respectively). Negative relationships for year indicate that dropping densities were higher in 2012 relative to 2013 and positive relationships indicate higher dropping densities in 2013. *Considered biologically significant given the proximity to the significance level and broader trends across the estuary. **Significant in chi-square test, but probability value >0.05 for the model parameter estimate.

4.2 Shorebird Abundance

Estimates of Total Numbers of Shorebirds using the Estuary during Migrations

Estimates of cumulative abundance were determined for dunlin during the 2013 northward migration and for western sandpipers during the 2012 southward and 2013 northward migrations. The total number of western sandpipers using the FRE over the course of the 2012 southward migration was estimated at 287,000, of which approximately 49,000 and 238,000 were observed during the adult and juvenile migration respectively. Conservative estimates of the total number of western sandpipers and dunlin using the estuary during the 2013 northward migration were 301,000 and 365,000, respectively.

Shorebird Abundances across Years and Seasons

Abundances of peep sandpipers were greatest during the northward migration, lowest during the southward adult migration, and intermediate during the southward juvenile migration. In contrast, abundances of black-bellied plovers were similar during the northward and southward migrations (**Appendix A: Figure 9, 10,** and **11**). Abundances of juvenile peep sandpipers were similar during the 2012 and 2013 southward migration. In contrast, black bellied plover and adult peep sandpiper abundances were lower during the southward migration of 2013 relative to 2012 (**Appendix A: Figure 10** and **11**).

Shorebird Abundances and Densities across the FRE

Northward Migration

During the 2013 northward migration, peep sandpipers and dunlin were generally more abundant at Brunswick Point than any other area, whereas black-bellied plovers were most abundant in Boundary Bay. Almost half of the peep sandpipers (48%) and dunlin (43%) were observed at Brunswick Point (**Figure 4-7**). Although, peep sandpipers were most abundant in Boundary Bay during the early northward migration (~10,000 individuals), Brunswick Point supported the highest abundances during the anticipated peak (~175,000 individuals) and late migration (~40,000 individuals). Dunlin were most abundant at Brunswick Point during all periods of the northward migration (**Appendix B: Table 14**). In contrast, 65% of black-bellied plovers were recorded at Boundary Bay as compared to 26% at Brunswick Point and far lower proportions in other areas (**Figure 4-8**). During all periods of the northward migration, abundances black-bellied plovers were highest Boundary Bay. Abundances of shorebirds were generally lowest in the Inter-causeway Area and Sturgeon Bank (**Appendix B: Table 14**).

Densities of peep sandpipers and dunlin during the northward migration were generally higher at Brunswick Point than other survey areas; however, densities of dunlin were often similarly high at 88^{th} to 104^{th} streets in Boundary Bay (**Figure 4-9; Appendix B: Tables 15** and **16**). In contrast, densities of black-bellied plovers were greatest at the 88^{th}-104^{th} survey area, and densities were similar to Brunswick Point at most other survey areas in Boundary Bay (**Figure 4-10**; **Appendix B: Table 15)**.

Southward Migration

The distributions of peep sandpipers across survey areas (i.e. proportions) varied dramatically between the 2012 and 2013 southward migrations of adult western sandpipers. For example, the greatest proportions of peep sandpiper abundances were at Sturgeon Bank in 2012 (i.e., 54%) as compared to 75% at Roberts Bank in 2013 (**Figure 4-11**). The only consistent results across years were low abundances in the Inter-causeway Area and in the 64th to 72nd survey area (**Figure 4-11**). ANOVA and Tukey's comparison of means described significantly lower abundances of peep sandpipers in the Inter-causeway Area as compared to other areas of the FRE during the adult migration. Differences in peep sandpiper abundance amongst Brunswick Point, Boundary Bay, and the Sturgeon Bank, Westham Island region were not significant (**Table 4-2**).

During the southward migration of juvenile western sandpipers, proportions of peeps were more consistent across years and were evenly dispersed across study sites. Survey areas at Sturgeon Bank supported 26-28% of individuals, survey areas in Boundary Bay supported 30-32% of individuals, and survey areas at Brunswick Point and Westham Island supported 31-32% and 8-10% of individuals, respectively (**Figure 4-12**). Abundances of juveniles were, again, lower in the Inter-causeway Area than other major areas. ANOVA and Tukey's comparison of means described significantly lower abundances of juvenile peep sandpipers in the Inter-causeway Area as compared to Brunswick Point and other areas of the FRE, but differences amongst Brunswick Point and other survey areas were not significant (**Table 4-2**).

Black-bellied plovers were most abundant within Boundary Bay during southward migrations (**Figure 4-8**). ANOVA and Tukey's comparison of means indicate that black-bellied plover abundances during the 2012 southward migration were significantly greater at Boundary Bay than Brunswick Point and as compared to combined abundances at Sturgeon Bank and Westham Island (**Table 4-2**). Mean black-bellied plover abundances across these areas were not significantly different in 2013, but abundances in the Inter-causeway Area were significantly lower than all other areas (**Table 4-2**).

Densities of peep sandpipers during the southward migrations were consistently high at Brunswick Point and 88th to 104th streets relative to other survey areas (**Figure 4-13** and **Figure 4-14**). Densities of peep sandpipers at Sturgeon Bank were generally lower than at Brunswick Point and 88th to 104th streets, varied more dramatically than at any other site, and included some of the highest individual records of density (**Figure 4-13** and **Figure 4-14**). Densities of peep sandpipers in the Inter-causeway Area were some of the lowest observed across the estuary and were often zero, thereby excluding this area from statistical comparisons.

Densities of black-bellied plovers were highest at Boundary Bay in the 88th to 104th streets and 104th to 112th street survey areas; however, Brunswick Point supported a similarly high median density in 2013 (**Figure 4-15**). Tukey's tests indicated that differences in mean densities were not significant between survey areas (BP, 88th to 104th, and 104th to 112th) in either year. Black-bellied plover densities in the Inter-causeway Area also were some of the lowest observed across the estuary (**Figure 4-15)**.

Table 4-2 Comparisons of Peep Sandpiper and Black-bellied Plover Abundances across the Fraser River Estuary: 2012 and 2013 Southward Migration

Species/Age Class	Adult Peep Sandpipers		Juvenile Peep Sandpipers		Black-bellied Plovers	
Year	2012	2013	2012*	2013	2012*	2013
ANOVA Statistics	$p < 0.001$ $F = 24.79$ $n = 7$	$p = 0.006$ $F = 6.88$ $n = 5$	$p = 0.823$ $F = 0.20$ $n = 11$	$p < 0.001$ $F = 25.52$ $n = 7$	$p = 0.001$ $F = 10.22$ $n = 10$	$p < 0.006$ $F = 6.88$ $n = 5$
Brunswick Point	A	A	A	A	B	A
Boundary Bay	A	A	A	A	A	A
Sturgeon Bank and Westham Island	A	AB	A	A	B	A
Inter-causeway Area	B	B	-	B	-	B

Notes: Analyses only consider data collected during the peak of each species/age class migration (see **Table 3-4**). Areas that do not share letters within year columns are significantly different and are ranked in alphabetical order. *Comparisons do not consider abundances at YVR, IC and Mud Bay due to low sample sizes in those survey areas.

Temporal Trends in Abundance during Migrations

Temporal trends in shorebird abundance within each migration were similar across Sturgeon Bank, Roberts Bank, and Boundary Bay (**Appendix A: Figures 9, 10,** and **11)**. Trends in abundance show that the majority of the western sandpiper migration was captured by abundance surveys during the 2012 southward migration, and peak abundances of the juvenile and western sandpiper southward migration were captured in 2013. There was no apparent peak of shorebird abundances during the southward migration of adult western sandpipers in 2013. Reconnaissance surveys conducted at Brunswick Point, Sturgeon Bank, and Boundary Bay on earlier dates in 2013 confirm that the peak did not occur earlier than the surveys conducted for the adult migration. During the northward migration, dunlin abundances were highest before the western sandpiper migration began and then declined (**Appendix A: Figure 9**). Black-bellied plover abundances were generally stable during the northward migration until the peak of the western sandpiper migration, at which point they also declined (**Appendix A: Figure 9**). The southward migration of black-bellied plovers largely coincided with the timing of the juvenile western sandpiper migration, but began and ended about one week earlier (**Appendix A: Figure 10**).

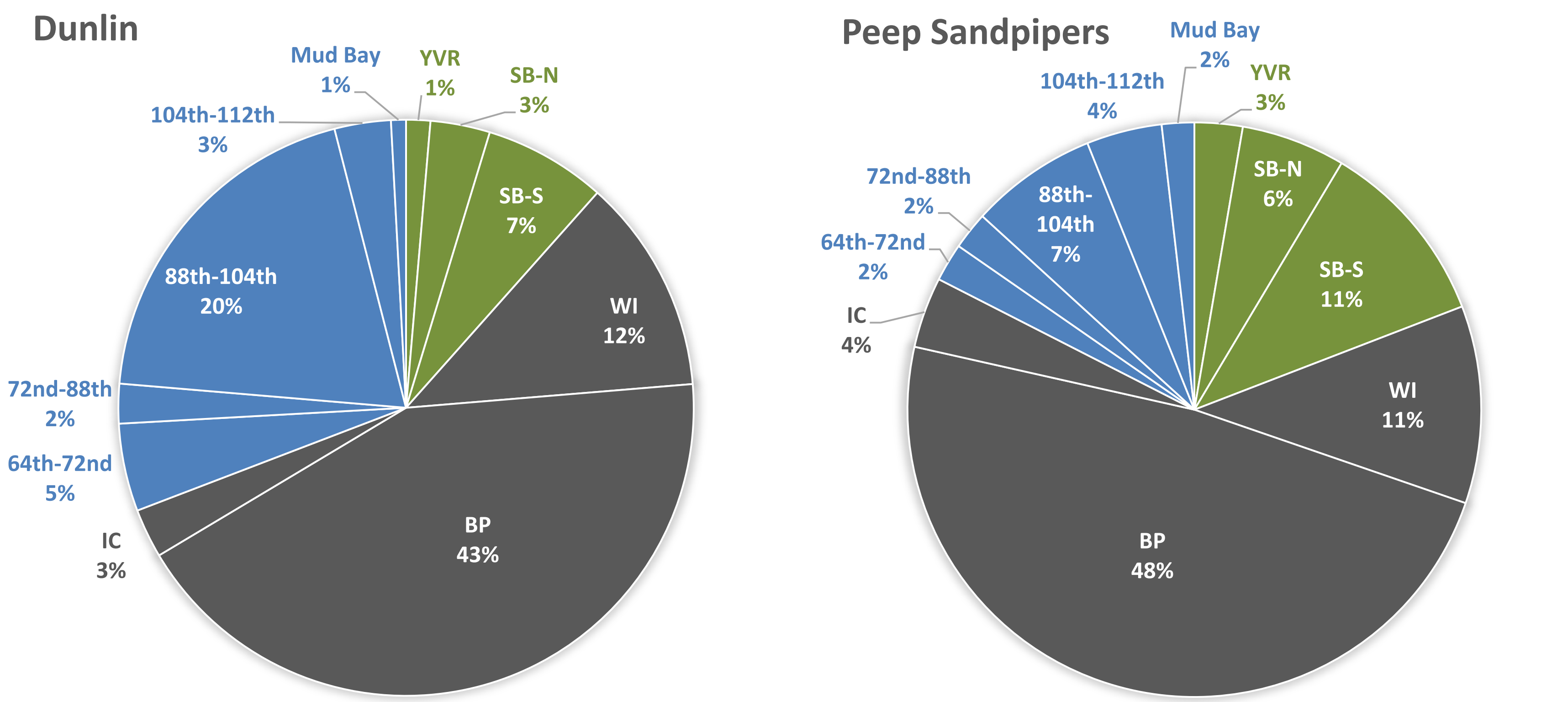
Abundance of Other Bird Species

Summary tables describing cumulative counts of shorebird, heron, and raptor species during southward (2012 and 2013) and northward (2013) migrations are provided in **Appendix B: Tables 17, 18**, and **19**. Bald eagles (*Haliaeetus leucocephalus)* and peregrine falcons were the most abundant raptors in the mudflats, and northern harriers were the most abundant raptors in marsh habitat. Bald eagles were several times more abundant during the northward migration as compared to the southward migration and were fairly evenly dispersed across survey areas, with the exception of low abundances in the YVR, IC, 104^{th}-112^{th}, and Mud Bay survey areas. Peregrine falcons were similarly abundant during the northward and southward migrations overall, and were most abundant in the Brunswick Point and 88^{th} to 104^{th} survey areas. More than 50% of peregrine falcons (i.e., 53 of 97 records) were observed in those areas during southward migrations and more than 40% of individuals (i.e., 15 of 37 records) were observed there during the northward 2013 migration. Great blue herons were regularly observed in all survey areas and were particularly abundant at Brunswick Point (997 of 1978 records) during the northward migration and in the Inter-causeway Area (i.e., 2051 of 7354 records) during the southward migrations.

Apart from the focal species of this report, the only other shorebird species that were commonly observed during northward migrations were greater yellowlegs (*Tringa melanoleuca)* (**Appendix B: Table 19**). During the southward migration, killdeer *(Charadrius vociferous),* semipalmated plovers *(Charadrius semipalmatus)* and lesser yellowlegs (*Tringa flavipes*) were also regularly observed (**Appendix B: Tables 17 and 18**). Flocks of dowitchers (*Limnodromus sp.*) and sanderling (*Calidris alba*) were occasionally observed during both migrations.

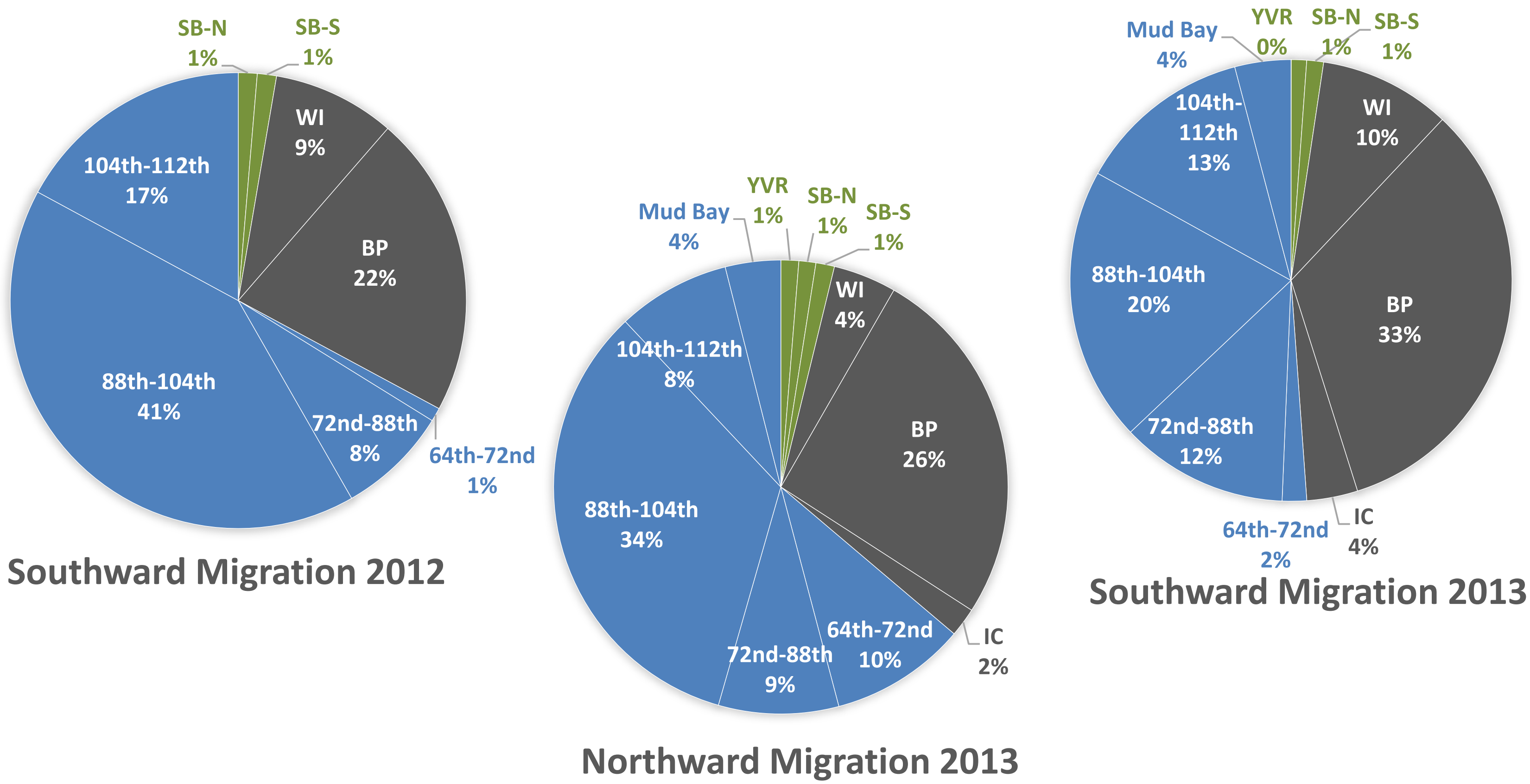
Abundances of waterfowl and gulls are not reported due to uneven sampling across survey areas and dates.

Figure 4-7 Proportions of Dunlin and Peep Sandpipers across Survey Areas in the Fraser River Estuary: 2013 Northward Migration



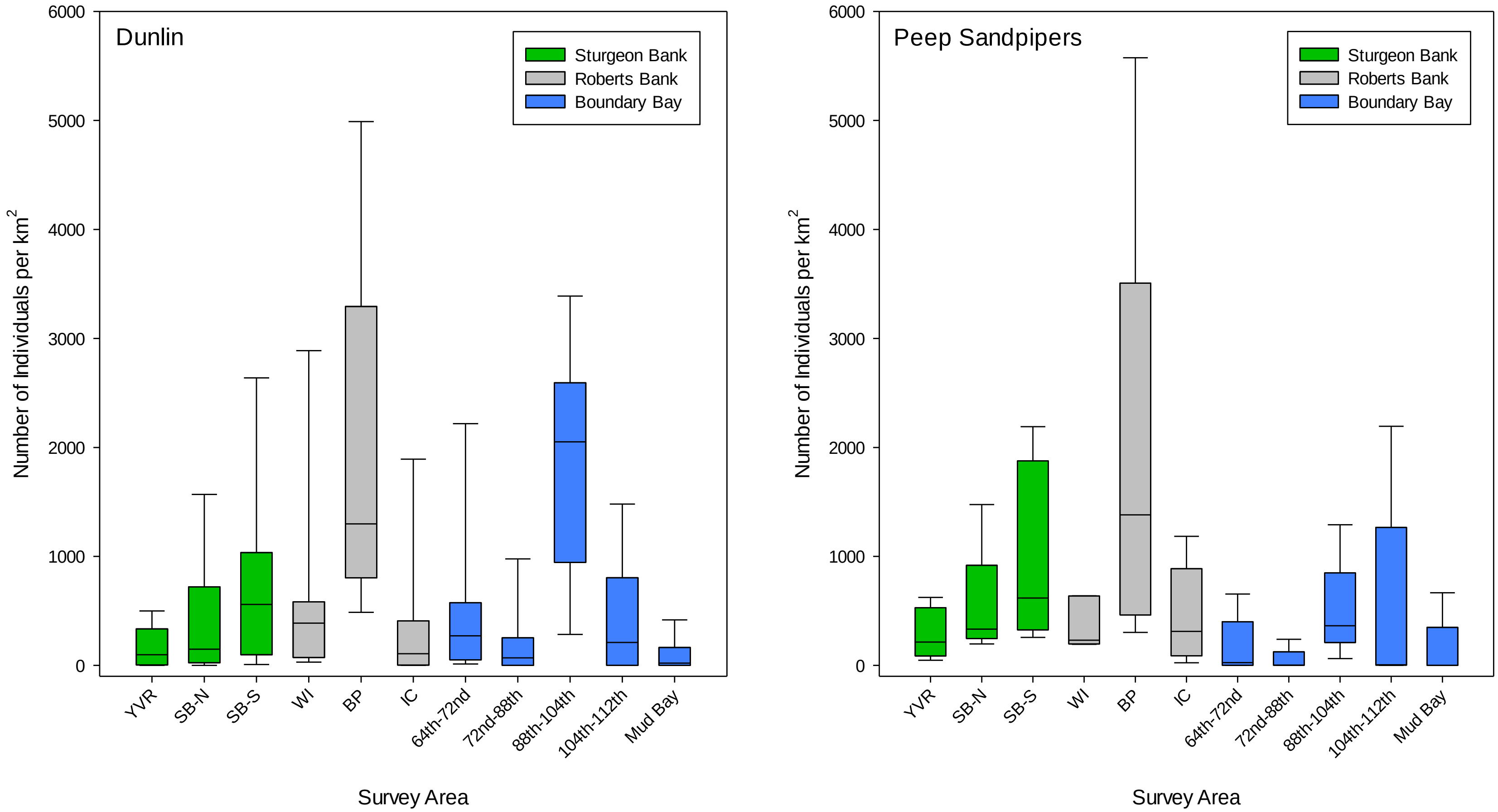
Notes: Proportions of peeps from Sturgeon Bank, Roberts Bank, and Boundary Bay are reported in green, gray, and blue respectively. Percentages were determined from abundance records summed across 13 surveys from April 6 to May 6, 2013 and 5 surveys from April 26 to May 6, 2013 for dunlin and western sandpipers, respectively.

Figure 4-8 Proportions of Black-bellied Plovers within Survey Areas in the Fraser River Estuary Mudflats: 2012 and 2013 Southward Migrations, 2013 Northward Migration



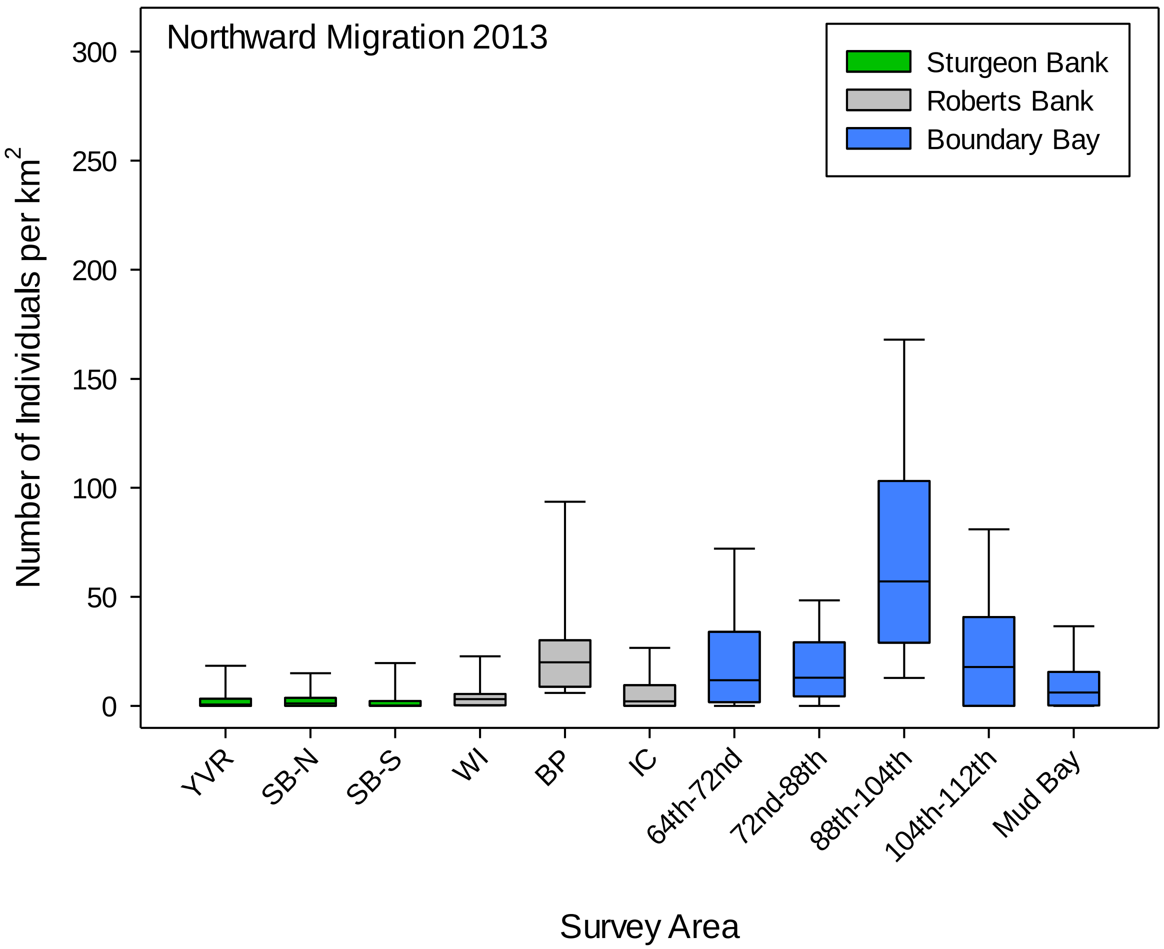
Notes: Proportions of abundances at Sturgeon Bank, Roberts Bank, and Boundary Bay are reported in green, gray, and blue respectively. Percentages were determined from abundance records summed across 23 surveys conducted from July 7 to September 19, 2012 (southward), 12 surveys conducted from July 13 to September 5, 2013 (southward), and 13 surveys conducted from April 6 to May 6, 2013 (northward).

Figure 4-9 Densities of Dunlin and Peep Sandpipers within Survey Areas in the Fraser River Estuary: 2013 Northward Migration



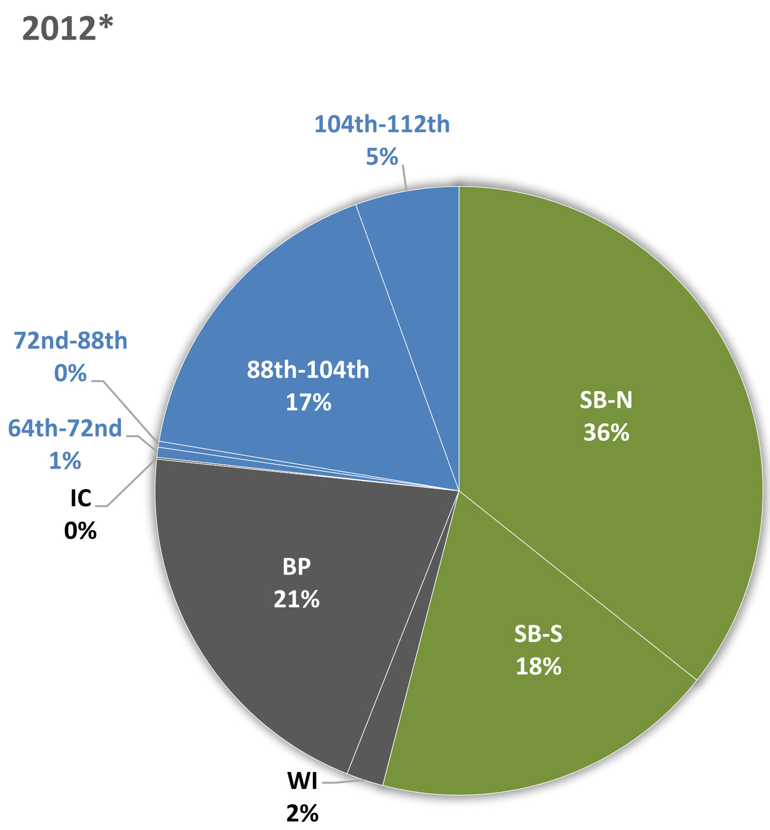
Notes: Box plots describe median densities (centre line), 25th, 75th percentiles (box), and 10th, 90th percentiles (whiskers) from 13 surveys conducted from April 6 to May 6, 2013 for dunlin and 5 surveys from April 26 to May 6, 2013 for western sandpipers. Densities were calculated as cumulative abundance estimates from surveys divided by the exposed intertidal area in each survey area during the mean low tide of the northward migration (1.3 m).

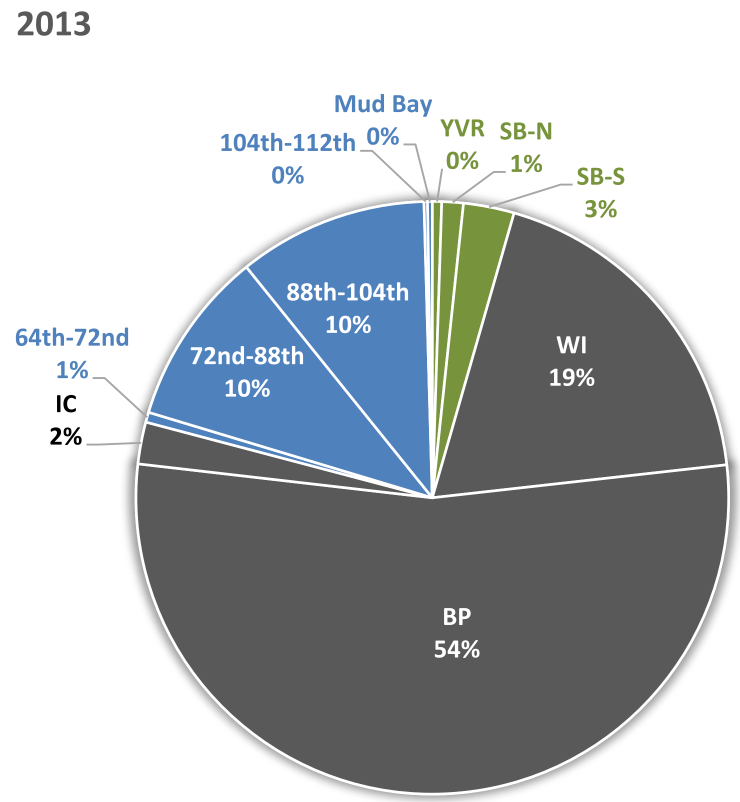
Figure 4-10 Density Records of Black-bellied Plovers within Survey Areas in the Fraser River Estuary Mudflats: 2013 Northward Migration



Notes: Box plots describe median densities (center line), 25th, 75th percentiles (box), and 10th, 90th percentiles (whiskers) from 13 surveys conducted from April 6 to May 6, 2013. Densities were calculated as cumulative abundance estimates from surveys divided by the exposed intertidal area in each survey area during the mean low tide of the southward migration (1.3 m).

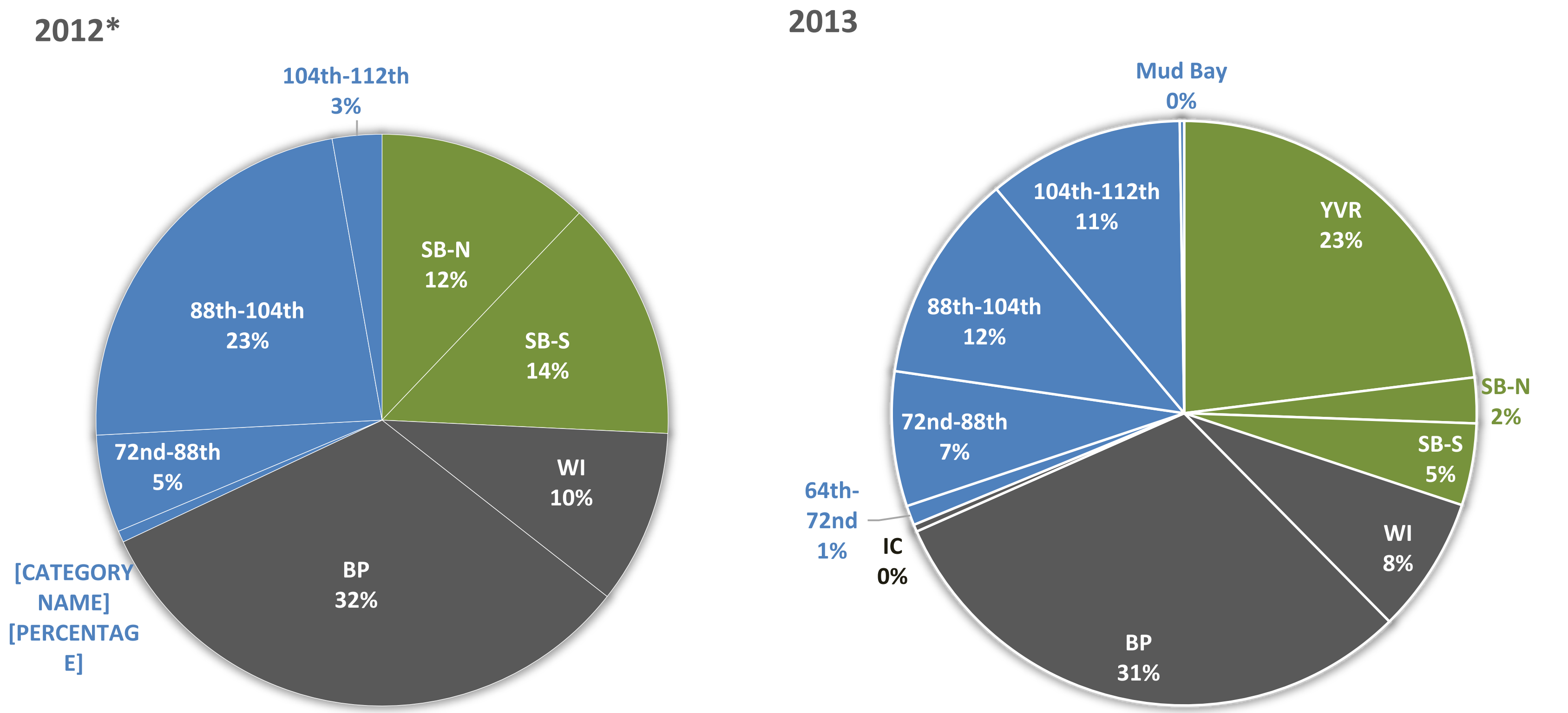
Figure 4-11 Proportions of Peep Sandpipers across Survey Areas in the Fraser River Estuary: Adult Southward Migration of 2012 and 2013





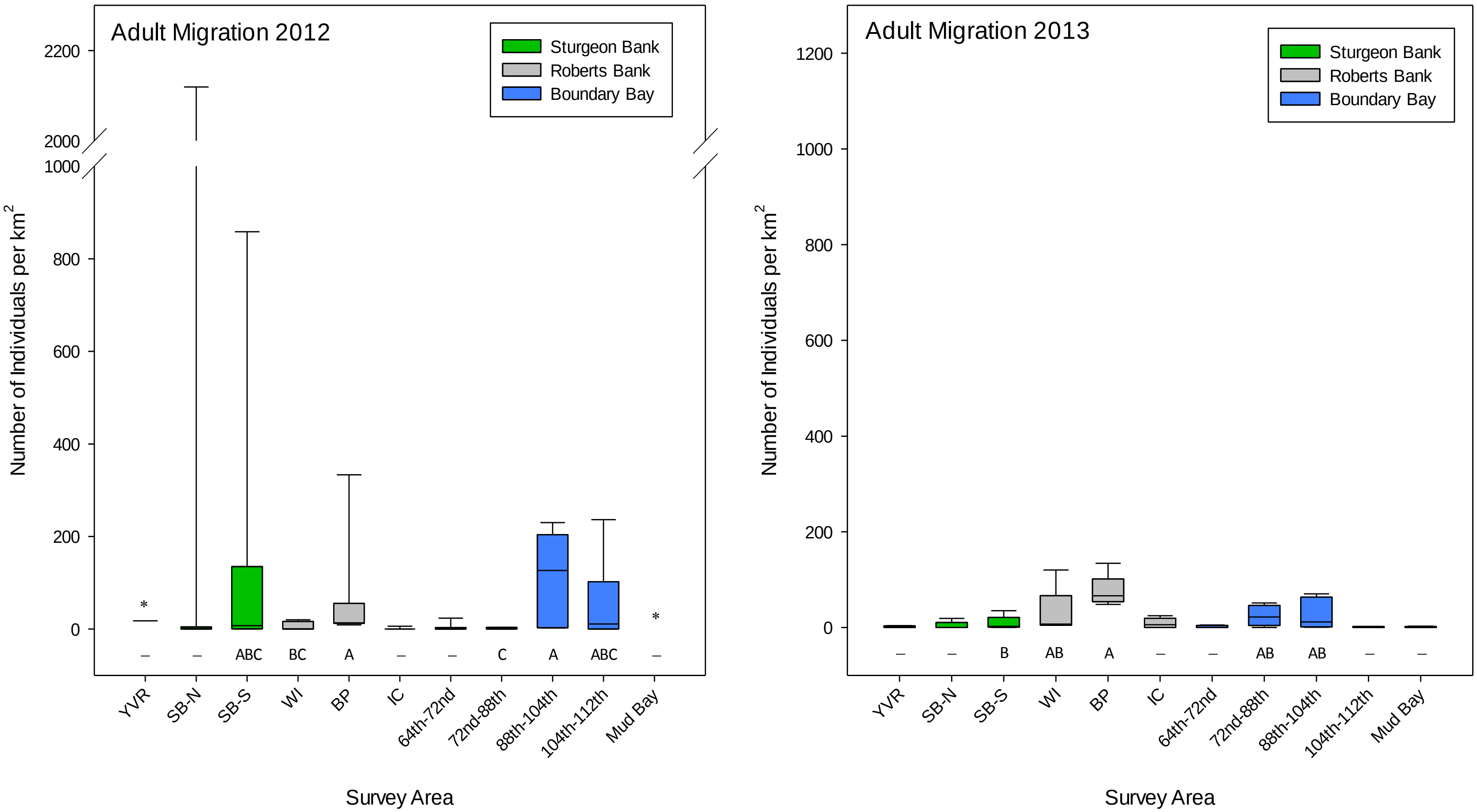
Notes: Proportions of western sandpipers from Sturgeon Bank, Roberts Bank, and Boundary Bay are reported in green, gray, and blue respectively. Percentages were determined from abundance records across seven surveys from July 7 to 31, 2012, and five surveys from July 13 to 21, 2013. *YVR was excluded from 2012 surveys as these areas were not expected to host important numbers of sandpipers.

Figure 4-12 Proportions of Peep Sandpipers within Survey Areas in the Fraser River Estuary: Juvenile Southward Migration of 2012 and 2013



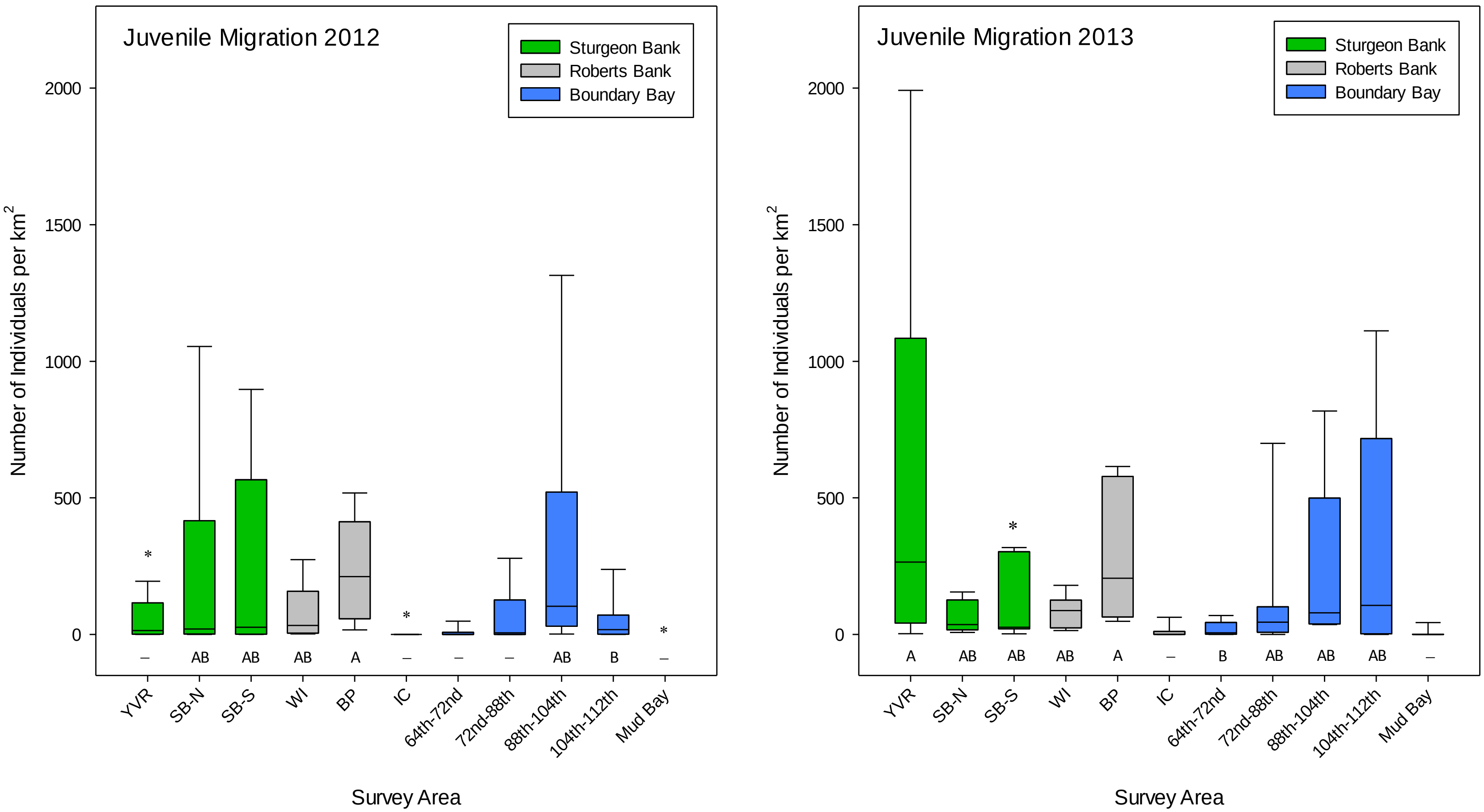
Notes: Proportions of abundances from Sturgeon Bank, Roberts Bank, and Boundary Bay are reported in green, gray, and blue respectively. Proportions were determined from abundance records summed across 16 surveys conducted from August 3 to September 19, 2012, and 6 surveys conducted from August 18 to September 5, 2013. *Survey area IC is excluded from Figure A due to uneven sampling, but is assumed to be 0% based on 4 surveys with no shorebirds.

Figure 4-13 Densities of Peep Sandpipers within Survey Areas in the Fraser River Estuary: Adult Southward Migration of 2012 and 2013



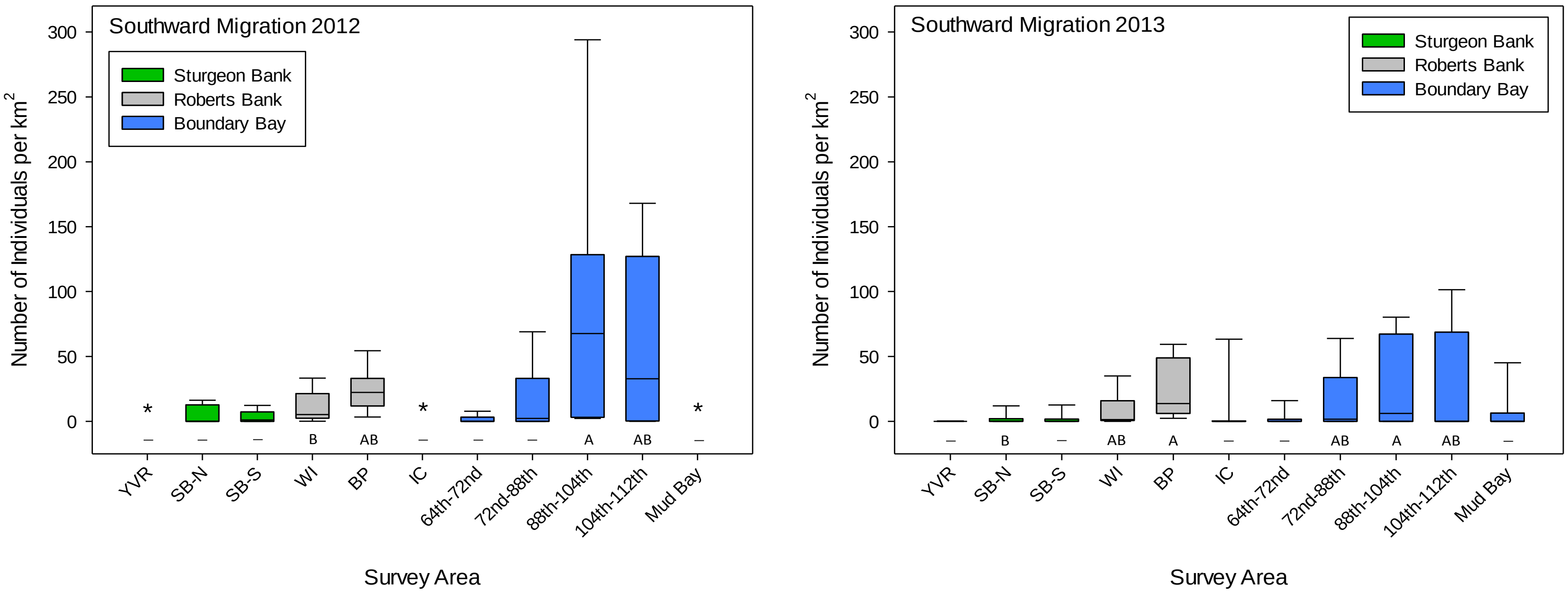
Notes: Box plots describe median densities (centre line), 25th, 75th percentiles (box), and 10th, 90th percentiles (whiskers) from abundance surveys conducted during seven surveys from July 7 to 31, 2012, and five surveys from July 13 to 21, 2013. Densities were calculated as cumulative abundance estimates from surveys divided by the exposed intertidal area in each survey area during the mean low tide of the southward migration (1.3 m).*In 2012, a reduced number of surveys were conducted at YVR (n=1), and Mud Bay (n=0). Survey areas that do not share letters are significantly different according to ANOVA analyses and are ranked in alphabetical order ("A" represents the highest densities).

Figure 4-14 Densities of Peep Sandpipers within Survey Areas in the Fraser River Estuary: Juvenile Southward Migration of 2012 and 2013



Notes: Box plots describe median densities (centre line), 25th, 75th percentiles (box), and 10th, 90th percentiles (whiskers) from abundance surveys conducted during 16 surveys from August 3 to September 19, 2012 and 8 surveys from August 18 to September 8, 2013. Densities are calculated from counts in survey areas divided by the exposed intertidal area in each survey area during the mean low tide of the southward migration (1.3 m). *A reduced number of surveys were conducted in 2012 at YVR (n=5), IC (n=4), and Mud Bay (n=0), and in 2013 at SB-S (n=7). Survey areas that do not share letters are significantly different according to ANOVA analyses and are ranked in alphabetical order ("A" represents the highest densities).

Figure 4-15 Densities of Black-bellied Plovers within Survey Areas in the Fraser River Estuary: 2012 and 2013 Southward Migrations



Notes: Box plots describe median densities (centre line), 25th, 75th percentiles (box), and 10th, 90th percentiles (whiskers) from 18 surveys conducted from July 28 to September 19, 2012 (A) and 7 surveys conducted from August 18 to September 5, 2013. Densities were calculated as cumulative abundance estimates from surveys divided by the exposed intertidal area in each survey area during the mean low tide of the southward migration (1.3 m). *Limited surveys were conducted at YVR (n=5), IC (n=6), and Mud Bay (n=0) during surveys conducted in 2012 due to anticipated low abundance. In these surveys average densities per km^2 were less than 1 at both YVR and IC. Survey areas that do not share letters are significantly different according to ANOVA analyses and are ranked in alphabetical order (“A” represents the highest densities).

4.3 COMPARISON OF SURVEY TECHNIQUES

Comparison of Abundance Survey Methods

Boundary Bay surveys conducted by walking on the mudflat generally yielded greater counts of peep sandpipers and similar or lower counts of black-bellied plovers than simultaneous surveys conducted by driving on the dyke (**Table 4-3**).

Table 4-3 Abundance Estimates of Shorebirds at Boundary Bay from Simultaneous Driving Surveys Conducted from the Dyke and Walking Surveys conducted from the Mudflats

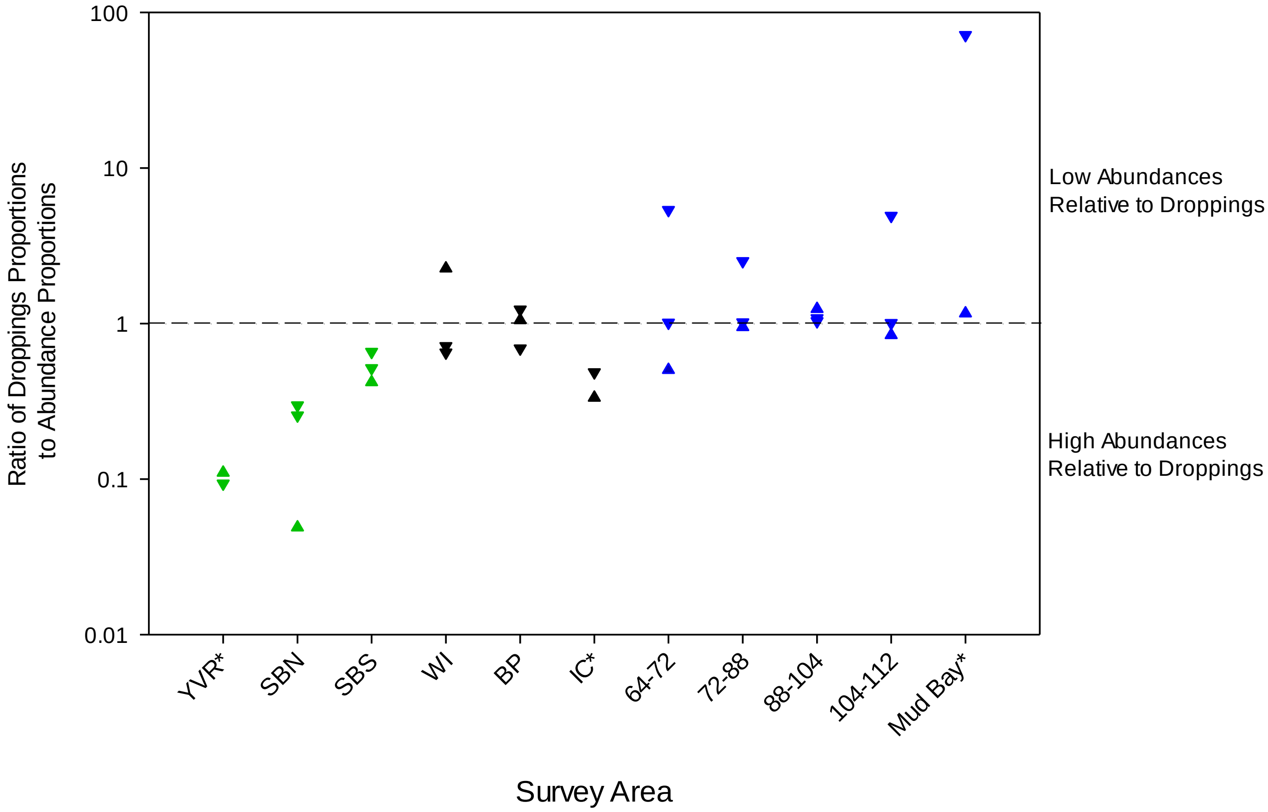
Survey Date	Western Sandpipers			Black-bellied Plovers		
	Dyke	Mudflat	Difference*	Dyke	Mudflat	Difference*
Aug 27, 2013**	12872	19420	6548	1463	1560	97
Aug 30, 2013**	12586	28175	15589	1771	1182	-589
Sep 2, 2013	320	733	413	380	366	14

Notes: *Difference calculated as mudflat counts minus dyke counts. **Multiple attacks by peregrine falcons caused frequent flock movements between survey areas.

Comparison of Abundance and Droppings Surveys

The ratios of droppings proportions to shorebird abundance proportions within survey areas were greatest at Boundary Bay, intermediate at Roberts Bank, and smallest at Sturgeon Bank (**Figure 4-16**). These results indicate that abundance surveys describe lower proportions of use at Boundary Bay and higher proportions of use at Sturgeon Bank relative to droppings surveys. Droppings and abundance surveys describe similar proportions of use at Brunswick Point and Westham Island, but abundance surveys describe higher proportions of use in the Inter-causeway Area relative to droppings surveys. Ratios of droppings and abundance proportions from each survey area within the 2012 and 2013 southward migration and the 2013 northward migration are presented in **Appendix B: Table 20**.

Figure 4-16 Ratios of the Proportions of Shorebird Droppings in Survey Areas Relative to Proportions of Shorebird Abundances



Notes: ▲ – 2013 Northward migration, ▼ – 2012, 2013 Southward migrations. Green, black, and blue symbols represent survey areas at Sturgeon Bank, Roberts Bank, and Boundary Bay, respectively. Ratios describe the proportion (i.e., percentage) of total FRE droppings in survey areas divided by the proportion of average abundances in each survey area. Droppings per survey area were estimated by multiplying the area of exposed mudflat at the average low tide (1.3 m) by the average dropping densities recorded during each migration. Means (points) and standard errors (whiskers) were calculated from the ratios determined for each of the three migrations in which both droppings and abundances were surveyed: southward migration 2012 and 2013; and northward migration 2013. *Due to reduced sampling efforts during the 2012 southward migration, only two estimates were obtained from YVR, IC, and Mud Bay.

4.4 Influence of Artificial Light

Models supported by AIC in their description of the likelihood of nocturnal shorebird presence in Brunswick Point mudflats included Tide Height, Tide Line and Light as predictor variables (**Table 4-4**). Tide Height was the only predictor variable included in all supported models. Tide Height was also the only variable that was significantly related to shorebird presence in general linear models (**Table 4-5**). The relationship of Tide Height with shorebird presence was negative in all models.

Table 4-4 AIC Model Comparison Results for Supported Models of Intertidal Habitat Use by Nocturnally Foraging Shorebirds: 2014 Northward Migration

Model Parameters	df	AIC	AICc	ΔAIC	AICw
Tide Height	2	50.11	50.43	0	0.55
Tide Height + Tideline	3	51.43	52.10	1.66	0.24
Tide Height + Light	3	51.64	52.31	1.88	0.21

Notes: AICc values are AIC values corrected for a small sample size. ΔAIC values were determined from AICc values (model AICc minus minimum AICc of all models). AICw are Akaike weights that describe the relative support for each model.

Table 4-5 General Linear Model Results for AIC Supported Models of Intertidal Habitat Use by Nocturnally Feeding Shorebirds: 2014 Northward Migration

Model	Model Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Tide Height	(Intercept)	7.915	3.158	2.507	0.012
	Tide Height	-2.656	1.122	-2.368	0.018
Tide Height + Tideline	(Intercept)	8.209	3.198	2.567	0.010
	Tide Height	-2.825	1.148	-2.460	0.014
	Tideline (Present)	0.697	0.869	0.802	0.423
Tide Height + Light	(Intercept)	8.355	3.248	2.573	0.010
	Tide Height	-2.778	1.143	-2.431	0.015
	Light	-0.319	0.473	-0.676	0.499

4.5 Incidental Observations

Abundance surveys conducted at the South Arm Marshes behind Westham Island revealed minimal use by shorebirds during 2013 northward and southward migrations (i.e., ~500 shorebirds during eight surveys). The two South Arm Marshes surveys that encompassed the mud and sandbanks at Canoe Pass during the 2013 northward migration (i.e., on the north and south banks of Brunswick Point and Westham Island), found 955 peep sandpipers and 925 dunlin. The majority of shorebirds observed on these days were in a tidal channel at the south end of Westham Island.

5.0 DISCUSSION

5.1 Overview

This section synthesizes results from this and previous studies to form conclusions regarding the importance and quality of shorebird habitat in the Project area and the FRE as a whole, the relationships between environmental factors and foraging use, and the influence of artificial light on nocturnal habitat use.

5.2 Importance of Shorebird Habitat

The FRE supports the greatest number of individuals during the northward migration. An estimated 9 to 12% of the western sandpiper population (i.e., 301,000 of 3 to 4 million) and 60 to 75% of the Pacific dunlin population (i.e., 365,000 of 500,000 to 600,000) used FRE habitat during the 2013 northward migration. Drever et al. (2014) estimated similar numbers at Brunswick Point alone in 2013, highlighting the conservative nature of cumulative abundance estimates provided here.

Dropping and abundance data recorded during the 2013 northward migration indicate that Brunswick Point supported nearly half of the foraging activity observed across the FRE. Dropping data from 2012, and surveys conducted across a slightly broader area of the FRE in 1992 (see Butler et al. 2002), indicate similar proportions of use (i.e., 45% and 40% respectively) at Brunswick Point during the northward migration. These proportions demonstrate that Brunswick Point is consistently the most important area in the FRE for shorebirds overall during the most important migratory period.

For the adult southward migration, inter-annual variability in shorebird distributions across survey areas provides little certainty in the importance of the Project area for shorebirds. Variability in distributions during the southward migration of adults is likely related to the small number of birds (i.e., typically less than 5,000 across the estuary) relative to flock sizes. For example, one flock of 20,000 individuals was observed at Sturgeon Bank during the 2012 adult migration.

The relatively even distribution of abundance and droppings across study sites during the juvenile southward migration suggest reduced importance of Brunswick Point relative to other periods. The more even distribution of use during the juvenile migration could reflect a reduced capacity for juveniles to select high quality habitat relative to adults. Indeed, juvenile sandpipers tend to forage less efficiently (i.e., consume more and use more energy) than adults (Stein and Williams 2006). The change in distribution may also reflect a change in prey composition or preference across the estuaries between the northward and southward migration.

Abundance records suggest that Boundary Bay provides the most important habitat for black-bellied plovers during both the northward and southward migrations. During the southward adult migration and the northward migration of western sandpipers, black-bellied plovers represent less than 5% of total shorebirds, whereas during the southward juvenile migration they comprise much greater proportions. Thus, the distribution of black-bellied plovers is likely to contribute to both the relatively low proportion of droppings at Sturgeon Bank and the higher proportion of droppings at Boundary Bay during juvenile western sandpipers' southward migration.

Dropping and abundance records in the Inter-causeway Area were some of the lowest observed across the estuary during both northward and southward migrations. Higher proportions of use in the Inter-causeway Area (i.e., 8% of FRE records) are reported by Butler et al. (2002) from the 1992 northward migration, so there may have been a shift towards lower use in the Inter-causeway Area since that time.

5.3 QUALITY OF SHOREBIRD HABITAT

During northward migrations, dropping densities were substantially higher in Brunswick Point than in any other survey area suggesting superior habitat quality for shorebirds as a whole in this area. Abundance records indicate that the high proportion of droppings at Brunswick Point was driven by high densities of peep sandpipers in that area. In contrast, dunlin densities during this period suggest that habitat quality was similar between Brunswick Point and the 88th-104th survey area at Boundary Bay, while black-bellied plover densities suggest that habitat quality was actually inferior at Brunswick Point as compared to Boundary Bay.

Westham Island hosted the second highest mean dropping densities during the 2012 and 2013 northward migrations, but did not host high densities of dunlin or peep sandpipers relative to other survey areas (**Appendix B: Table 11**). Substantial inconsistencies between droppings and abundance survey results from the northward migration are also apparent for survey areas at Sturgeon Bank and the Inter-causeway Area, where observed shorebird densities were high relative to dropping densities. The sources and implications of such discrepancies are discussed in **Section 5.6**.

Variability in droppings and shorebird densities observed during the 2012 and 2013 southward migrations of adult western sandpipers was higher than in any other migratory period. As a result, the statistical power to identify significant differences in habitat quality across survey areas was low compared to other migratory periods; however, peep sandpiper densities were most consistently and significantly higher at Brunswick Point and the 88th-104th survey area at Boundary Bay.

During southward migration of juvenile western sandpipers, mean dropping densities were highest at Boundary Bay in the 88th-104th and 104th-112th survey areas, while median peep sandpiper densities were highest at Brunswick Point. Brunswick Point was the only survey area to have significantly higher densities than other survey areas during the 2012 and 2013 juvenile migrations; however, densities at Brunswick Point were not significantly different from most areas. Peep sandpiper densities at YVR were greater than at Brunswick Point during 2013, but mean dropping densities in YVR were substantially lower suggesting potentially over-represented densities at YVR from abundance surveys (see **Section 5.6**). Droppings and peep sandpiper densities in the Inter-causeway Area were consistently lower than most other survey areas, indicating poor habitat quality.

In contrast to other migratory periods, densities of black-bellied plovers during the southward juvenile western sandpiper migration reflected similar results as overall dropping densities. This result is likely due to the fact that black-bellied plovers comprised a much greater portion of total shorebird abundances during this period than during other migrations.

5.4 VARIABLES INFLUENCING FORAGING USE

Relationships of environmental variables (e.g., TOC, Salinity, Distance from Shore) with foraging use often varied in direction (i.e., positive vs. negative) and significance between the northward and southward migration. Relationships were more similar across models of different regions within the respective migrations. Thus, conclusions regarding the influence of environmental variables on foraging use are described separately for each migration.

During the northward migration, foraging use was highest in areas with relatively low salinity and generally decreased with distance to shore; however, exceptions to the significance of these trends described by models suggest that the relationships are not entirely linear. Models defined significance based on conformation to a linear trend (i.e., foraging use increases or decreases incrementally along every step of a predictor variable's gradient). The highest levels of foraging use did not occur at the most extreme levels observed for these variables (e.g., directly adjacent to shore, at the lowest salinities), but at apparently optimal conditions at low to intermediate salinities and close to shore, but sufficiently far to buffer the effects of predation danger. Thus, while modelling results were not always significant, the data suggests that distance to shore and salinity had important influences on foraging distributions. In contrast to findings from previous studies, there was little evidence that TOC in sediments had an important influence on foraging use.

Survey areas with the greatest freshwater influence (e.g., Westham Island, Brunswick Point) supported the highest dropping densities in the FRE (**Figure 4-1; Appendix A: Figure 13**), but dropping densities were not always greater in areas with lower salinity. For example, dropping densities were lower on average at Westham Island (mean: 6.4 partial salinity units (psu)) than in the more saline Brunswick Point survey area (mean: 18.3 psu). Additionally, dropping densities at Brunswick Point were higher in areas of intermediate salinity (i.e., 10 to 12 psu) than in less saline areas (**Figure 4-1**; **Appendix A; Figure 13)**. These results suggest that the relationship between foraging use and salinity during the northward migration is not linear and that there may be an optimal salinity level around 10 to 12 psu (LGL and Hemmera 2014). The areas with the greatest densities of foraging use at Westham Island were at lower salinity levels, but salinity does not reach 10 psu until approximately 1.5 km from shore at Westham Island, so use in those areas is likely constrained by availability due to more prolonged tidal inundation. The relationship between foraging use and Salinity may also reflect the influence of other factors related to freshwater inputs. For instance, organic materials flocculate and settle out of solution at the freshwater-saltwater interface. Settling of organic materials onto mudflat sediments underlying this interface could potentially contribute important quantities of diatoms resulting in relatively enriched intertidal biofilms and foraging use in these areas.

Distance to Shore was negatively related to foraging use at Brunswick Point and the BB, IC region; however, the relationship was not significant in the SB, WI region and dropping densities generally declined within 200 m from shore. The reduction in foraging use close to the shoreline is almost certainly a result of higher risk of predation (Pomeroy 2005). This effect is particularly prominent in the Brunswick Point survey area and between 88th to 112th streets at Boundary Bay (**Figure 4-1** and **Figure 4-5**) where intertidal mudflats are closest to upland habitat (i.e., vegetative cover) and where more than 50% of falcon observations were recorded during surveys (**Appendix B: Tables 17, 18,** and **19**). Distance to Shore was not found to be related to foraging use in the SB, WI region because the highest dropping densities were approximately 1 km from shore at Westham Island (**Figure 4-1; Appendix A: Figure 11**) and droppings at SB were evenly dispersed up to 3 km from shore. At Westham Island, foraging use was concentrated in areas further from shore than at other sites, potentially because the optimal salinity level or the freshwater-saltwater interface was also present further from shore. The even distribution of foraging use across the SB may also be related to homogenous salinity in that area.

Levels of TOC in intertidal sediments are known to have important, positive relationships with shorebird prey and foraging distributions in the FRE and other systems (Yates et al. 1993, Zharikov et al. 2009, Sutherland et al. 2013); however, TOC was not significantly related to dropping densities in any of the northward migration models. In the Brunswick Point survey area, TOC decreased with Distance to Shore (**Appendix A: Figure 11**) so the influence of TOC on foraging use may have been confounded with the apparently significant influence of Distance to Shore. In the SB, WI region, neither Distance to Shore nor TOC were significantly related to foraging use and in the BB, IC region, TOC was not correlated with Distance to Shore so its negative relationship with foraging use can be attributed to increased habitat availability closer to shore (i.e., mudflats are exposed for more time closet to shore), and the influence of tidal elevation on the composition and abundance of shorebird prey.

During the southward migration, foraging use again decreased with Distance to Shore across the FRE; however, in contrast to results from the northward migration, foraging use increased significantly with TOC and Salinity. Foraging use during the southward migration was higher in the more saline areas of Brunswick Point and the SB, WI region and the highest concentrations of foraging use were found within survey areas at Boundary Bay where the highest levels of Salinity occur during the southward migration (**Figure 4-3** and **Figure 4-5; Appendix A: Figure 14**). TOC was positively related to foraging use at Brunswick Point and in the BB, IC region, but not in the SB, WI region. As described for Brunswick Point, TOC decreases with distance to shore at Sturgeon Bank and Westham Island, so the influence may have been confounded with decreasing use at greater distances from shore. Reduced foraging use was also observed during the southward migration in areas immediately adjacent to shore, demonstrating a consistent influence from predation pressure.

The distribution of shorebird foraging use is influenced by habitat availability and predation danger, but is largely driven by food abundance. The influence of habitat availability and predation danger, as described by Distance to Shore, were generally consistent between the migrations. Foraging use declined in areas immediately adjacent to shore where predation risk was higher. Otherwise, foraging use declined at greater distances from shore where inundation more often made mudflats inaccessible. In contrast, factors which have been more directly linked to food abundance (e.g., TOC and Salinity) varied in their influence on foraging use across migrations. During the northward migration, the most concentrated foraging use occurred at sites with freshwater influence (e.g., Brunswick Point and Westham Island) and the influence of TOC on foraging distributions was relatively unimportant. During the southward migration, foraging use was higher in areas with higher Salinity and greater TOC. The abundance of invertebrate shorebird prey has been positively linked to both Salinity and TOC in previous studies (Yates et al. 1993, Zharikov et al. 2009, Sutherland et al. 2013, Hemmera 2014*b*). Thus, modelling results suggest that foraging use is more focused on invertebrate prey during the southward migration as compared to the northward migration. Diet studies of western sandpipers conducted during the northward migration suggest that biofilm comprises the majority of the diet at Brunswick Point (Kuwae et al. 2008, 2012, Hemmera 2014*a*). Considering that foraging use during the northward migration was more concentrated at Brunswick Point than in any other area, it follows that the distribution of biofilm was a more important driver of use than invertebrate prey.

Important variation in habitat availability and shorebird abundance was described by Year, Shorebird Abundance, and Low Tide Height. In all models, at least one of these variables accounted for significant variation in dropping densities that was unrelated to habitat characteristics and increased the power to detect significant relationships with environmental variables.

5.5 Influence of Artificial Light

While AIC selection of models describing the likelihood of shorebird presence at night found some support for Light, GLM analyses indicate that shorebird presence in surveys was almost entirely driven by Tide Height. The parameter estimate for light was negative, but it was not significant and did little to improve the fit of the model. The negative parameter estimate for Tide Height suggests that, during the northward migration, nocturnally foraging shorebirds prefer to use intertidal habitat when more area is exposed. This tendency could reflect higher nocturnal predation pressure with reduced area or in areas closer to shore, or a preference for prey at lower elevations at night. The finding of an insignificant effect of light is in accordance with findings from a previous study at Roberts Bank that found no significant relationship between nocturnal light and over-wintering dunlin presence (Zharikov et al. 2009).

5.6 DATA GAPS AND LIMITATIONS

Areas of the FRE located to the north of the Iona Jetty, south of B.C. Ferries Terminal, and south of the Serpentine River outflow were not surveyed in this study. In addition, Centennial Beach in southwest Boundary Bay was not surveyed for the shorebird abundance study. Historical data based on one year of monthly surveys of the entire FRE attributed only 1.5% of western sandpiper abundances to the three areas that were excluded from the study and only 4% of western sandpipers in the estuary to the four areas excluded from abundance surveys (Butler and Cannings 1989); therefore, surveys should account for the large majority of western sandpipers in the estuary, and estimates of the proportions of birds across survey areas should be representative of at least 95% of the use and abundance in the FRE.

Dropping density IDWs do not account for the influence of shorebird abundance on observed droppings records. Because dropping densities across the estuary correspond to trends in shorebird abundance (**Appendix A: Figure 8),** areas surveyed on days with more birds in the estuary recorded more droppings and are biased high relative to areas surveyed on days with fewer birds. Usage surveys were evenly allocated across study sites during most survey days so averages across sites and survey areas should not be influenced by this effect. Droppings densities were not directly corrected for abundance for two reasons: 1) zero records could not be adjusted with a correction factor; and 2) the relationship between dropping densities and abundance was not necessarily linear because of the potential for density dependent usage (i.e., high use areas may become saturated in which case dropping densities would not increase beyond a certain level regardless of the number of birds in the estuary). Consequently, the IDWs should be considered a representation of the raw data rather than a true reflection of relative use across the estuary. A more refined spatial representation of usage would require a better understanding of the relationship of foraging use with density dependence.

5.7 COMPARISON OF SURVEY TECHNIQUES

Comparison of Abundance Survey Methods

At Boundary Bay, walking surveys tended to overestimate the number of shorebirds compared to surveys conducted by driving the dyke. While the discrepancy between the two survey methods was large (i.e., 50% to 130% differences), falcon attacks led to dramatic flock movements during the simultaneous surveys and likely exaggerated the difference. Counts from driving surveys were considered more accurate estimates of abundance because lower numbers of observers and faster movement through survey areas reduced the likelihood that birds were counted more than once. In other areas of the estuary where walking counts were conducted, survey areas were smaller and often separated by landscape features that reduce shorebird movement between areas. Consequently, the likelihood of different observers counting the same flocks was lower at other sites. Therefore, the driving survey is an appropriate adaptation to increased risks of over-estimating abundances at Boundary Bay and counts from driving surveys at Boundary Bay are likely more comparable to walking surveys at other sites than the results of survey method comparisons at Boundary Bay suggest.

Comparison of Abundance and Droppings Surveys

In comparison to abundance surveys, droppings surveys described similar or higher proportions of use at survey areas in Boundary Bay, similar proportions of use at Roberts Bank, and lower proportions of use at Sturgeon Bank. Potential sources of these discrepancies are as follows: 1) droppings survey methods were the same across all survey areas whereas abundance survey methods were different between Boundary Bay and other areas; 2) droppings surveys primarily captured foraging use during the falling and low tide whereas abundance surveys only captured use during the rising tide and distributions during the rising tide (i.e., captured during abundance surveys) may not be representative of use during the rest of the tidal cycle.

More conservative counting methods at Boundary Bay, may be responsible for the higher proportions of use described for that region by dropping surveys, but do not explain the relatively high proportions of abundance reported for Sturgeon Bank. Abundance surveys describe use during the rising tide so a shift in the distribution of shorebirds between tidal stages could account for these and other differences in the ratio of droppings to abundance across sites. For example, birds that forage on the north side of the Iona Jetty were sometimes seen flying in to the YVR survey area as the tide rose. Abundance surveys during the falling tide appear to over-represent use in that area because birds were not foraging there at other periods of the tide cycle. In contrast, relatively high proportions of droppings as compared to abundances at Mud Bay indicate reduced use of habitat in that area during the rising tide.

6.0 CLOSURE

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8.0 STATEMENT OF LIMITATIONS

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

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

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

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

APPENDIX A
Figures

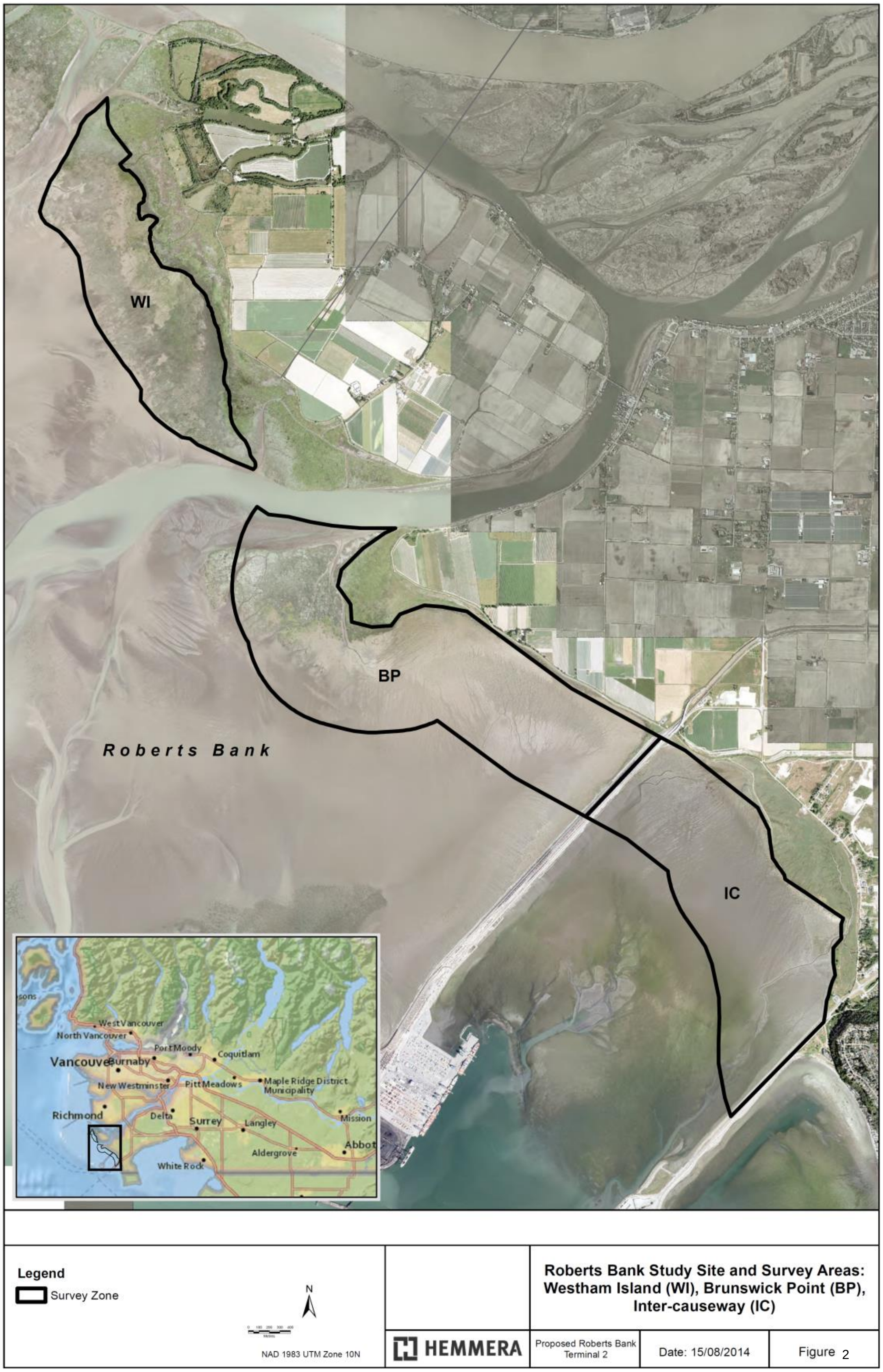
Legend
Survey Zone

NAD 1983 UTM Zone 10N

HEMMERA

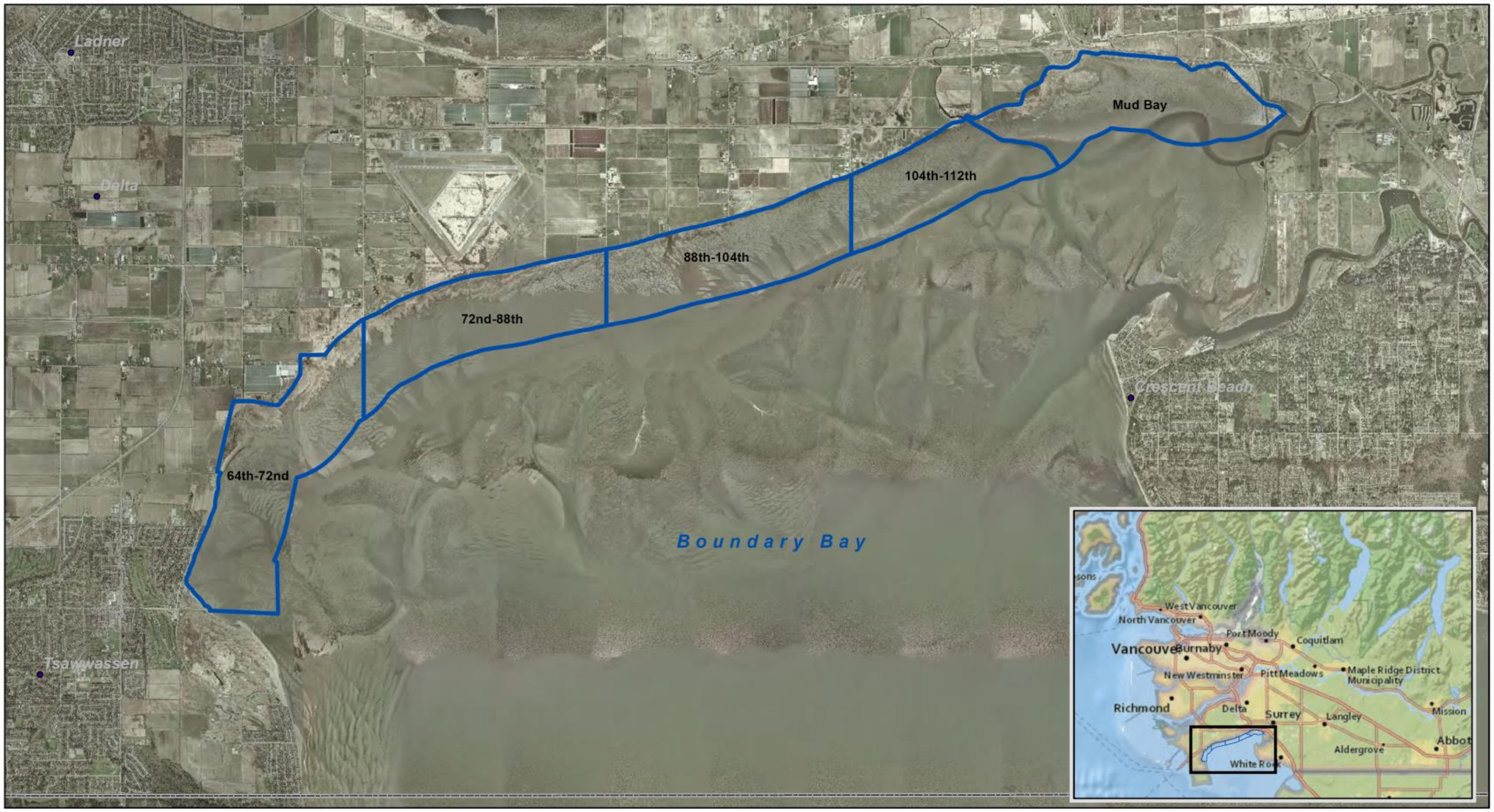
Sturgeon Bank Study Site and Survey Areas: Vancouver Airport (YVR), Sturgeon Bank North (SB-N), Sturgeon Bank South (SB-S)

Proposed Roberts Bank Terminal 2	Date: 15/08/2014	Figure 1



Roberts Bank Study Site and Survey Areas: Westham Island (WI), Brunswick Point (BP), Inter-causeway (IC)

HEMMERA | Proposed Roberts Bank Terminal 2 | Date: 15/08/2014 | Figure 2



Legend

Survey Zone
Canada / USA Border

N
Kilometres
NAD 1983 UTM Zone 10N

HEMMERA

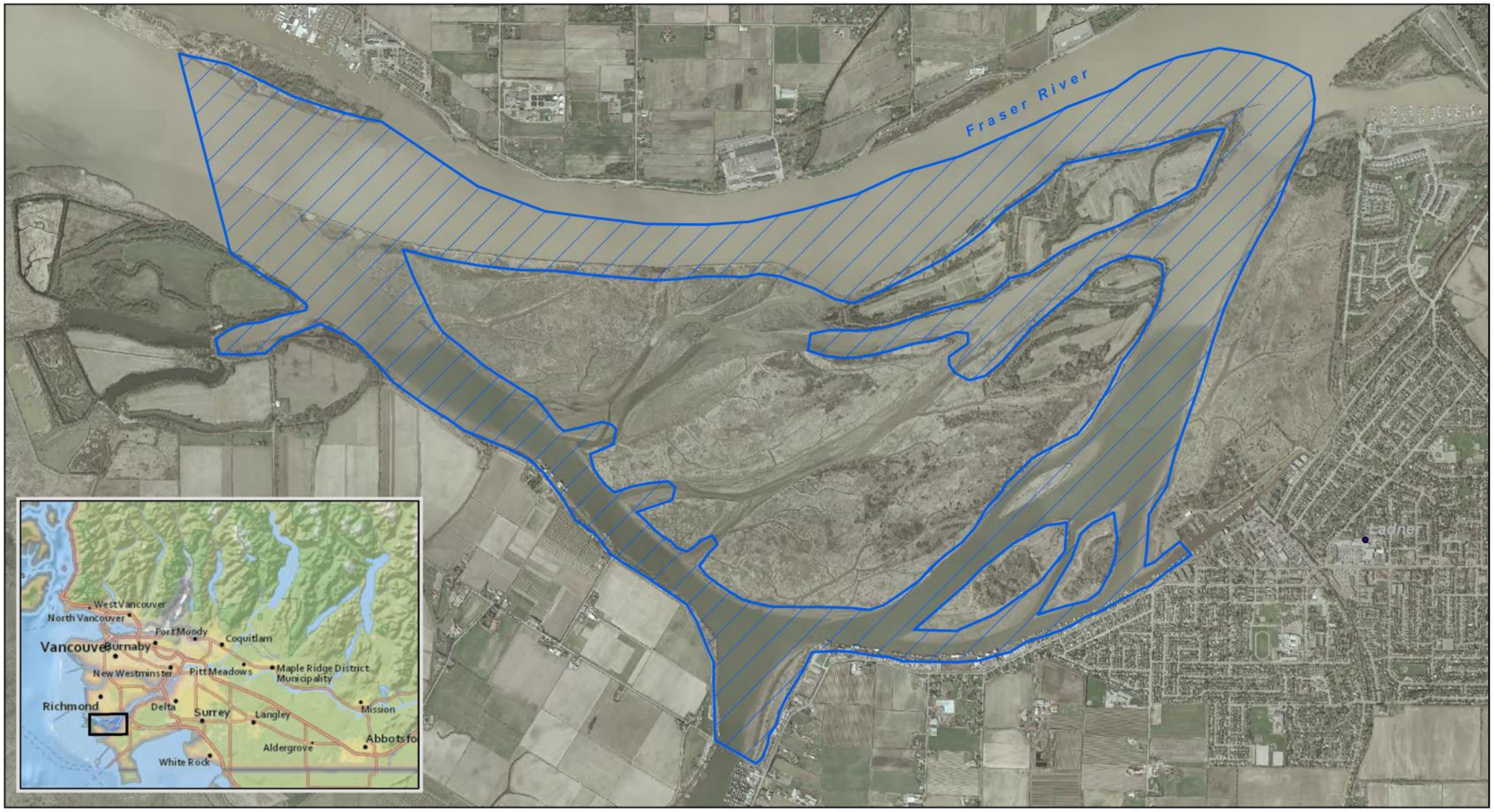
FIG No. 3

Boundary Bay
Study Site and Survey Areas

Proposed Roberts Bank Terminal 2

Date: 15/08/2014

Path: O:\1200-\1246\001.04\120216_Birds\Shorebird_Counts\arcmap\140812_TDR_Fig07_Dunlin_Shorebird_Counts_SAM.mxd



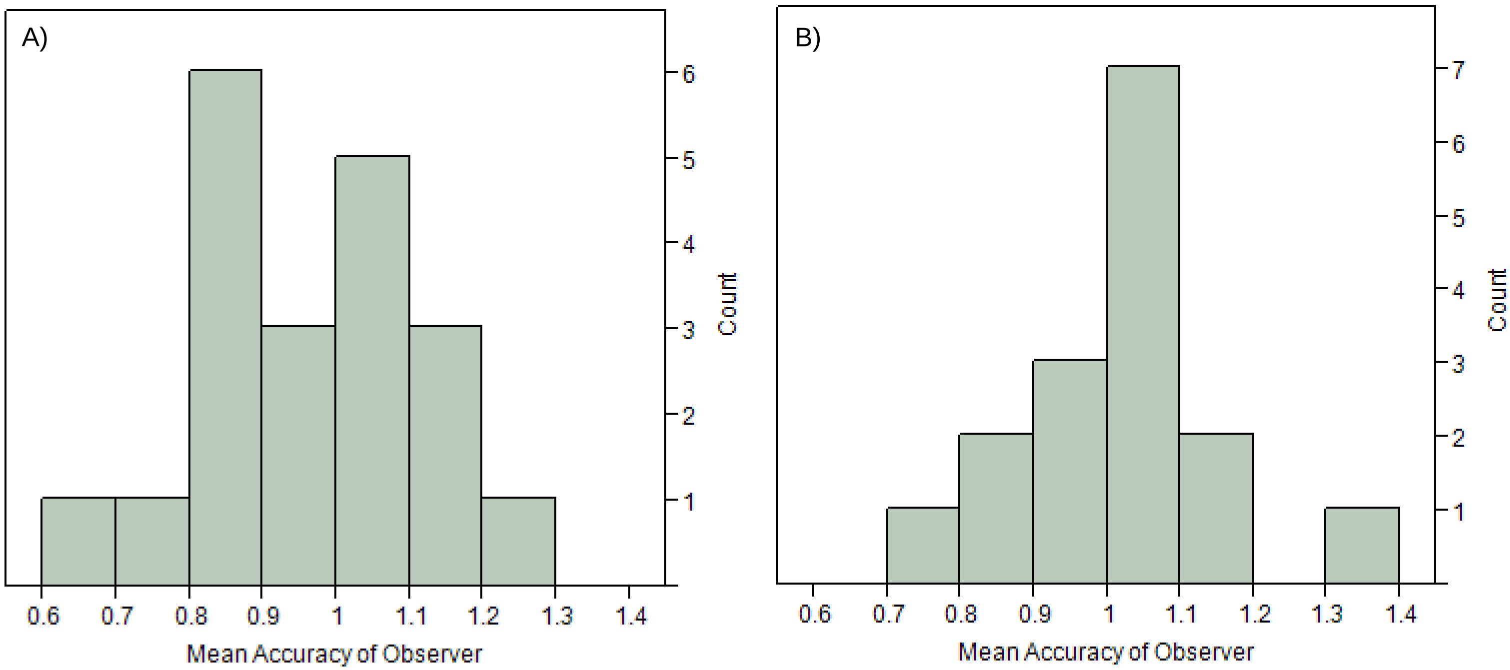
Legend

South Arm Marshes Survey Area

N
0 250 500
Metres
NAD 1983 UTM Zone 10N

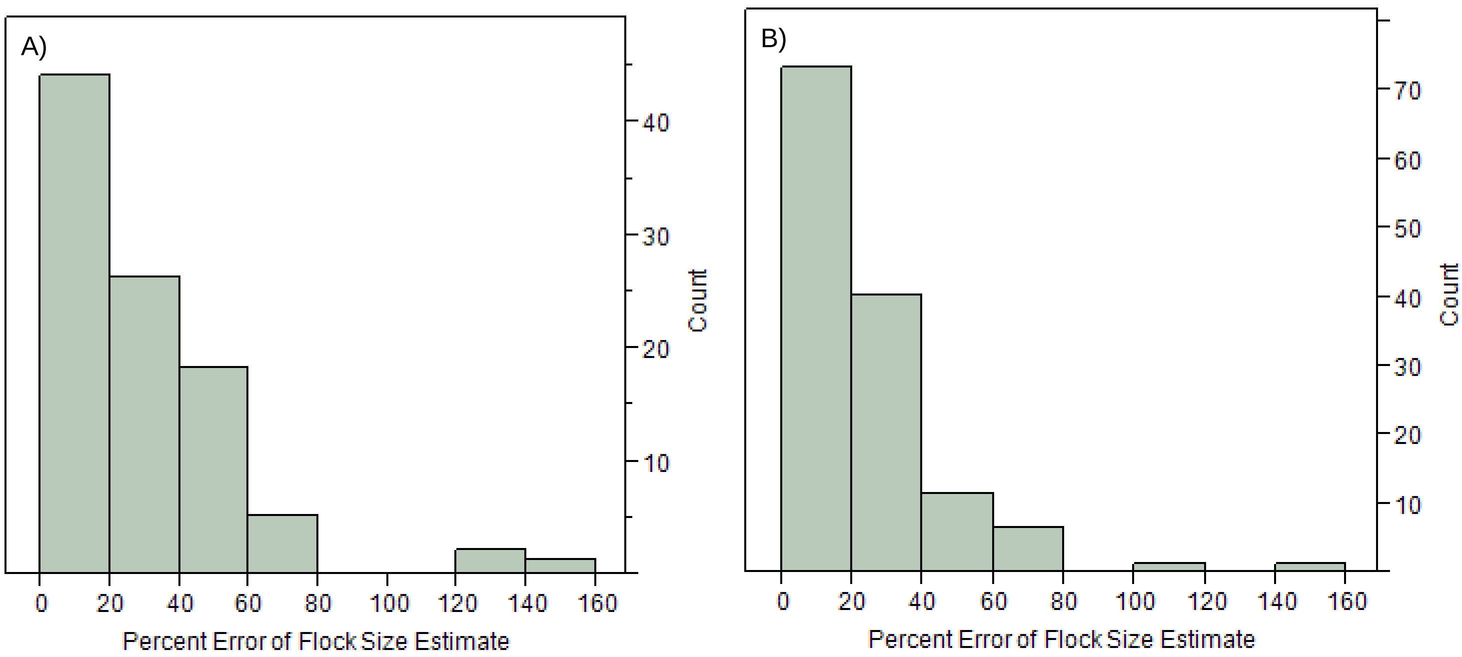
FIG No. 4	Proposed Roberts Bank Terminal 2	
South Arm Marshes Shorebird Survey Areas		
HEMMERA		Date: 13/08/2014

Figure 5 Frequency Distribution of Mean Accuracy of Observer Flock Size Estimates from Field-based Quality Assurance Counts during the Northward (A) and Southward (B) Migrations of Western Sandpipers in 2013



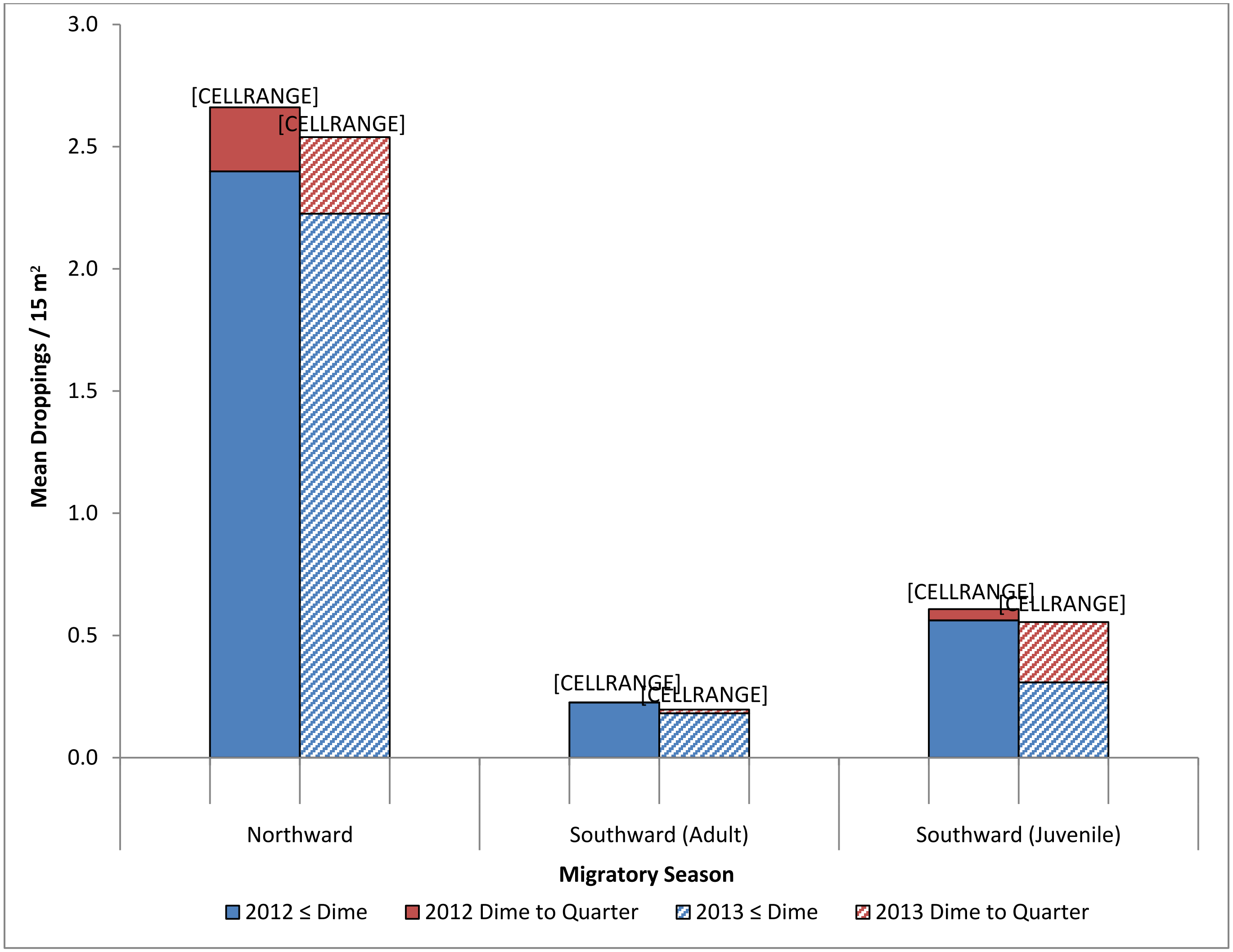
Notes: Mean and standard deviation of count accuracy was 0.96 and 0.15 for the northward migration and 1.00 and 0.15 for the southward migration. The accuracy of flock size estimates determined from quality assurance counts were likely reduced relative to the accuracy of field counts due to the potential for error resulting from misinterpretation of flock boundaries.

Figure 6 Frequency Distribution of Percent Error of Individual Flock Size Estimates from Field-based Quality Assurance Field Counts during the Northward (A) and Southward (B) Migrations of Western Sandpipers in 2013



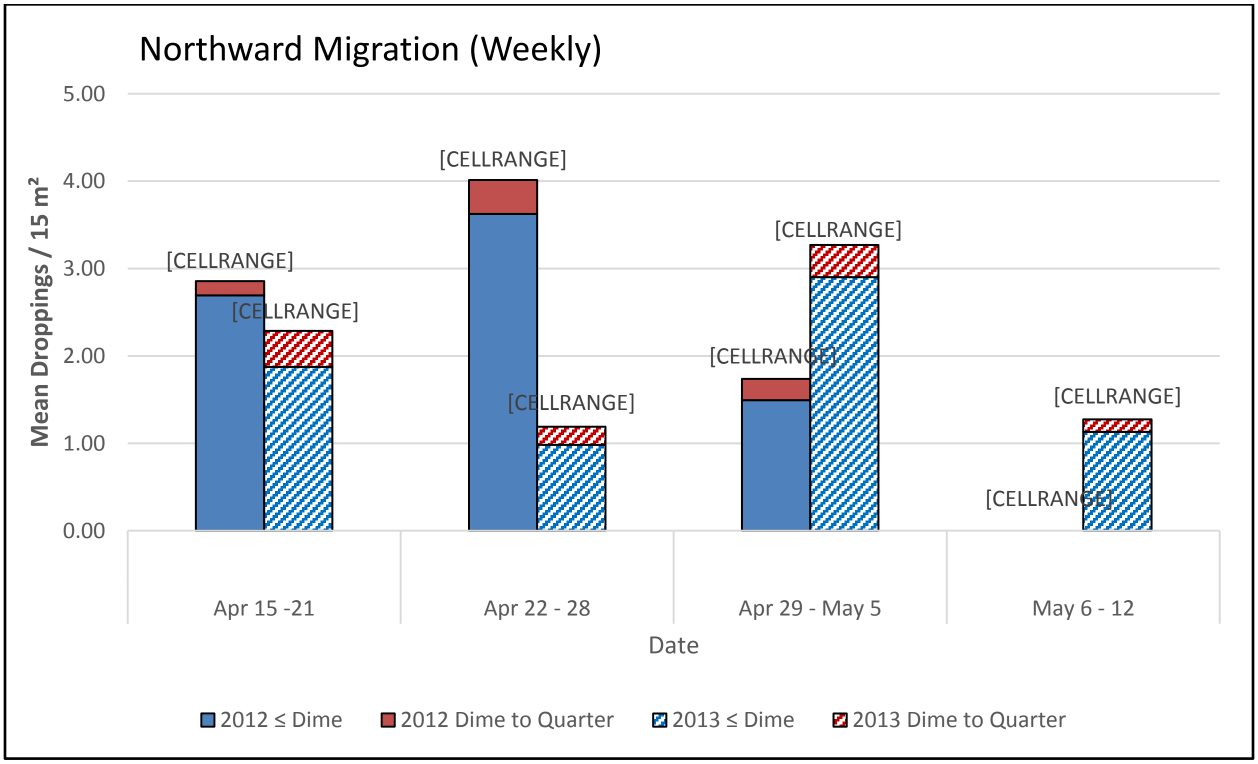
Notes: Median percent error for individual flock size estimates was 22% for the northward migration and 17% for the southward migration. The accuracy of flock size estimates determined from quality assurance counts were likely reduced relative to the accuracy of field counts due to the potential for error resulting from misinterpretation of flock boundaries. For example, outlying errors over 140% are unlikely to be due to observer error.

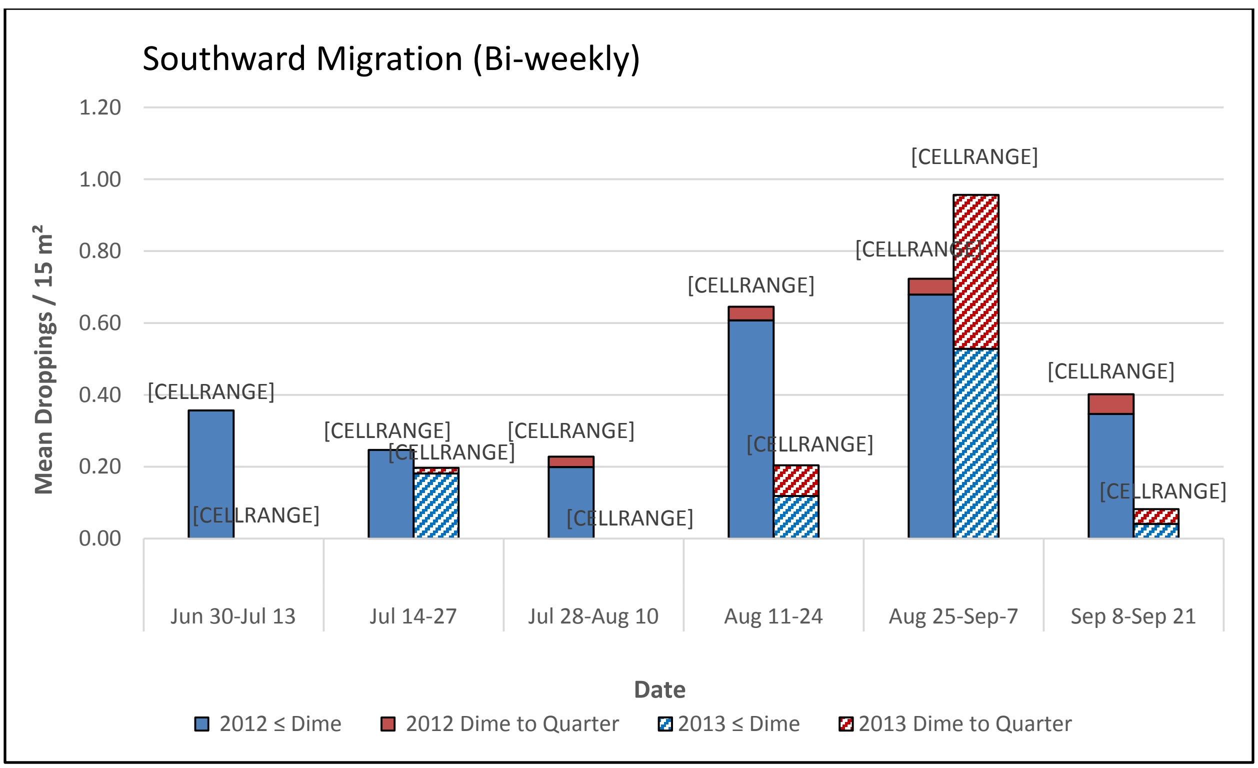
Figure 7 Mean Dropping Densities during the Northward and Southward Migrations of Western Sandpipers in 2012 and 2013



Notes: Number of survey stations for each category above bar plots. Percent of droppings ≤ dime size during migratory seasons of 2012 and 2013: Northward: 90 and 88%, respectively; Southward Adult: >99 and 92%; Southward Juvenile: 92 and 55%.

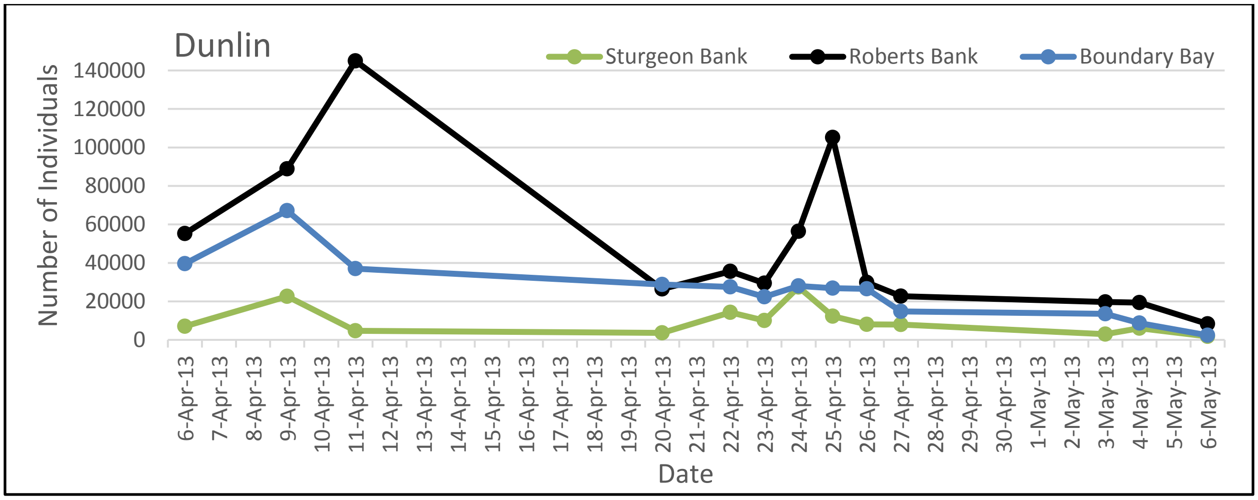
Figure 8 Weekly and Bi-weekly Averages of Shorebird Dropping Densities across the Fraser River Estuary: Northward and Southward Migrations of 2012 and 2013

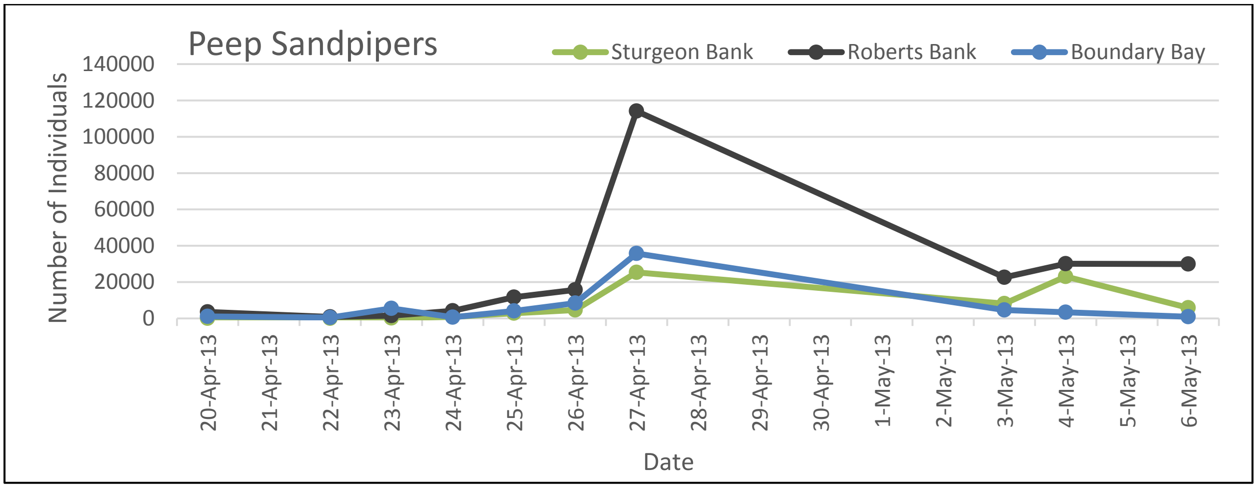


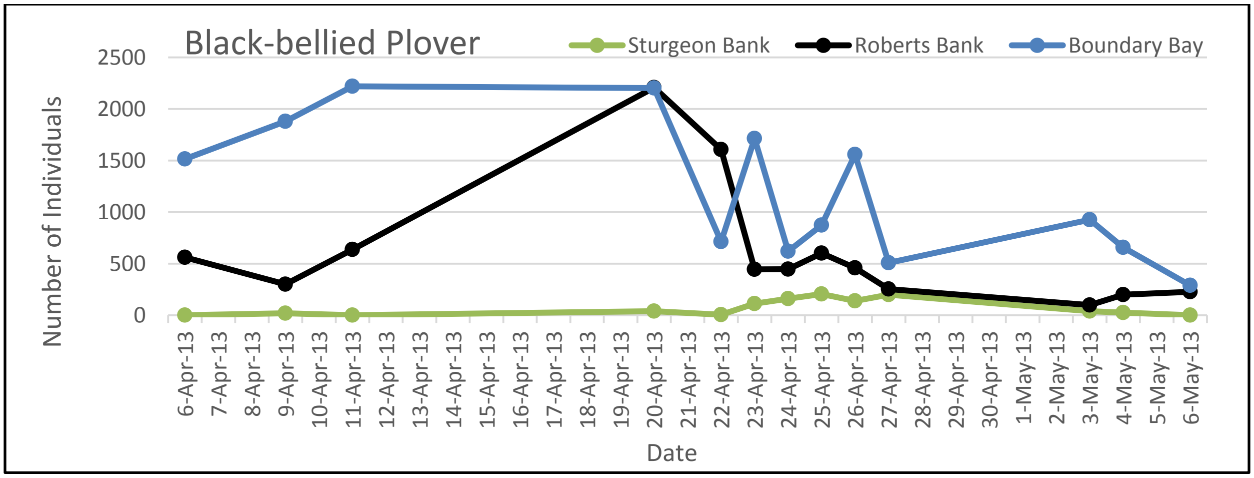


Notes: Number of survey stations for each category presented above bar plots

Figure 9 Abundances of Dunlin, Peep Sandpipers, and Black-bellied Plovers within Sturgeon Bank, Roberts Bank, and Boundary Bay: 2013 Northward Migration

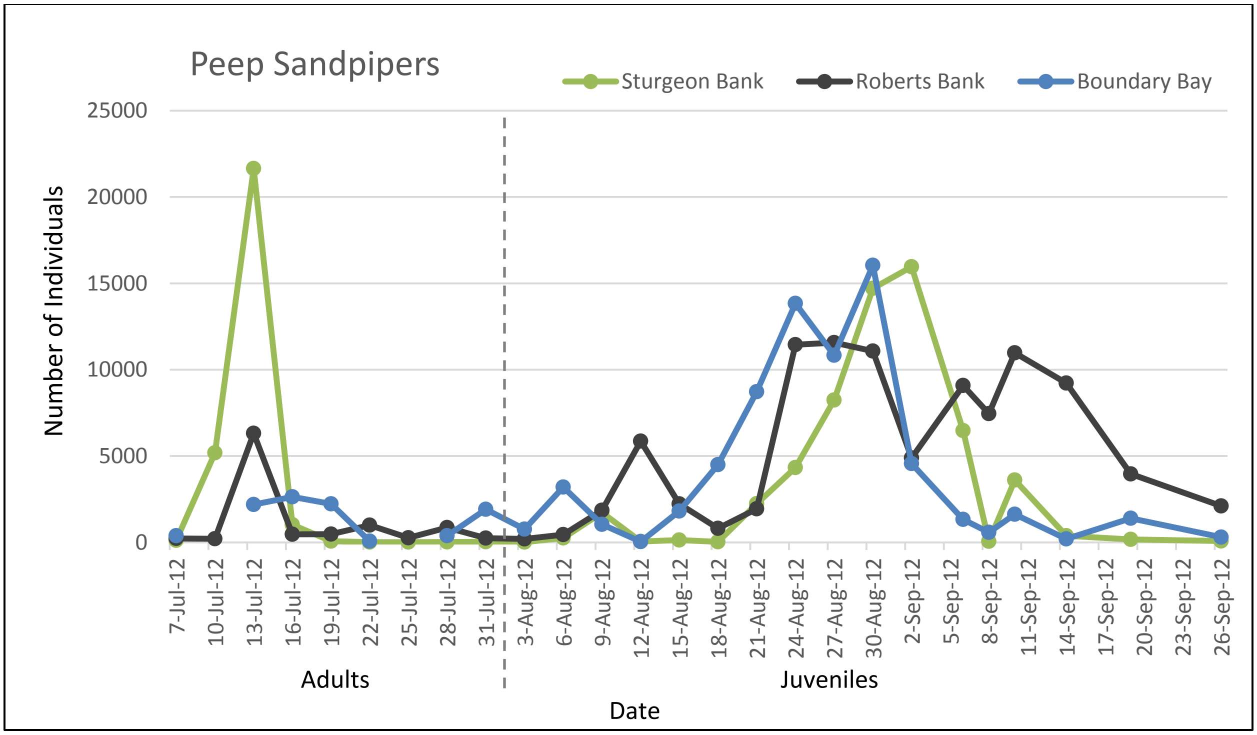


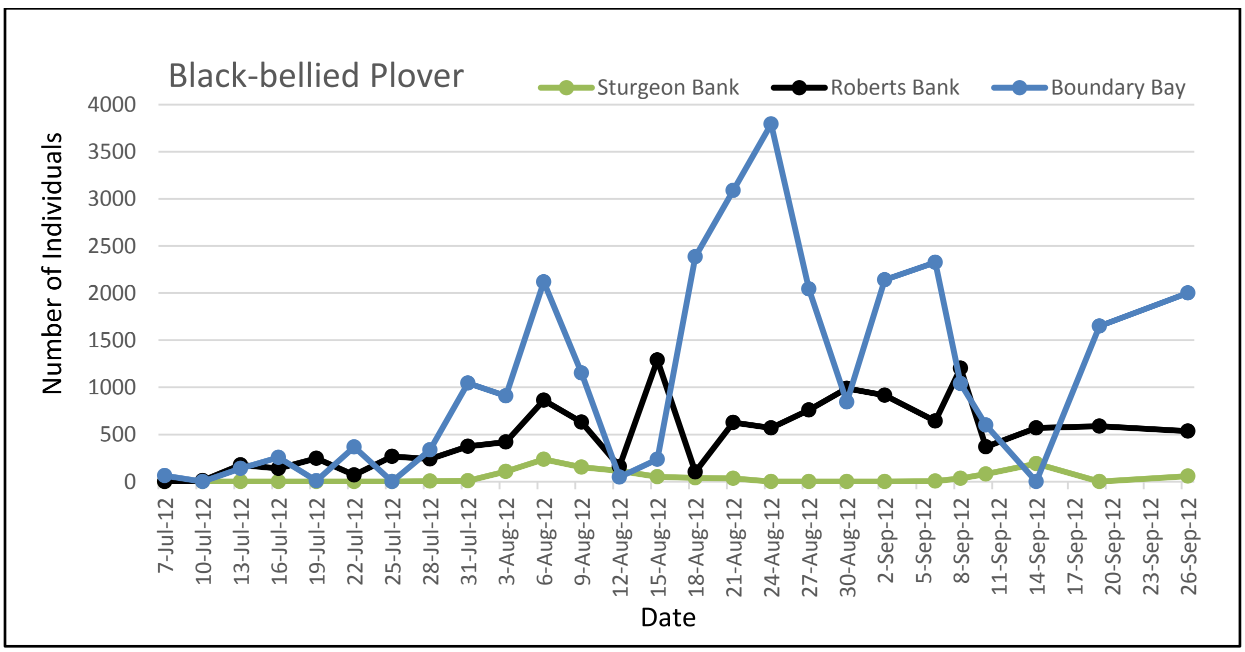




Note: Early dates (April 6 to 19) are not shown for peep sandpipers due to negligible abundances.

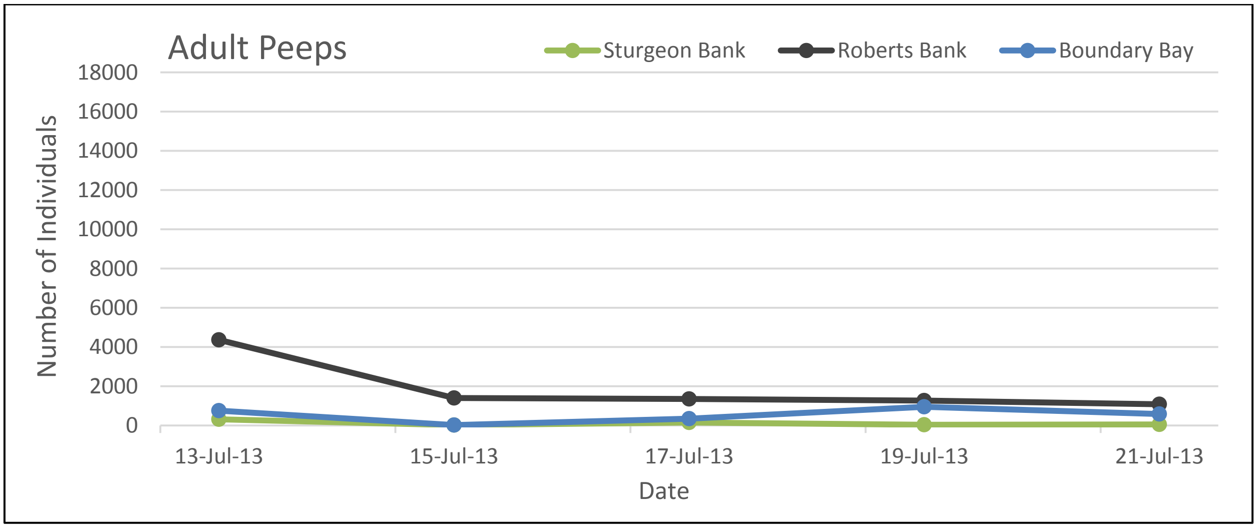
Figure 10 Abundances of Peep Sandpipers and Black-bellied Plovers within Sturgeon Bank, Roberts Bank, and Boundary Bay: 2012 Southward Migration

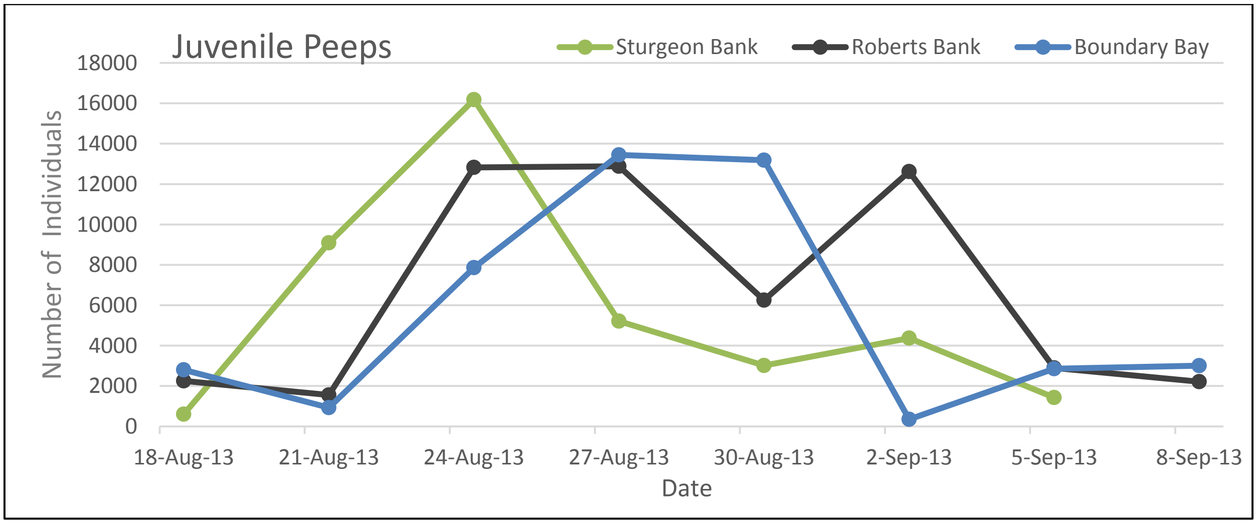


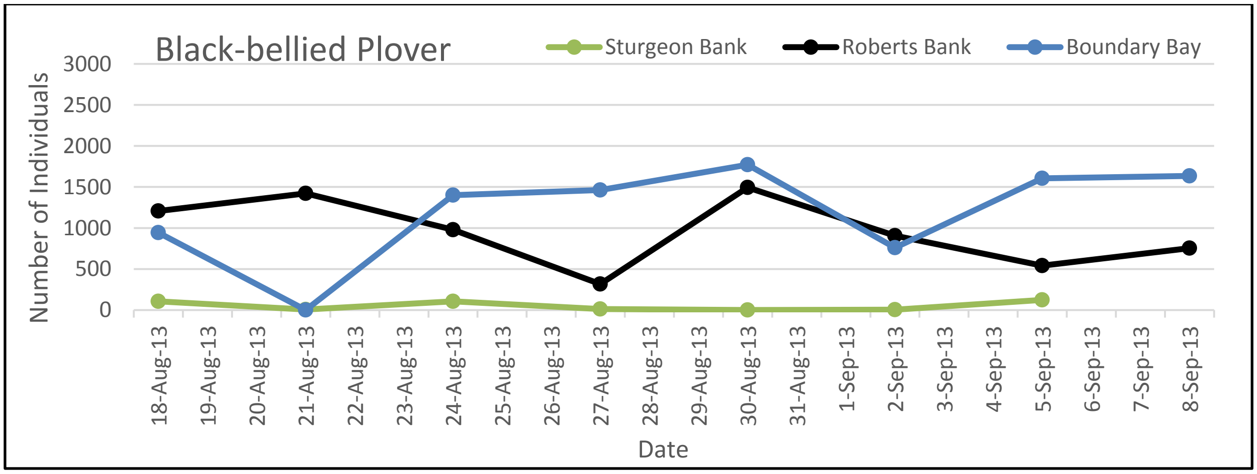


Notes: Abundance records at Sturgeon Bank, Roberts Bank, and Boundary Bay exclude counts from survey areas at YVR, Inter-causeway, and Mud Bay, respectively. Dashed line before indicates the average date on which abundances of juveniles begin to outnumber adults (between August 2 and 3: (Ydenberg et al. 2004)).

Figure 11 Abundances of Adult and Juvenile Peep Sandpipers and Black-bellied Plovers within Sturgeon Bank, Roberts Bank, and Boundary Bay: 2013 Southward Migration

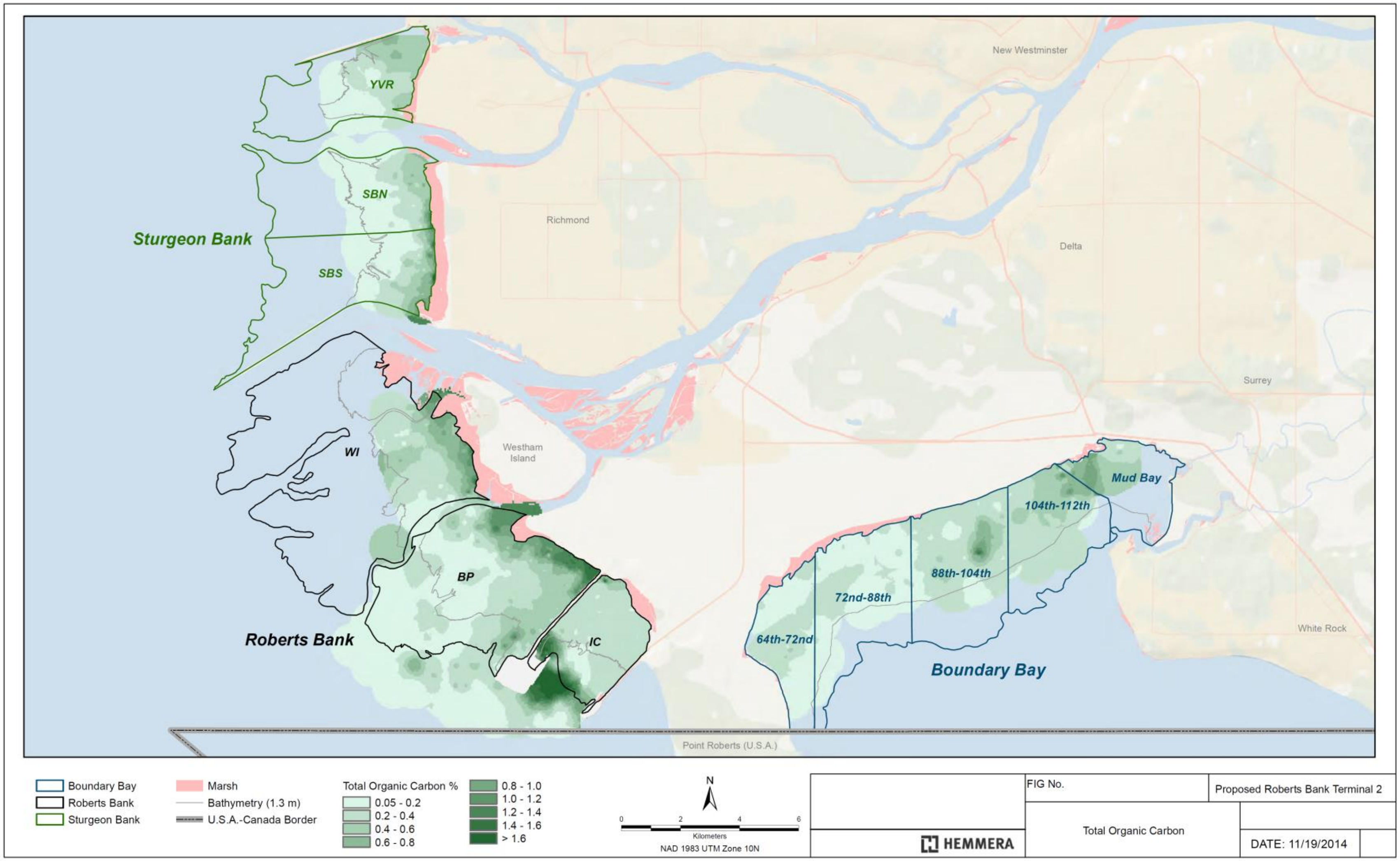






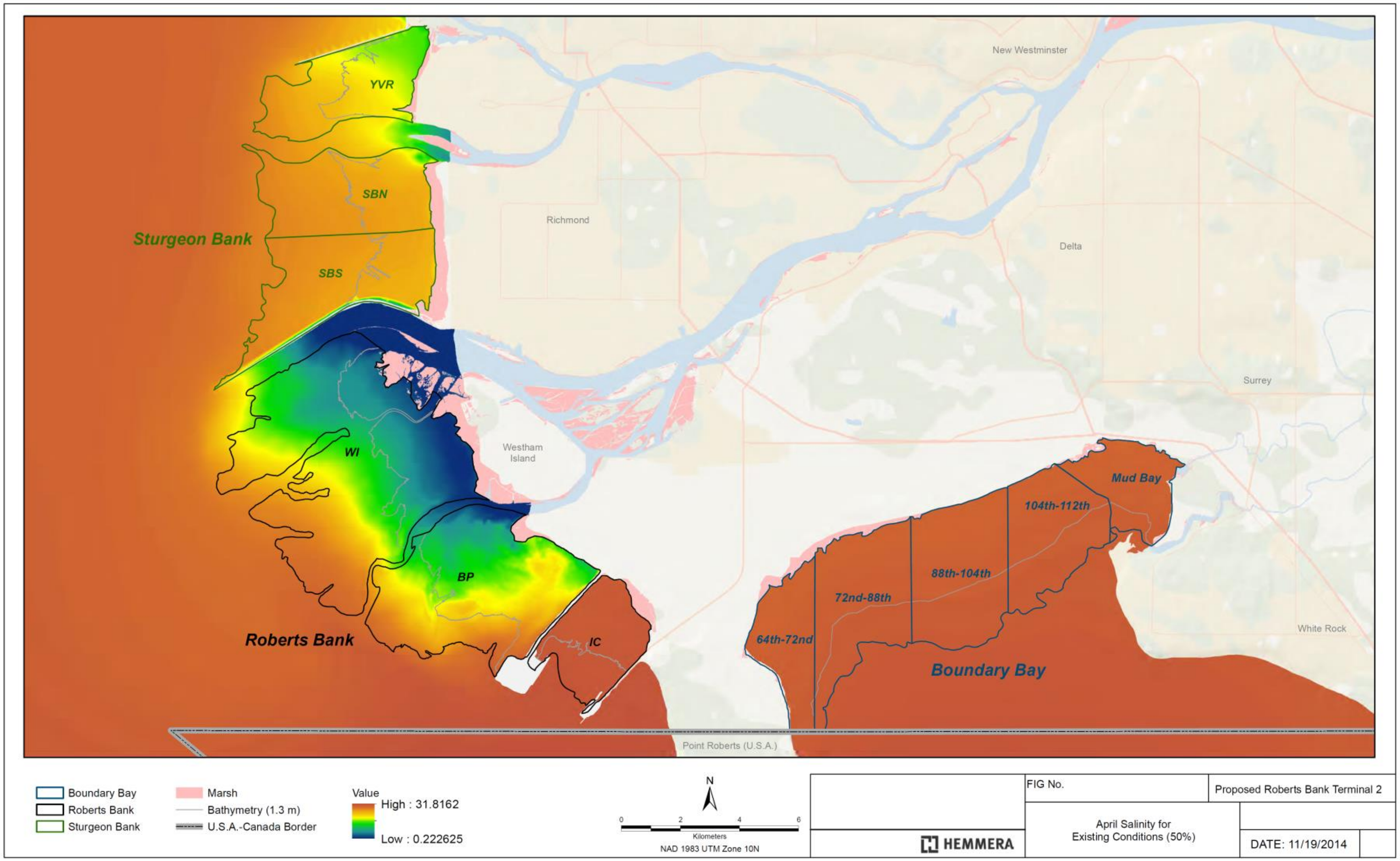
Notes: Black-bellied plover records are not shown for July due to negligible abundances (<250 individuals across the estuary). Data from Sturgeon Bank on September 8, 2013 are excluded due to incomplete records.

Figure 12 **Inverse Distance Weighted Interpolation of Total Organic Carbon Concentrations in Sediments of the Fraser River Estuary Intertidal from Samples Collected between April 2012 and February 2014**



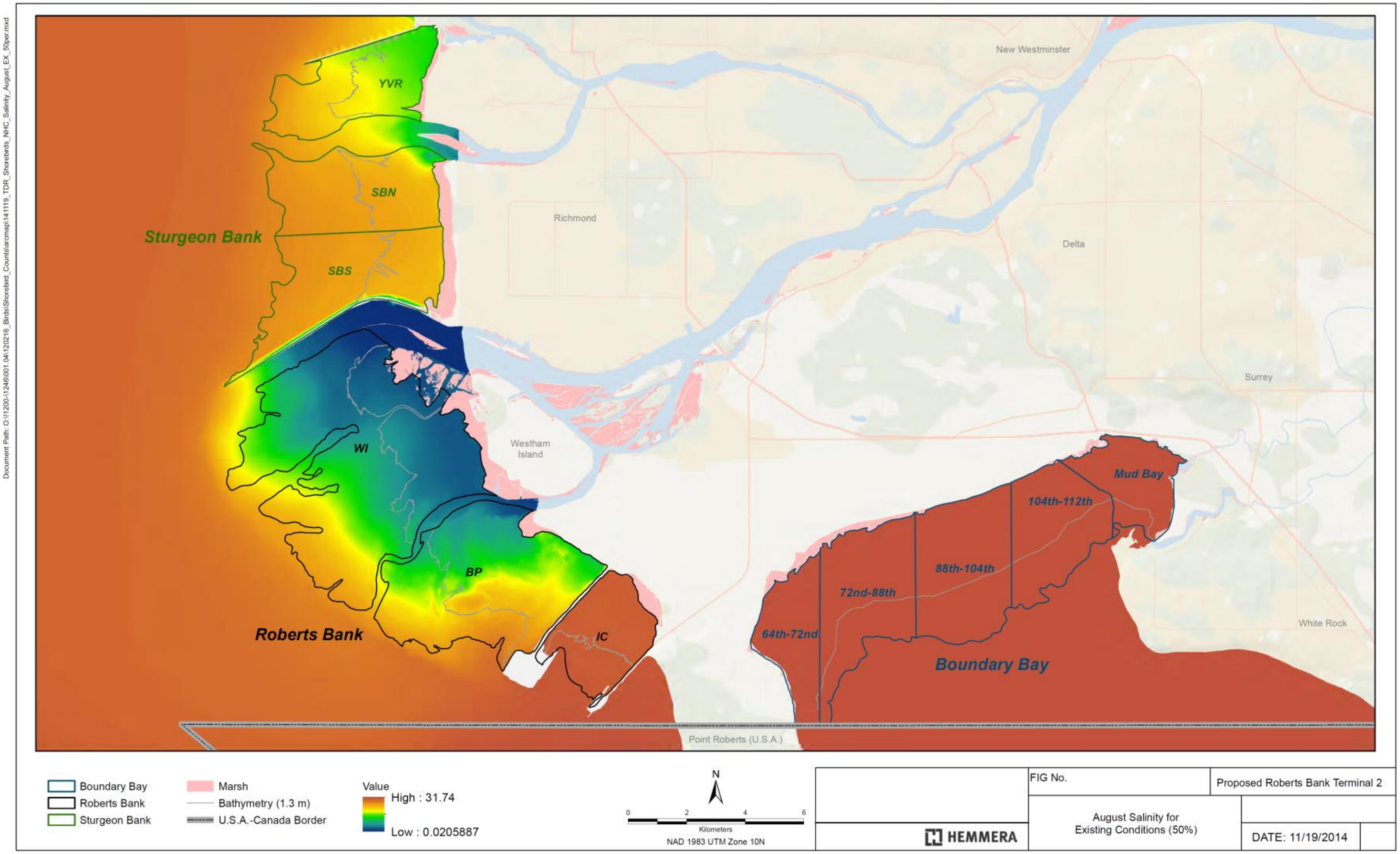
Notes: Dropping densities were estimated across the estuary at a resolution of 50 m^2 using IDW interpolation of the twelve nearest survey stations sampled between April 2012 and February 2014. Interpolation was limited to a distance of 300 m.

Figure 13 Existing Conditions of 50th Percentile Salinity (Practical Salinity Units) for the Month of April Interpolated across the Fraser River Estuary from Models Developed by Northwest Hydraulics Consultants



Document Path: O:\1200-\1246\001.04\120216_Birds\Shorebird_Counts\arcmap\141119_TDR_Shorebirds_NHC_Salinity_April_EX_50per.mxd

Figure 14 Existing Conditions of 50th Percentile Salinity (psu) for the Month of August Interpolated across the Fraser River Estuary from Models Developed by Northwest Hydraulics Consultants



APPENDIX B
Tables

Table 1 Number of Stations Surveyed for Shorebird Droppings in Survey Areas of the Fraser River Estuary during 2012 Northward Migration of Western Sandpipers

Date	Sturgeon Bank			Roberts Bank			Boundary Bay				
	YVR	SBN	SBS	WI	BP	IC	64th-72nd	72nd-88th	88th-104th	104th-112th	Mud Bay
17-Apr-12	40	89	24	25	53	98	41	48	63	0	35
18-Apr-12	0	30	50	7	9	73	55	20	77	0	0
21-Apr-12	33	48	125	58	20	44	28	58	13	28	39
23-Apr-12	31	77	62	26	77	29	24	43	51	85	0
24-Apr-12	0	0	0	0	10	0	0	0	0	0	0
25-Apr-12	29	86	81	56	30	0	0	0	0	0	0
26-Apr-12	0	13	0	0	0	0	0	0	0	0	0
27-Apr-12	35	67	93	93	56	20	40	91	81	46	0
29-Apr-12	0	126	33	34	81	74	62	56	44	6	34
01-May-12	4	4	0	30	57	64	69	77	61	36	50
02-May-12	0	0	0	2	0	0	0	0	0	0	0
03-May-12	42	67	113	22	43	0	103	34	160	0	38
04-May-12	0	0	0	0	0	7	0	0	0	0	0
05-May-12	0	76	92	65	81	0	76	158	65	82	0
06-May-12	0	0	0	0	0	0	0	0	0	10	1
07-May-12	0	0	8	0	0	0	0	0	0	0	0
Total	**214**	**683**	**681**	**418**	**517**	**409**	**498**	**585**	**615**	**293**	**197**
	1578			**1344**			**2188**				

Table 2 Number of Stations Surveyed for Shorebird Droppings in Survey Areas of the Fraser River Estuary during the 2012 Southward Migration of Western Sandpipers

Date	Sturgeon Bank			Roberts Bank			Boundary Bay				
	YVR	SBN	SBS	WI	BP	IC	64th-72nd	72nd-88th	88th-104th	104th-112th	Mud Bay
02-Jul-12	0	0	0	0	14	0	0	0	0	0	0
03-Jul-12	0	0	0	0	0	11	0	0	0	0	0
04-Jul-12	0	0	0	0	0	12	0	0	0	0	0
06-Jul-12	30	68	0	15	28	0	39	5	33	35	0
09-Jul-12	33	23	25	0	43	56	0	62	39	35	0
12-Jul-12	64	59	0	31	47	0	0	8	47	0	52
13-Jul-12	0	0	11	0	0	0	0	0	0	0	0
15-Jul-12	0	6	112	66	0	0	7	97	0	0	0
18-Jul-12	0	82	51	73	0	63	16	43	17	35	0
19-Jul-12	0	0	0	0	0	0	0	0	13	0	0
21-Jul-12	73	0	42	41	43	0	54	13	59	0	0
23-Jul-12	0	0	0	0	14	0	0	0	0	0	0
24-Jul-12	28	0	51	60	47	0	7	42	0	0	42
25-Jul-12	0	0	0	0	14	0	0	0	0	0	0
27-Jul-12	0	25	19	73	98	0	0	16	52	59	0
30-Jul-12	73	36	13	81	45	0	43	4	27	48	0
31-Jul-12	0	0	0	0	12	0	0	0	0	0	0
01-Aug-12	0	14	0	0	0	0	0	0	0	0	0
02-Aug-12	43	12	32	67	0	93	0	0	46	37	0
05-Aug-12	32	0	0	0	116	28	60	33	0	0	0
08-Aug-12	0	50	36	8	88	0	0	17	73	61	0
10-Aug-12	15	0	0	0	0	0	0	0	0	0	0
11-Aug-12	37	0	37	40	89	0	54	0	0	0	36
14-Aug-12	0	43	61	49	86	0	34	53	0	0	0
15-Aug-12	0	0	0	0	0	0	0	0	0	0	12
16-Aug-12	0	4	8	0	0	0	0	0	0	0	0
17-Aug-12	0	42	41	102	12	0	35	4	0	0	42
20-Aug-12	45	38	11	63	103	0	80	13	40	0	0
21-Aug-12	0	0	0	0	0	0	0	0	5	4	0
23-Aug-12	0	29	29	7	10	62	28	57	34	33	0
26-Aug-12	0	1	40	82	36	0	6	58	41	0	0
27-Aug-12	0	0	0	14	0	0	0	0	0	0	0
28-Aug-12	0	0	0	8	0	0	0	0	0	0	0
29-Aug-12	26	0	35	85	39	0	50	19	16	50	1
01-Sep-12	49	9	32	76	141	0	47	31	35	0	0

Table 2 Continued

Date	Sturgeon Bank			Roberts Bank			Boundary Bay				
	YVR	SBN	SBS	WI	BP	IC	64th-72nd	72nd-88th	88th-104th	104th-112th	Mud Bay
04-Sep-12	0	40	44	53	0	0	19	15	50	24	0
12-Sep-12	60	0	56	38	51	0	51	8	0	0	35
18-Sep-12	47	0	35	27	89	0	0	77	66	0	0
Total	**655**	**581**	**821**	**1159**	**1265**	**325**	**630**	**675**	**693**	**421**	**220**
	2057			**2749**			**2639**				

Table 3 Number of Stations Surveyed for Shorebird Droppings Survey Areas of the Fraser River Estuary during the 2013 Northward Migration of Western Sandpipers

Date	Sturgeon Bank			Roberts Bank			Boundary Bay				
	YVR	SBN	SBS	WI	BP	IC	64th-72nd	72nd-88th	88th-104th	104th-112th	Mud Bay
15-Apr-13	87	64	5	62	44	0	0	27	0	22	0
17-Apr-13	0	28	83	38	0	0	0	0	0	0	0
23-Apr-13	111	0	83	36	0	65	57	0	30	34	0
25-Apr-13	0	81	59	31	63	0	3	173	87	0	0
27-Apr-13	0	0	0	30	0	0	0	0	2	10	1
29-Apr-13	0	0	0	0	0	94	0	0	2	86	71
30-Apr-13	0	7	89	0	120	0	8	137	0	0	0
01-May-13	0	136	64	47	72	0	154	0	24	105	0
02-May-13	87	45	0	35	90	0	0	83	0	0	118
03-May-13	154	0	94	51	97	0	124	0	61	0	0
05-May-13	66	80	0	0	258	62	86	27	59	0	0
07-May-13	25	5	51	129	169	0	0	5	124	53	0
Total	**530**	**446**	**528**	**459**	**913**	**221**	**432**	**452**	**389**	**310**	**190**
	1504			**1593**			**1773**				

Table 4 Number of Stations Surveyed for Shorebird Droppings in Survey Areas of the Fraser River Estuary during the 2013 Southward Migration of Western Sandpipers

Date	Sturgeon Bank			Roberts Bank			Boundary Bay				
	YVR	SBN	SBS	WI	BP	IC	64th-72nd	72nd-88th	88th-104th	104th-112th	Mud Bay
14-Jul-13	55	12	67	0	32	76	5	37	0	0	0
16-Jul-13	0	46	7	74	147	0	0	7	66	45	0
18-Jul-13	42	0	0	53	77	115	66	13	27	47	0
20-Jul-13	81	1	34	27	81	0	8	90	86	0	0
22-Jul-13	33	93	22	70	52	0	54	55	5	95	0
16-Aug-13	41	0	84	30	34	0	0	10	55	71	0
19-Aug-13	72	48	31	87	86	0	76	22	37	65	0
22-Aug-13	11	44	0	53	68	0	20	108	53	0	0
25-Aug-13	73	64	27	85	51	0	0	52	57	0	81
28-Aug-13	0	0	0	0	62	86	12	70	0	0	69
31-Aug-13	0	0	0	88	82	32	94	0	8	86	0
06-Sep-13	85	28	46	66	78	0	0	95	104	0	0
09-Sep-13	0	69	107	18	77	0	143	120	0	0	0
Total	**493**	**405**	**425**	**651**	**927**	**309**	**478**	**679**	**498**	**409**	**150**
	1323			**1887**			**2214**				

Table 5 Summary Statistics of Droppings Records and Estimates of Average Droppings Abundances in Survey Areas of the Fraser River Estuary during the Northward Migration of Western Sandpipers

		YVR	SBN	SBS	WI	BP	IC	64-72	72-88	88-104	104-112	Mud Bay
2012	Mean Density	2.64	1.83	2.43	6.07	9.09	0.99	1.10	0.69	1.13	2.49	0.53
	n	214	683	681	418	517	409	498	585	615	293	197
	SD	10.40	5.24	8.53	13.46	15.07	4.42	3.78	2.52	3.34	6.74	2.03
	SE	0.71	0.20	0.33	0.66	0.66	0.22	0.17	0.10	0.13	0.39	0.14
	Estimate of Average Number of Droppings	12241	8645	12304	64267	109054	4289	6158	4494	6982	10155	2601
2013	Mean Density	0.12	0.11	1.62	4.40	7.83	0.57	0.35	0.57	2.67	1.63	0.81
	n	530	446	528	459	913	221	432	452	389	310	190
	SD	0.76	0.80	6.84	9.55	16.78	2.05	1.37	1.53	10.42	7.38	4.27
	SE	0.03	0.04	0.30	0.45	0.56	0.14	0.07	0.07	0.53	0.42	0.31
	Estimate of Average Number of Droppings	550	529	8199	46558	93878	2456	1989	3713	16414	6640	3930

Notes: Estimates of average number of droppings based on area exposed at the average low tide during migratory periods (1.3 m)

Table 6 Summary Statistics of Droppings Records and Estimates of Average Droppings Abundances in Survey Areas of the Fraser River Estuary during the Southward Migration of Adult Western Sandpipers

		YVR	SBN	SBS	WI	BP	IC	64-72	72-88	88-104	104-112	Mud Bay
2012	Mean Density	0.01	0.20	0.31	0.02	0.27	0.00	0.02	0.53	0.57	0.08	0.86
	n	344	325	356	507	405	235	166	290	333	249	94
	SD	0.18	1.32	2.63	0.21	1.10	0.00	0.17	3.08	6.79	0.64	6.43
	SE	0.01	0.07	0.14	0.01	0.05	0.00	0.01	0.18	0.37	0.04	0.66
	Estimate of Average Number of Droppings	67	929	1593	167	3257	0	102	3459	3510	327	4205
2013	Mean Density	0.04	0.00	0.14	0.03	0.87	0.01	0.01	0.01	0.05	0.05	*
	n	211	152	130	224	389	191	133	202	184	187	*
	SD	0.32	0.00	1.19	0.21	5.43	0.07	0.09	0.10	0.74	0.47	*
	SE	0.02	0.00	0.10	0.01	0.28	0.01	0.01	0.01	0.05	0.03	*
	Estimate of Average Number of Droppings	175	0	701	284	10450	23	42	65	334	196	*

Notes: Estimates of average number of droppings based on area exposed at the average low tide during migratory periods (1.3 m). *No droppings surveys were conducted in Mud Bay during the 2013 adult migration due to extreme weather on the scheduled and re-scheduled survey days.

Table 7 Summary Statistics of Dropping Records and Estimates of Average Droppings Abundances in Survey Areas of the Fraser River Estuary during the Southward Migration of Juvenile Western Sandpipers

		YVR	SBN	SBS	WI	BP	IC	64-72	72-88	88-104	104-112	Mud Bay
2012	Mean Density	0.04	0.34	0.54	0.30	0.65	0.11	0.21	0.55	1.72	2.67	0.03
	n	311	256	465	652	860	90	464	385	360	172	126
	SD	0.32	1.56	2.63	1.30	2.53	0.68	1.74	2.55	6.55	5.69	0.22
	SE	0.02	0.10	0.12	0.05	0.09	0.07	0.08	0.13	0.35	0.43	0.02
	Estimate of Average Number of Droppings	164	1623	2744	3182	7850	482	1198	3627	10577	10901	155
2013	Mean Density	0.20	0.08	0.19	0.23	1.17	0.04	0.08	0.52	0.92	1.36	1.11
	n	282	253	295	427	538	118	347	477	314	222	150
	SD	1.44	0.45	1.20	1.49	4.06	0.33	0.49	2.75	3.39	5.45	3.81
	SE	0.09	0.03	0.07	0.07	0.17	0.03	0.03	0.13	0.19	0.37	0.31
	Estimate of Average Number of Droppings	935	354	978	2479	13974	184	437	3409	5662	5545	5433

Notes: Estimates of average number of droppings based on area exposed at the average low tide during migratory periods (1.3 m).

Table 8 Statistics Describing the Relationships of Predictor Variables with Dropping Densities: Northward Migration of 2012 and 2013 at Sturgeon Bank and Westham Island

Predictor Variables	Model Parameter Estimate*	Model Standard Error	Model Probability	X^2	X^2 Probability
Count model (models non-zero records)					
Year (2013)	-0.092	0.145	0.528	0.157	0.692
Shorebird Abundance	0.0004	0.0001	**<0.001**	3.851	**0.050**
Distance to Shore	-0.0002	0.0001	0.172	1.410	0.235
Low Tide	1.418	0.198	**<0.001**	42.419	**<0.001**
TOC	-0.350	0.222	0.115	2.288	0.130
Salinity	-0.012	0.006	**0.029**	4.223	**0.040**
Spatial Covariance	0.097	0.011	**<0.001**	94.486	**<0.001**
Constant (Intercept)	-0.781	0.554	0.159	NA	NA
Zero model (accounts for zero records)					
Year (2013)	0.455	0.203	0.025	NA	NA
Shorebird Abundance	-0.001	0.000	<0.001	NA	NA
Distance to Shore	-0.001	0.000	0.010	NA	NA
Low Tide	-1.071	0.307	<0.001	NA	NA
TOC	-2.942	0.543	<0.001	NA	NA
Salinity	0.059	0.010	<0.001	NA	NA
Spatial Covariance	-0.717	0.106	<0.001	NA	NA
Constant (Intercept)	5.140	0.931	<0.001	NA	NA
Log Likelihood	-4186.972			NA	
Number of Observations	3912				

Notes: Bolded values are statistically significant and reported within the results section. *Magnitudes of parameter estimates are dependent on the scale of the variable and cannot be compared directly.

Table 9 Statistics Describing the Relationships of Predictor Variables with Dropping Densities: Southward Migration of 2012 and 2013 at Sturgeon Bank and Westham Island

Predictor Variables	Model Parameter Estimate*	Model Standard Error	Model Probability	X^2	X^2 Probability
Count model (models non-zero records)					
Year (2013)	-0.529	0.251	**0.035**	4.451	**0.035**
Shorebird Abundance	0.001	0.001	0.207	1.706	0.192
Distance to Shore	-0.001	0.001	**0.043**	9.135	**0.003**
Low Tide	0.383	0.204	**0.061****	3.558	**0.059****
TOC	-0.828	0.694	0.233	2.128	0.145
Salinity	0.036	0.013	**0.006**	8.295	**0.004**
Spatial Covariance	-0.055	0.037	0.139	1.752	0.186
Constant (Intercept)	-0.335	0.713	0.638	NA	NA
Zero model (accounts for zero records)					
Year (2013)	0.211	0.282	0.456	*NA*	*NA*
Shorebird Abundance	-0.009	0.002	<0.001	*NA*	*NA*
Distance to Shore	0.000	0.001	0.574	*NA*	*NA*
Low Tide	-0.369	0.217	0.089	*NA*	*NA*
TOC	-3.799	1.195	0.001	*NA*	*NA*
Salinity	0.023	0.017	0.182	*NA*	*NA*
Spatial Covariance	-0.162	0.089	0.068	*NA*	*NA*
Constant (Intercept)	0.211	0.282	0.456	NA	NA
Log Likelihood	-1421.844			NA	
Number of Observations	4911				

Notes: Bolded values are statistically significant and reported within the results section. *Magnitudes of parameter estimates are dependent on the scale of the variable and cannot be compared directly. ** Near significant

Table 10 Statistics Describing the Relationships of Predictor Variables with Dropping Densities: Northward Migration of 2012 and 2013 at Brunswick Point

Predictor Variables	Model Parameter Estimate*	Model Standard Error	Model Probability	X^2	X^2 Probability
Count model (models non-zero records)					
Year (2013)	0.134	0.153	0.382	1.270	0.260
Shorebird Abundance	0.0005	0.0001	**<0.001**	22.714	**<0.001**
Distance to Shore	-0.0005	0.0002	**0.001**	11.331	**0.001**
Low Tide	0.275	0.155	0.076	4.063	**0.044**
TOC	0.230	0.211	0.274	1.266	0.261
Salinity	-0.014	0.011	0.217	1.551	0.213
Spatial Covariance	0.060	0.007	**<0.001**	88.798	**<0.001**
Constant (Intercept)	1.216	0.517	**0.019**	NA	NA
Zero model (accounts for zero records)					
Year (2013)	0.814	0.516	0.115	NA	NA
Shorebird Abundance	-0.001	0.000	<0.001	NA	NA
Distance to Shore	-0.001	0.001	0.182	NA	NA
Low Tide	-4.080	0.739	<0.001	NA	NA
TOC	-6.434	1.234	<0.001	NA	NA
Salinity	-0.129	0.037	0.001	NA	NA
Spatial Covariance	-0.878	0.189	<0.001	NA	NA
Constant (Intercept)	13.012	2.226	<0.001	NA	NA
Log Likelihood	-3460.551			NA	
Number of Observations	1422				

Notes: Bolded values are statistically significant and reported within the results section. *Magnitudes of parameter estimates are dependent on the scale of the variable and cannot be compared directly.

Table 11 Statistics Describing the Relationships of Predictor Variables with Dropping Densities: Southward Migration of 2012 and 2013 at Brunswick Point

Predictor Variables	Model Parameter Estimate*	Model Standard Error	Model Probability	X^2	X^2 Probability
Count model (models non-zero records)					
Year (2013)	0.767	0.173	**<0.001**	18.524	**<0.001**
Shorebird Abundance	0.002	0.001	**0.048**	4.596	**0.032**
Distance to Shore	-0.0011	0.0005	**0.030**	12.200	**<0.001**
Low Tide	0.492	0.174	**0.005**	8.054	**0.005**
TOC	1.145	0.515	**0.026**	6.690	**0.010**
Salinity	0.180	0.031	**<0.001**	24.206	**<0.001**
Spatial Covariance	0.005	0.013	0.719	0.135	0.713
Constant (Intercept)	-3.684	0.859	**<0.001**	NA	NA
Zero model (accounts for zero records)					
Year (2013)	0.399	0.324	0.219	NA	NA
Shorebird Abundance	-0.009	0.002	<0.001	NA	NA
Distance to Shore	-0.001	0.001	0.088	NA	NA
Low Tide	0.168	0.263	0.523	NA	NA
TOC	-1.076	0.872	0.217	NA	NA
Salinity	0.116	0.054	0.031	NA	NA
Spatial Covariance	-0.191	0.057	0.001	NA	NA
Constant (Intercept)	0.399	0.324	0.219	NA	NA
Log Likelihood	-1478.531			NA	
Number of Observations	2160				

Notes: Bolded values are statistically significant and reported within the results section. *Magnitudes of parameter estimates are dependent on the scale of the variable and cannot be compared directly.

Table 12 Statistics Describing the Relationships of Predictor Variables with Dropping Densities: Northward Migration of 2012 and 2013 at Boundary Bay and the Inter-causeway Area

Predictor Variables	Model Parameter Estimate*	Model Standard Error	Model Probability	X^2	X^2 Probability
Count model (models non-zero records)					
Year (2013)	0.013	0.156	0.932	0.010	0.920
Shorebird Abundance	0.0005	0.0001	**<0.001**	13.880	**<0.001**
Distance to Shore	-0.0003	0.0001	**0.002**	8.348	**0.004**
Low Tide	0.209	0.164	0.202	1.805	0.179
TOC	-0.740	0.513	0.149	2.010	0.156
Salinity	0.529	0.239	**0.027**	5.343	**0.021**
Spatial Covariance	0.244	0.026	**<0.001**	177.770	**<0.001**
Constant (Intercept)	-16.418	7.202	**0.023**	NA	NA
Zero model (accounts for zero records)					
Year (2013)	0.578	0.308	0.061	NA	NA
Shorebird Abundance	-0.001	0.000	<0.001	NA	NA
Distance to Shore	0.000	0.000	0.175	NA	NA
Low Tide	0.233	0.314	0.458	NA	NA
TOC	0.042	0.892	0.962	NA	NA
Salinity	1.871	0.389	<0.001	NA	NA
Spatial Covariance	-6.520	1.163	<0.001	NA	NA
Constant (Intercept)	*-53.309*	*11.645*	*<0.001*	*NA*	*NA*
Log Likelihood	-3781.89			NA	
Number of Observations	4105				

Notes: Bolded values are statistically significant and reported within the results section. *Magnitudes of parameter estimates are dependent on the scale of the variable and cannot be compared directly.

Table 13 Statistics Describing the Relationships of Predictor Variables with Dropping Densities: Southward Migration of 2012 and 2013 at Boundary Bay and the Inter-causeway Area

Predictor Variables	Model Parameter Estimate*	Model Standard Error	Model Probability	X^2	X^2 Probability
Count model (models non-zero records)					
Year (2013)	-0.817	0.240	**0.001**	14.475	**<0.001**
Shorebird Abundance	0.005	0.001	**<0.001**	26.122	**<0.001**
Distance to Shore	-0.0006	0.0004	0.087	6.244	**0.012**
Low Tide	0.101	0.144	0.484	0.508	0.476
TOC	3.002	0.889	**0.001**	12.559	**<0.001**
Salinity	1.295	0.442	**0.003**	5.928	**0.015**
Spatial Covariance	0.070	0.032	**0.031**	5.549	**0.019**
Constant (Intercept)	-41.574	13.965	**0.003**	NA	NA
Zero model (accounts for zero records)					
Year (2013)	-0.461	0.371	0.213	NA	NA
Shorebird Abundance	-0.007	0.001	<0.001	NA	NA
Distance to Shore	0.001	0.000	0.106	NA	NA
Low Tide	-0.816	0.233	<0.001	NA	NA
TOC	0.601	1.051	0.568	NA	NA
Salinity	-1.392	0.472	0.003	NA	NA
Spatial Covariance	-0.754	0.405	0.063	NA	NA
Constant (Intercept)	46.887	14.865	0.002	NA	NA
Log Likelihood	-2285.87			NA	
Number of Observations	4915				

Notes: Bolded values are statistically significant and reported within the results section. *Magnitudes of parameter estimates are dependent on the scale of the variable and cannot be compared directly.

Table 14 Mean abundances of Dunlin (A), Black-bellied Plovers (B), and Peep Sandpipers (C) in Survey Areas Adjacent to the Anticipated RBT2 Location Relative to Other Areas of the Fraser River Estuary: 2013 Northward Migration

A) Dunlin									
Rank	Early Migration (April 6-11)			Middle Migration (April 20-27)			Late Migration (May 3-6)		
	Survey Area	Mean	SD	Survey Area	Mean	SD	Survey Area	Mean	SD
1	*Brunswick Point*	*65542*	*12622*	Brunswick Point	34276	30230	*Brunswick Point*	*13324*	*6102*
2	*Boundary Bay*	*47916*	*16679*	Boundary Bay	24990	4947	*Boundary Bay*	*8236*	*5574*
3	*Strgn. Bank, WI*	*35180*	*32245*	Strgn. Bank, WI	20610	8941	*Strgn. Bank, WI*	*4731*	*2101*
4	*Inter-causeway*	*7105*	*9435*	Inter-causeway	755	1415	*Inter-causeway*	*1381*	*1497*

B) Black-bellied Plovers									
Rank	Early Migration (April 6-11)			Middle Migration (April 20-27)			Late Migration (May 3-6)		
	Survey Area	Mean	SD	Survey Area	Mean	SD	Survey Area	Mean	SD
1	*Boundary Bay*	*1872*	*353*	Boundary Bay	1175	652	*Boundary Bay*	*713*	*455*
2	*Brunswick Point*	*369*	*217*	Brunswick Point	704	666	*Brunswick Point*	*145*	*50*
3	*Inter-causeway*	*112*	*101*	Strgn. Bank, WI	257	193	*Strgn. Bank, WI*	*20*	*14*
4	*Strgn. Bank, WI*	*72*	*80*	Inter-causeway	18	33	*Inter-causeway*	*18*	*15*

C) Peep Sandpipers								
Rank	Early Migration (April 20-26)			Middle Migration (April 27)		Late Migration (May 3-6)		
	Survey Area	Mean	SD	Survey Area	Abundance	Survey Area	Mean	SD
1	Boundary Bay	4926	5959	*Brunswick Point*	*100292*	Brunswick Point	20637	36168
2	Brunswick Point	3358	3198	*Boundary Bay*	*35713*	Strgn. Bank, WI	15654	10764
3	Strgn. Bank, WI	2682	2402	*Strgn. Bank, WI*	*35379*	Inter-causeway	3575	2941
4	Inter-causeway	25	62	*Inter-causeway*	*3847*	Boundary Bay	2938	13073

Notes: Italicised numbers may not represent true means and standard deviations considering small sample size and/or the potential for dunlin and black-bellied plovers to move amongst areas between survey days. Only one survey was conducted during the peak of the peep sandpiper migration, so no mean or standard deviation could be calculated.

Table 15 Mean Densities (Individuals/km^2) of Dunlin (A) and Black-bellied Plover (B) across Survey Areas in the Fraser River Estuary: 2013 Northward Migration

A) Dunlin									
Rank	Early Migration (April 6-11)			Middle Migration (April 20-27)			Late Migration (May 3-6)		
	Survey Area	Mean	SD	Survey Area	Mean	SD	Survey Area	Mean	SD
1	*BP*	*3644*	*702*	88th-104th	1961	888	*BP*	*741*	*339*
2	*88th-104th*	*2627*	*983*	BP	1906	1681	*88th-104th*	*712*	*416*
3	*WI*	*1493*	*2295*	SB-S	736	948	*SB-S*	*290*	*238*
4	*64th-72nd*	*1457*	*1330*	SB-N	688	690	*IC*	*212*	*230*
5	*SB-S*	*1358*	*1127*	WI	544	231	*64th-72nd*	*162*	*258*
6	*IC*	*1091*	*1449*	104th-112th	470	448	*SB-N*	*134*	*69*
7	*104th-112th*	*819*	*785*	64th-72nd	237	246	*WI*	*69*	*7*
8	*72nd-88th*	*478*	*827*	YVR	219	216	*YVR*	*68*	*117*
9	*Mud Bay*	*232*	*294*	72nd-88th	144	123	*72nd-88th*	*25*	*38*
10	*YVR*	*149*	*180*	IC	116	217	*104th-112th*	*9*	*15*
11	*SB-N*	*18*	*31*	Mud Bay	83	85	*Mud Bay*	*0*	*0*

B) Black-bellied Plovers									
Rank	Early Migration (April 6-11)			Middle Migration (April 20-27)			Late Migration (May 3-6)		
	Survey Area	Mean	SD	Survey Area	Mean	SD	Survey Area	Mean	SD
1	*88th-104th*	*106*	*70*	88th-104th	61	50	*88th-104th*	*55*	*38*
2	*64th-72nd*	*46*	*42*	BP	39	37	*64th-72nd*	*16*	*17*
3	*104th-112th*	*37*	*34*	104th-112th	30	31	*BP*	*8*	*3*
4	*BP*	*20*	*12*	72nd-88th	23	19	*72nd-88th*	*6*	*8*
5	*Mud Bay*	*19*	*16*	64th-72nd	15	14	*IC*	*3*	*2*
6	*IC*	*17*	*15*	Mud Bay	11	12	*104th-112th*	*2*	*4*
7	*72nd-88th*	*14*	*15*	WI	9	9	*WI*	*1*	*1*
8	*SB-S*	*5*	*7*	SB-N	6	7	*SB-N*	*1*	*0*
9	*YVR*	*2*	*2*	YVR	6	9	*YVR*	*0*	*0*
10	*WI*	*1*	*2*	SB-S	4	9	*SB-S*	*0*	*0*
11	*SB-N*	*1*	*1*	IC	3	5	*Mud Bay*	*0*	*0*

Notes: Densities are based on the estimated area of exposed mudflat during the average low tide during the northward migration (1.3 m tide). Italicised numbers may not represent true means and standard deviations considering small sample size and/or the potential for dunlin and black-bellied plovers to move amongst areas between survey days. Means from the middle migration period provide a close approximation of the true mean.

Table 16 Mean Densities (Individuals/km2) of Peep Sandpiper across Survey Areas in the Fraser River Estuary: 2013 Northward Migration

Peep Sandpipers								
Rank	Early Migration (April 20-26)			Peak Migration (April 27)		Late Migration (May 3-6)		
	Survey Area	Mean	SD	Survey Area	Density	Survey Area	Mean	SD
1	BP	924	134	BP	5576	BP	1147	455
2	104th-112th	366	136	104th-112th	2194	SB-S	1068	979
3	SB-N	316	187	SB-S	1563	IC	549	556
4	88th-104th	298	163	SB-N	1475	YVR	320	266
5	WI	281	256	88th-104th	1290	SB-N	284	83
6	SB-S	277	101	Mud Bay	666	88th-104th	260	172
7	Mud Bay	132	54	64th-72nd	655	WI	208	20
8	72nd-88th	112	197	WI	633	64th-72nd	57	78
9	64th-72nd	110	44	IC	591	72nd-88th	4	5
10	IC	88	9	YVR	434	104th-112th	3	3
11	YVR	8	19	72nd-88th	0	Mud Bay	0	1

Notes: Densities are based on the estimated area of exposed mudflat during the average low tide during the northward migration (1.3 m tide).

Table 17 Cumulative Abundance of Shorebirds, Herons, and Raptors Observed in the Fraser River Estuary from Surveys during July to September 2012

Common Name	Scientific Name	Sturgeon Bank			Roberts Bank			Boundary Bay				Total
		YVR	SBN	SBS	WI	BP	IC	64th-72nd	72nd-88th	88th-104th	104th-112th	
Raptors		n=6	n=27	n=27	n=27	n=27	n=14	n=23	n=23	n=23	n=23	
Bald eagle	*Haliaeetus leucocephalus*	4	15	20	13	1	5	8	11	26	6	*109*
Northern harrier	*Circus cyaneus*	110	2	3	2	7	4	49	26	10	7	*49*
Peregrine falcon	*Falco peregrinus*	1	4	4	5	14	0	1	6	20	5	*60*
Osprey	*Pandion haliaetus*	0	0	1	0	3	0	0	0	2	11	*17*
Herons		n=6	n=27	n=27	n=27	n=27	n=14	n=23	n=23	n=23	n=23	
Great blue heron	*Ardea herodius*	46	171	405	155	420	1386	257	448	652	348	*4288*
Plovers		n=6	n=27	n=27	n=27	n=27	n=14	n=23	n=23	n=23	n=23	
Black-bellied plover	*Pluvialis squatarola*	5	586	539	3456	9313	10	383	3127	16318	6776	*40513*
Semipalmated plover	*Charadrius semipalmatus*	4	0	3	5	35	0	10	1	142	11	*211*
Killdeer	*Charadrius vociferous*	11	1	28	92	340	2	0	2	39	62	*577*
Sandpipers		n=6	n=27	n=27	n=27	n=27	n=14	n=23	n=23	n=23	n=23	
Lesser yellowlegs	*Tringa flavipes*	0	0	1	8	0	0	0	4	51	8	*72*
Greater yellowlegs	*Tringa melanoleuca*	1	3	0	9	1	15	0	0	22	2	*53*
Unknown yellowlegs	*Tringa sp.*	0	0	4	14	1	0	19	18	756	11	*823*
Spotted sandpiper	*Actitis Macularia*	0	0	1	0	4	0	0	5	7	42	*59*
Dowitcher	*Limnodromus sp.*	0	5	8	26	25	36	0	13	97	4	*214*
Pectoral sandpiper	*Calidris melanotos*	0	0	152	2	29	0	0	0	45	0	*228*
Sanderling	*Calidris alba*	0	0	0	1426	20	0	0	1	125	0	*1572*
Dunlin	*Calidris alpina*	0	1	3501	3	14	0	0	0	16	0	*3535*
Red knot	*Calidris canutus*	0	0	0	2	0	0	0	0	65	0	*67*
Unknown shorebird	*NA*	700	11	103	2	4571	0	500	0	88	0	*5975*
Peep sandpipers	*C.mauri, minutilla, pusilla,*	1838	43468	41299	22708	82566	43	1659	12459	58467	8655	*273162*
Total sandpipers		*2539*	*43488*	*45069*	*24200*	*87231*	*94*	*2178*	*12500*	*59739*	*8722*	*285760*

Notes: Cumulative abundance totalled from 27 surveys at all survey areas unless otherwise indicated in gray headings. BP = Brunswick Point; IC = Inter-causeway; SBN = northern Sturgeon Bank; SBS = southern Sturgeon Bank; WI = Westham Island; YVR = Vancouver International Airport. Uncommon shorebird observations: black oystercatcher (*Haematopus bachmani*); 2 at IC; Wilson's phalarope (*Phalaropus tricolour*): 1 at SB-S; whimbrel (*Numenius phaeopus*): 2 at BP, 1 at 88th-104th; ruddy turnstone (*Arenaria interpres*): 2 at 88th-104th, 2 at 104th-112th. Uncommon raptor observations: golden eagle (*Aquila chrysaetos*): 2 at BP; red-tailed hawk (*Buteo jamaicensis*): 1 at 64th-72nd; merlin (*Falco columbarius*): 2 at BP, 1 at SB-N, 1 at SB-S; great horned owl (*Bubo virginianus*): 1 at 64th-72nd; unknown raptor: 4 at WI.

Table 18 Cumulative Abundance of Shorebirds, Herons, and Raptors Observed in the Fraser River Estuary from Surveys during Jul to Sep 2013

Common Name	Scientific Name	Sturgeon Bank			South Arm Marsh	Roberts Bank			Boundary Bay					*Total*
		YVR	SBN	SBS		WI	BP	IC	64th-72nd	72nd-88th	88th-104th	104th-112th	Mud Bay	
Raptors		n=11	n=13	n=12	n=5	n=13	n=13	n=13	n=13	n=13	n=13	n=13	n=13	
Bald eagle	*Haliaeetus leucocephalus*	3	7	9	34	11	18	1	3	11	9	2	5	*113*
Northern harrier	*Circus cyaneus*	1	2	2	0	8	4	0	15	14	6	2	3	*57*
Peregrine falcon	*Falco peregrinus*	5	1	0	1	2	9	1	2	3	10	2	1	*37*
Osprey	*Pandion haliaetus*	2	0	0	0	0	2	2	1	0	0	6	3	*16*
Unknown raptor		0	0	3	0	0	0	0	0	0	1	0	0	*4*
Herons		n=11	n=13	n=12	n=5	n=13	n=13	n=13	n=12	n=13	n=13	n=13	n=13	
Great blue heron	*Ardea herodius*	148	63	164	38	162	457	665	158	315	988	340	408	*3906*
Plovers		n=13	n=13	n=12	n=5	n=13	n=13	n=13	n=13	n=13	n=13	n=13	n=13	
Black-bellied plover	*Pluvialis squatarola*	3	179	197	0	1569	6037	597	286	2620	3837	2426	657	*18408*
Semipalmated plover	*Charadrius semipalmatus*	2	2	0	0	3	37	134	0	3	82	5	1	*269*
Killdeer	*Charadrius vociferous*	9	0	2	13	64	154	43	22	1	16	36	65	*425*
Unknown plover	*NA*	0	0	11	0	25	200	0	0	0	0	0	0	*236*
Total Plovers		*14*	*181*	*210*	*9*	*1661*	*6428*	*774*	*308*	*2624*	*3935*	*2467*	*723*	*19325*
Sandpipers		n=13	n=13	n=12	n=5	n=13	n=13	n=13	n=13	n=13	n=13	n=13	n=13	
Lesser yellowlegs	*Tringa flavipes*	0	0	0	0	21	0	0	4	1	12	0	2	*40*
Greater yellowlegs	*Tringa melanoleuca*	0	2	0	5	34	3	1	2	0	10	0	2	*59*
Unknown yellowlegs	*Tringa spp.*	0	0	0	0	7	0	0	0	0	178	7	0	*192*
Spotted sandpiper	*Actitis Macularia*	0	0	0	7	0	0	0	0	0	0	13	2	*22*
Dowitcher	*Limnodromus spp.*	3	3	0	0	28	18	0	0	1	17	1	0	*71*
Pectoral sandpiper	*Calidris melanotos*	0	1	0	0	0	1	0	0	0	79	0	7	*88*
Sanderling	*Calidris alba*	1	0	0	0	0	15	0	1	0	0	0	0	*17*
Dunlin	*Calidris alpina*	15	0	0	0	10	41	0	0	0	0	0	0	*66*
Peep sandpipers	*C. mauri, minutilla, pusilla*	35457	1815	2508	9	8133	27331	744	24	205	696	56	34	77012
Unknown sandpiper	*NA*	351	2110	3671	0	4557	20332	0	6577	10435	17691	14077	485	*80286*
Total sandpipers		*35827*	*3931*	*6179*	*21*	*12790*	*47741*	*745*	*6608*	*10642*	*18683*	*14154*	*532*	*157853*

Notes: Cumulative abundance totalled from 13 surveys at all survey areas, with the exception of 12 surveys at SB-S and 5 surveys at South Arm Marshes. BP = Brunswick Point; IC = Inter-causeway; SBN = northern Sturgeon Bank; SBS = southern Sturgeon Bank; WI = Westham Island; YVR = Vancouver International Airport. Uncommon bird observations: marbled godwit (*Limosa fedoa*) 1 at WI; whimbrel (*Numenius phaeopus*) 1 at WI, 1 at YVR; merlin (*Falco columbarius*): 1 at SAM; American kestrel (*Falco sparverius*): 1 at 88th-104th.

Table 19 Cumulative Abundance of Shorebirds, Herons, and Raptors Observed in the Fraser River Estuary from Surveys during April to May 2013

Common Name	Scientific Name	Sturgeon Bank			South Arm Marsh *	Roberts Bank			Boundary Bay					*Total*
		YVR	SBN	SBS		WI	BP	IC	64th-72nd	72nd-88th	88th-104th	104th-112th	Mud Bay	
Raptors		n=13	n=13	n=13	n=3	n=12	n=12	n=13	n=13	n=13	n=13	n=13	n=13	
Bald eagle	*Haliaeetus leucocephalus*	33	23	23	39	72	174	9	105	87	106	27	32	*730*
Northern harrier	*Circus cyaneus*	2	0	1	2	7	6	1	15	14	11	0	6	*65*
Peregrine falcon	*Falco peregrinus*	1	1	7	0	5	10	1	1	1	5	4	1	*37*
Herons		n=13	n=13	n=13	n=3	n=12	n=13	n=13	n=13	n=13	n=13	n=13	n=13	
Great blue heron	*Ardea herodius*	58	40	45	50	156	997	244	36	50	102	56	144	1978
Plovers		n=13	n=13	n=13	n=3	n=13	n=13	n=13	n=13	n=13	n=13	n=13	n=13	
Black-bellied plover	*Pluvialis squatarola*	318	302	331	20	1098	6429	516	2159	2134	8405	2018	962	*24692*
Semipalmated plover	*Charadrius semipalmatus*	0	0	0	0	0	9	26	0	0	11	0	3	*49*
Killdeer	*Charadrius vociferous*	2	0	0	1	0	8	1	4	6	0	1	3	*26*
Sandpipers		n=13	n=13	n=13	n=3	n=13	n=13	n=13	n=13	n=13	n=13	n=13	n=13	
Greater yellowlegs	*Tringa melanoleuca*	0	11	27	40	64	104	0	22	6	39	8	10	*331*
Unknown yellowlegs	*Tringa ssp.*	1	1	2	0	27	17	0	0	3	18	1	7	*77*
Dowitcher	*Limnodromus spp.*	0	0	0	19	0	0	5	2	0	8	0	0	*34*
Sanderling	*Calidris alba*	0	0	0	0	0	0	0	23	0	81	0	0	*104*
Red knot	*Calidris canatus*	0	0	0	0	0	0	0	12	1	4	0	0	*17*
Dunlin	*Calidris alpina*	12131	34782	70866	1061	139504	455202	26025	51118	19570	225408	34310	6770	*1076747*
Peep sandpipers	*C. mauri, minutilla, pusilla*	7260	20219	35221	1241	45170	168638	13791	6272	2991	16101	3246	7	*320157*
Unknown sandpiper	*NA*	2832	0	5076	0	0	8100	20	3900	11000	12780	15335	9150	*68193*
Total sandpipers		*22227*	*55013*	*111192*	*2362*	*184765*	*632061*	*39842*	*61349*	*33571*	*254441*	*52900*	*15944*	*1465667*
Unknown Shorebirds	*NA*	0	0	0	0	15850	1200	0	4000	350	0	0	700	*22100*

Notes: Cumulative abundance totalled from 13 surveys at most survey areas, *3 surveys at South Arm Marshes, 2 of which included Canoe Pass. BP = Brunswick Point; IC = Inter-causeway; SBN = northern Sturgeon Bank; SBS = southern Sturgeon Bank; WI = Westham Island; YVR = Vancouver International Airport. Uncommon shorebird observations: American avocet (*Haematopus bachmani*): 3 at SB-N, 5 at YVR; lesser yellowlegs (*Tringa flavipes*): 2 at 88th-104th; spotted sandpiper (*Actitis macularia*): 1 at South Arm Marshes; whimbrel (*Numenius phaeopus*) 1 at IC, 3 at YVR; Wilson's snipe (*Galinago delicata*) 1 at BP, 3 at SB-S. Uncommon raptor observations: red-tailed hawk (*Buteo jamaicensis*): 1 at 64th-72nd, 1 at Mud Bay, 1 at South Arm Marshes; merlin (*Falco columbarius*): 1 at 88th-104th, 1 at WI; short-eared owl (*Aseo flammeus*): 1 at 72nd-88th, 1 at BP, 2 at YVR; Unknown raptor sp: 1 at IC.

Table 20 Ratios of the Proportions of Shorebird Droppings Relative to Proportions of Shorebird Abundances across Survey Areas

Study Site	Sturgeon Bank			Roberts Bank			Boundary Bay				
Survey Area	**YVR**	**SBN**	**SBS**	**WI**	**BP**	**IC**	**64-72**	**72-88**	**88-104**	**104-112**	**Mud Bay**
North 2013	0.11	0.05	0.42	2.26	1.05	0.33	0.50	0.95	1.24	0.84	1.16*
South 2012	-	0.26	0.52	0.72	0.69	-	5.38	2.52	1.08	4.93	-*
South 2013	0.09	0.30	0.66	0.65	1.23	0.49	1.01	1.02	1.04	1.01	71.69*

Notes: Droppings per survey area were estimated for each migration by dividing the area of exposed mudflat at the average low tide (1.3 m) by the average dropping densities recorded in the 15 m^2 survey plots. *Dropping densities recorded at Mud Bay during the southward 2013 migration of juveniles were high relative to the southward migration of 2012 (1.11 vs. 0.03). Droppings surveys conducted at Mud Bay in 2013 were only conducted during the peak of the juvenile migration and are likely biased high relative to the average abundance throughout the migration.

APPENDIX C
Photographs

Plate 1: Shorebirds feeding at Brunswick Point mudflats observed through night vision optics (Armasight NYX-14 GEN 2+) with 5x magnification lens.

Plate 2: Surveyor navigating along dropping count transect.

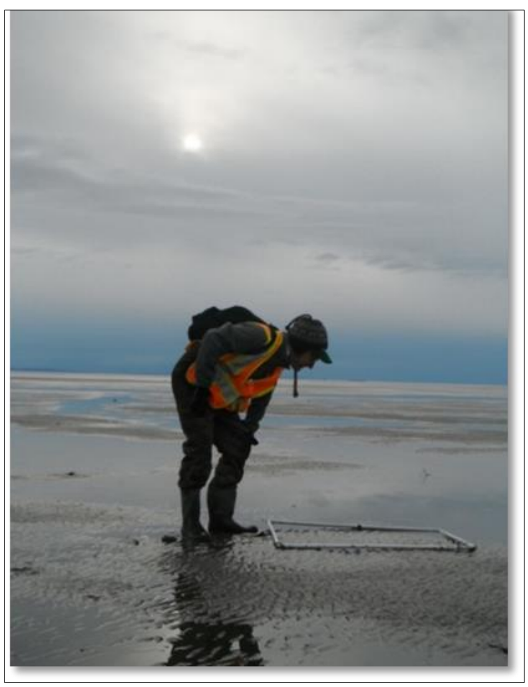


Plate 3: Surveyor counting shorebird droppings inside 1-m^2 quadrat.

Plate 4: Shorebird dropping inside 1-m^2 quadrat.

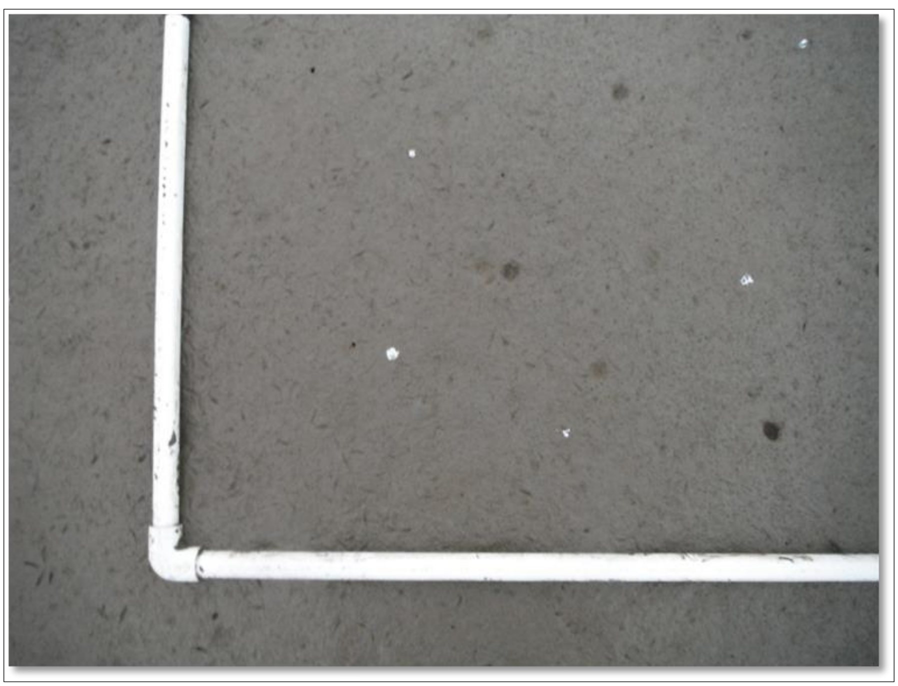


Plate 5: High concentration of shorebird droppings inside 1-m^2 quadrat.

Plate 6: Western sandpipers using Roberts Bank during northward migration.

Plate 7: Dunlin feeding at Roberts Bank during northward migration.

Plate 8: Shorebirds feeding on intertidal mudflats within the Inter-causeway Area at Roberts Bank. Spotting scope in the foreground and Roberts Bank terminals in the background.

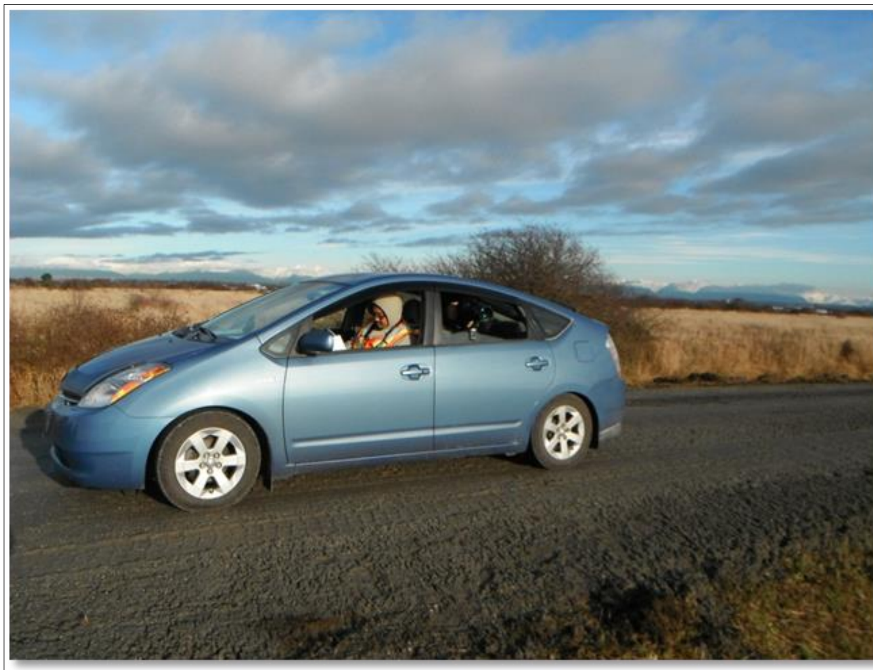


Plate 9: Biologists surveying for shorebirds from car along Boundary Bay dyke. Driver stops and records data while observer in back of car calls out birds observed through spotting scope mounted to rear window.

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