Recommendations for Fine Scale Bird Monitoring to Inform the Impact of Wetland Restoration on the Fraser Delta

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Disclaimer

This report was produced as part of the UBC Sustainability Scholars Program, a partnership between the University of British Columbia and various local governments and organisations in support of providing graduate students with opportunities to do applied research on projects that advance sustainability across the region.

This project was conducted under the mentorship of Birds Canada and was intended to be a scoping document to inform further discussion about the development of a community based shorebird monitoring protocol for the Fraser River Estuary Key Biodiversity Area. The opinions and recommendations in this report and any errors are those of the author and do not necessarily reflect the views of Birds Canada or the University of British Columbia. Birds Canada will be engaging other parties to refine the recommendations within this report as additional resources and capacity is secured.

A Review of Current Shorebird Monitoring Practices and Restoration Impacts

Abstract

Worldwide, bird populations are under severe decline. Climate change, human activity, habitat loss and prey loss are the main drivers of these declines. Shorebirds, commonly called waders due to their behaviour of wading and foraging in intertidal mudflats and beaches, are also in decline. The reasons for the decline of this charismatic and ecologically important order are unclear. This trend necessitates large-scale and unified monitoring efforts in order to understand the reasons for and effects of decline. Several groups have initiated large-scale monitoring of shorebirds and water birds throughout the Americas. These groups have different environments, resources, and research questions and therefore different protocols for monitoring. This document consists of a review of current shorebird and waterbird monitoring protocols employed in the Americas and compares and contrasts their methods. It also contains suggestions for a monitoring protocol for use by Birds Canada and other partners in studying shorebirds in the Fraser River Delta.

Positionality Statement

This report was prepared on the traditional and unceded territory of the Coast Salish peoples consisting of multiple communities around the Salish Sea and including, xʷməθkʷəy̓əm (Musqueam), Sḵwx̱wú7mesh (Squamish), and səlilwətaɬ (Tsleil-Waututh) peoples. The work proposed would take place on the traditional territory of many Coast Salish First Nations. The Fraser River and its estuary, which is the focus of this work, has been used and stewarded by First Nations people for millennia. Some of these include the Nlaka'pamux, Tsilhqot'in, Secwepemc, Okanagan, St'át'imc, Wet'suwet'en, Sekani, and Daakelh. Now, the Fraser River Delta and its ecosystem are facing threats as a direct result of colonization. As a white settler, I recognize the hypocrisy and responsibility in making recommendations

for conservation for ecosystems harmed by colonialism, but hope to do a small part in bringing about environmental justice.

Background

For as long as humans and birds have co-existed people have closely observed and learned from birds. Birds have been integrated into the traditional systems of the Coast Salish people and we encourage engagement with these knowledge holders to learn more. Data on the numbers and activities of birds has been gathered through systematic citizen science methods such as the Christmas Bird Count for decades around the world. From 1970 to 2016 in Canada, the numbers of aerial insectivores have declined by 59%, grassland birds by 57%, and shorebirds by 40%[1]. Shorebirds are birds of the order Charadriiformes which commonly wade in the intertidal zone to forage. Shorebirds are critical indicators of mudflat ecosystem ecology, but are understudied in this regard[2]. The exact reasons for shorebird decline are unknown, but migration and breeding behaviour are correlated with rates of decline[3].

This staggering loss has spurred efforts at habitat restoration, but how successful have these efforts been? This question requires further monitoring and an adjustment of monitoring practices to appropriate species and spatial scale. Among California Least terns, for example, vegetation and habitat changes have been shown to impact nest location at both fine and large scales[4]. This highlights the importance of considering scale in the design of monitoring protocols. On the Fraser River estuary, river output, wind conditions, and tidal conditions have been found to affect sandpiper counts[5]. Monitoring in estuarine habitat necessitates special consideration of collection of weather and habitat data. Disturbance due to human activity also affects shorebirds in British Columbia[6], which prompts us to consider human population density and activity in data collection as well. The BC Coastal Waterbird Survey has successfully incorporated the use of citizen science, which increases the amount of data collected but causes protocols to require a tradeoff between effort and precision. Current literature highlights the many variables affecting shorebird counts and behaviour and researchers must carefully consider how and when to collect data on these variables when monitoring these birds.

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[1]North American Bird Conservation Initiative Canada (2019) State of Canada's Birds 2019. Retrieved on August 27, 2019.

[2] Mathot, K. J., Piersma, T., & Elner, R. W. (2018). Shorebirds as integrators and indicators of mudflat ecology. In *Mudflat ecology* (pp. 309-338). Springer, Cham.

[3] Thomas, G. H., Lanctot, R. B., & Székely, T. (2006). Can intrinsic factors explain population declines in North American breeding shorebirds? A comparative analysis. *Animal Conservation*, *9*(3), 252-258.

[4] Jesu, J. A. (2015). *The role of fine scale habitat features on nest placement and nest fate within California Least tern (Sternula antillarum browni) colonies* (Doctoral dissertation, San Diego State University).

[5] Canham, R., Flemming, S. A., Hope, D. D., & Drever, M. C. (2021). Sandpipers go with the flow: Correlations between estuarine conditions and shorebird abundance at an important stopover on the Pacific Flyway. *Ecology and evolution*, *11*(6), 2828-2841.

[6] Drever, M. C., Beasley, B. A., Zharikov, Y., Lemon, M. J., Levesque, P. G., Boyd, M. D., & Dorst, A. (2016). Monitoring migrating shorebirds at the Tofino Mudflats in British Columbia, Canada: Is disturbance a concern?. *Waterbirds*, *39*(2), 125-135.

Ecological monitoring can be used for many purposes. Lindenmayer and Likens (2010)[7] detailed some of these:

- Documenting and providing baselines against which change or extremes can be evaluated
- Evaluating ecological responses to natural or experimental disturbance
- Detecting and evaluating changes in ecosystem structure and function
- Guiding evidence-based environmental legislation
- Generating new and important questions about ecological dynamics

The aims of a monitoring program should be taken into account in its design. Lindenmayer and Likens also suggest four principles for the design of good monitoring programs:

1) Good questions.
(2) A conceptual model of an ecosystem or population.
(3) Strong partnerships between scientists, policymakers and managers.
(4) Frequent use of data collected.

An additional design challenge occurs when the monitored ecosystem experiences a disturbance, anthropogenic or natural. One common study design used to monitor disturbance is Before-After, Control-Impact (BACI.) In this design, a time series is performed on an impacted site before and after the disturbance. An additional "control" site is monitored to attempt to distinguish environmental change from disturbance-caused change. A distinction must be made between control sites vs. reference sites. Control sites are identical to the site being assessed, except for the disturbance, and are often in the vicinity of the assessed site. Reference sites are considered truly pristine sites, and while ideal for analysis, are difficult to find[8]. Additionally, some scholars have questioned the validity of analyses using only one "control" site[9].

Several groups have convened to coordinate large-scale monitoring of shorebirds in the Pacific. The Migratory Shorebird Project, founded in 2011 and coordinated by Point Blue Conservation Science, coordinates monitoring of migratory shorebirds from Alaska to South America. The project aims to study shorebird migration and land use in non-breeding seasons, evaluate which environmental factors affect shorebirds the most, and make recommendations for shorebird conservation and shoreline protection.

In 2018, stakeholders convened in Washington State to discuss unification of bird monitoring protocols in estuaries throughout Puget Sound and the Salish Sea[10]. These discussions highlighted the need for a unified monitoring framework for the region that encompasses different spatial and time scales, with

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[7] Lindenmayer, D. B., & Likens, G. E. (2010). The science and application of ecological monitoring. Biological conservation, 143(6), 1317-1328.

[8] Queensland Government (2018). Environmental Protection (Water) Policy 2009 - Monitoring and Sampling Manual

[9] Underwood, A. J. (1992). Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. *Journal of experimental marine biology and ecology*, *161*(2), 145-178.

[10] Bayard, T.Slater, G., Spragens, K., and A. Summers. 2019. Recommendations for a Puget Sound Estuary Avian Monitoring Strategy. A synthesis report to the Puget Sound Ecosystem Monitoring Program and Puget Sound Partnership. Tacoma, WA

broad relevance and quantitative rigor. In light of the decline in shorebird populations and the lack of unified monitoring practices, the purpose of this review is to examine current shorebird monitoring practices in the context of habitat management and restoration. Discussion will consider scale, type of hypothesis, amount of effort, level of required expertise, and species being considered. Finally, suggestions will be made for a protocol that transitions from abundance-related monitoring to habitat-use related monitoring.

Comparison of Methods

Shorebird Abundance Monitoring Methods

	Scale	**Sampling Type**	**Hypothesis Type/ Aim**	**Effort**	**Expertise**	**Species**	**Other data collected**	**Notes**	**Data Reporting**
BC Coastal Waterbird Survey	Time scale: monthly, emphasis September-April. Spatial scale 500m-1km distance.	Point counts	Monitoring effort	Spotting scope and binoculars required. Low time commitment from volunteers, large organizational effort.	Volunteer-based, but requires advanced bird ID skills.	All species of coastal waterbird, crows, ravens, kingfishers, raptors	Survey conditions, Human activity	Within 2 hours of high tide. Flying birds not counted. Inland, nearshore, offshore differentiated.	Post-survey online entry via NatureCounts.
Point Blue Conservation Science for Migratory Shorebird Project and Pacific Flyway Shorebird Survey	Count duration 1-2 hours, annual count. Spatial scale not defined, visibility of >300m recommended. Observer should move throughout chosen site.	Each transect consists of a series of fixed-radius point count surveys at pre-determined survey locations. Observers drive a predefined 10-mile transect to each of 20 survey	Aim to assess annual variation, long-term trends, and habitat variation of wintering shorebirds in coastal estuaries	Low effort due to annual frequency. Binoculars required, scope recommended.	Some bird identification expertise required.	Many shorebirds[11], raptors	Weather, cover type, vegetation height, tide	Survey during rising tide.	Online data entry via California Avian Data Center.

[11] Black-bellied Plover, Snowy Plover, Semipalmated Plover, Killdeer, Black Oystercatcher, Black-necked Stilt, American Avocet, Spotted Sandpiper, Greater Yellowlegs, Lesser Yellowlegs, yellowlegs spp., Willet, Whimbrel, Long-billed Curlew, Marbled Godwit, Curlew/Godwit, Ruddy Turnstone, Black Turnstone, Red Knot, Sanderling, Western Sandpiper, Least Sandpiper, Dunlin, Western/Least, Western/Least/Dunlin, dowitcher spp., Wilson's Snipe

	Scale	Sampling Type	Hypothesis Type/ Aim	Effort	Expertise	Species	Other data collected	Notes	Data Reporting
		locations. Survey locations are located approximately 0.5 miles along each transect.							
Caribbean Waterbird Census	At least once per season. Counts within maximum distance of 400m in 3-minute intervals for 6-12 minutes total. Recommended to repeat point counts within short time period eg. 2 weeks. Surveys begin 15 minutes after sunrise and last up to 5 hours.	Point counts	Aim to link species richness and abundance with habitat changes and habitat use behaviour	High effort in collecting extensive site description data and sexing birds	High level of knowledge and expertise required.	Common coastal waterbird species	Habitat type, hydrology, protection status, land use and human activity, sketch of site, water depth, turbidity, salinity. Bird breeding status and sex if known	Collect aural, visual, and flyover data	
Terrafauna Wildlife Consulting for Birds Canada	0-50m, 50-100m, 100-400m, and >400m. 5	Point counts	Investigating preferential land use by overwintering	Medium effort	One person with advanced bird identification	Dunlin, killdeer, Western sandpiper,	Temperature, wind, precipitation, cloud cover,	Flyovers recorded and denoted. Shorebirds	

	Scale	Sampling Type	Hypothesis Type/ Aim	Effort	Expertise	Species	Other data collected	Notes	Data Reporting
	minute counts divided 0-3 min and 3-5 min. Observations collected at intervals 1-18 days apart over 10-week period, February-March.		shorebirds		skills required	Least sandpiper, Black-bellied Plover, Greater Yellow-Leg	noise, exposed surface water, and habitat type.	counted in blocks of 10, flock sizes estimated. Survey within two hours of high tide.	
Coastal Shorebird Survey	For sandy and estuarine beach, 0.5km transect. For all other habitats, a polygon is drawn to encompass as much of the site as is visible with a scope. Assesses the entire coastline of a country, excluding areas where study is not feasible or shorebirds are	Sampling protocol varies by habitat type. For mud flats: Walk across the flat, stopping every 400m to count all birds in a 200m radius. For polygonal sampling, observers walk once along the length and once in a zigzag to calculate detection	Large-scale monitoring effort	Medium due to large spatial scale but lack of specified time scale. Low amount of habitat data collected.	Uses citizen science. Leaders are trained in a one-day training, volunteers more informally.	None specified	Verification of habitat type as previously determined through satellite image	Survey performed on a rising or falling tide, ideally 1-3 hours before or after low tide.	Uploaded to eBird using *Censo Costero de Aves playeras.* Data accessible through Avian Knowledge Network

	Scale	Sampling Type	Hypothesis Type/ Aim	Effort	Expertise	Species	Other data collected	Notes	Data Reporting
	not likely to be. Time scale not specified.	ratio. This is done once per site.							
Houston Audubon Coastal Bird Survey Protocol	Year-round observation at varying seasonal scales[12]. Total 19 annual observations. 10-15 representative 1-mile shoreline transects examined.	Line transect: All birds within ¼ mile on any side of transect are recorded.	Aim to provide data for scientists, land managers, and conservationists.	Low	Relatively low, requires shorebird identification skills.	Not specified	Wrack, human activity, garbage presence.	Age, breeding status, behavior, presence of oil, color bands, and other additional information reported in comment section of checklist.	Data reported through eBird.
United States National Park Service	High-intensity units sampled every 4 days, low-intensity once in a 16-day period. Transect length dependent on sampling	Line transect. Sampling locations are split between 'high-intensity units' (spits, points, bayside overwash) and	To inform park managers of the distribution of wintering and migratory shorebirds, their habitat, and variables that affect shorebirds.	High effort and cost. All observations done with binoculars.	High, carried out by paid professionals trained by the National Park. Minimum Bachelor's degree in natural resource field.	Shorebirds that migrate through or winter in Southeast Coast Network Parks in the U.S.	Wind, precipitation, tide, habitat type, beached and dead birds, cars, people, and dogs	Recommended to sample at the same time of day each time to ensure distribution of sampling during all portions of tidal cycle.	Online data reporting on sharepoint website post-survey.

[12] Winter (10 January – 20 February): conduct 3 surveys over a 5-week pulse at approximately 10-day intervals (7–14 day intervals are acceptable). Spring (20 March – 30 May): conduct 6 surveys over a 10-week pulse at approximately 10-day intervals with 7–14 day intervals are acceptable. Summer (June and July): Monthly or 2 surveys. Fall (20 August – 30 October): conduct 6 surveys over a 10-week pulse at approximately 10-day intervals with 7–14 day intervals are acceptable. Early Winter (November – December): Monthly or 2 surveys

	Scale	Sampling Type	Hypothesis Type/ Aim	Effort	Expertise	Species	Other data collected	Notes	Data Reporting
	frame, sampled for 30 minutes. Sampling 5 days a week from 1 August to 30 April each year.	'low-intensity units' (oceanside/beachfront.) Each park given one high-intensity (always sampled) and several low-intensity (several sampled based on available effort) units. Sites sampled at random order. Several transects done in high-intensity units.							
Roberts Bank Terminal 2 Technical Data Report	11 study sites on the Fraser River Estuary. Conducted during two Southward and one Northward migration (Approx. 3 month	Line transects. Exact transect and sampling station location varied by season. Surveyors walk along the beach, counting birds	Assess importance of intertidal mudflats to migrating shorebirds in the Fraser River Estuary and quality of intertidal mudflats (as	High effort due to complicated survey scheme and frequency of survey.	Surveys conducted by trained field staff.	Focal species shorebirds and birds of prey that may influence shorebird distribution. Great blue herons also recorded. Surveyors	Not specified	Surveys conducted during rising tide.	Data reported internally.

	Scale	Sampling Type	Hypothesis Type/ Aim	Effort	Expertise	Species	Other data collected	Notes	Data Reporting
	period.) Survey conducted every second day during northward migration, every third during southward migration. Conducted every day during migration peak. All points within 3km of shore. Survey time 0.75 to 1.5 hours	only in the intertidal areas, until the tide obstructs the survey area.	assessed by shorebird density)			trained and tested on accurate estimation of flock size.			

Shorebird Foraging Behaviour Methods

Roberts Bank Terminal 2 Technical Data Report:

Spatial scale described above. This study used methods developed by the Simon Fraser University Centre for Wildlife Ecology. This method involves counting fecal densities along transects. Shorebird droppings are distinguished from those of other birds by their size. Fifteen quadrats of $1m^2$ were counted at each sampling station. Quadrats were placed in a T-shaped layout, with five along the transect line and five perpendicular to the line. Sampling began 1.5 to 2.5 hours prior to low tide. Surveys were conducted during northward and southward migration over the course of two years, every second day for northward migration and every third day for southward migration. Prior to sampling, four potential

starting points of transects were located 100m apart along the mudflat edge. On the sampling day, the transect edge was randomly selected from one of these points. Also recorded were shorebird abundance, distance to shore, low tide height, total organic carbon, and salinity.

Kuwae (2007)[13]:

The study site, Banzu intertidal sandflat, encompassed 7.6km^2. Two sites, line transects of 100m each at 0-10 or 10-80m, were studied day and night for six days the first year and five the second. Observations were recorded using a camcorder with a telephoto zoom lens. Video footage was recorded and later analyzed utilizing slow and stop-motion in order to record the feeding behaviour of Kentish plovers. At night, a thermal camera was used and defecation rates were used as an approximation for feeding rates, as invertebrate prey were not visible through the thermal lens. Individuals were randomly selected for video recording. Foraging behaviour was classified as 'pecking' or 'probing.'

Yasué (2004)[14]:

Observations were collected at Pachena Beach, British Columbia, a 1km beach. Data were collected between 10:00 and 14:00 at low to mid-tide when at least 10m of tidal mudflat was exposed. Over 24 sample days, the researcher selected one to three focal individuals of each study species and counted the total number of prey items taken per minute using a 30x spotting scope. All observations were conducted from a seated position 50-100m from the bird, waiting 5 minutes for the birds to settle when moving to a new location. Flock size and feeding location were also recorded. Feeding rates were only collected for semipalmated plovers feeding on bloodworms and least sandpipers feeding on amphipods because other prey were too small to be seen via spotting scope.

Lourenço et al (2016)[15]:

This study took place at two intertidal sites at Banc d'Arguin, Mauritania, at sites representative of typical foraging conditions. Droppings were collected by following mono-specific flocks during an outgoing tide or by observing individual birds. Samples were stored in 70% ethanol. Later, samples were analyzed under a microscope (magnification x10-400,) and prey remains identified to the lowest possible taxonomic level. In addition, 341 focal individuals were subject to video recordings for periods of 1-2 minutes, 5-40 meters away. Foraging behaviour was classified as peck, non-random probe, or random probe.

[13] Kuwae, T. (2007). Diurnal and nocturnal feeding rate in Kentish plovers Charadrius alexandrinus on an intertidal flat as recorded by telescopic video systems. Marine Biology, 151(2), 663-673.
[14] Yasué, M. (2005). The effects of human presence, flock size and prey density on shorebird foraging rates. Journal of Ethology, 23(2), 199-204.

[15] Lourenço, P. M., Catry, T., Piersma, T., & Granadeiro, J. P. (2016). Comparative feeding ecology of shorebirds wintering at Banc d'Arguin, Mauritania. Estuaries and coasts, 39(3), 855-865.

Discussion

Scale

The protocols examined in this review vary wildly in both spatial and time scale. The time scale of the protocols ranged from two weeks (suggested, Caribbean Waterbird Census) to monthly counts over six month period (BC Coastal Waterbird Survey.) For point counts, the recommended time ranged from 5-12 minutes. Point counts were usually conducted with a maximum distance of 300 or 400m. Transect lengths varied from 1km to mile. Frequency of sampling was extremely varied, and should generally be regionally dependent.

Hypothesis and Sampling Type

The Migratory Shorebird Project utilizes different sampling strategies for different habitat types (point counts for flooded agriculture, area search for coastal estuary and managed wetlands.)
Terrafauna consulting recommended a set amount of site visits or high number of randomized visitsmonitor shorebirds only. Many studies have compared point counts and transects for assessment of biodiversity. Recommendations vary, and efficacy of these methods has been found to vary with season and study design[16]. Mixed-cluster point count sampling has also been shown to be an effective method for determining avian abundance[17]. In this method, a point is placed at the center of the sampling location, another point is randomly selected at a fixed distance from the second point, and five additional points selected at random within a fixed distance from the second point. The shorebird monitoring projects examined in this review employ a variety of sample strategies. Due to the lack of unified strategy and the seasonal and local variation in the efficacy of these strategies, a pilot study should be undertaken to compare point count vs. area search in the context of coastal and estuarine habitats in British Columbia.

None of the protocols examined explicitly mention the use of a control or reference site, likely due to their broad goals of examining shorebird abundance over time. In the context of the Fraser River Delta, Birds Canada aims to examine the effects of development projects on the delta on local shorebird populations. The use of a control site would be beneficial for this question. However, the Fraser River Delta is so highly developed that the identification of such a site is a difficult task. If a specific development project, such as the Roberts Bank Terminal 2, is constructed, a BACI study design could be utilized.

Effort and expertise

Many of the monitoring projects examined make use of citizen science and volunteer efforts. All protocols require at least one person experienced in bird identification, and many require an additional

[16] Verner, J., & Ritter, L. V. (1985). A comparison of transects and point counts in oak-pine woodlands of California. The Condor, 87(1), 47-68.

[17] Rempel, R. S., & Kushneriuk, R. S. (2003). The influence of sampling scheme and interpolation method on the power to detect spatial effects of forest birds in Ontario (Canada). *Landscape Ecology*, *18*(8), 741-757.

person for recording and supplemental ID. The effort of the protocols depends on the frequency of sampling, which is variable, and the additional data required. Depending on frequency of sampling , volunteers can be utilized, or a paid staff may be necessary. A balance of effort and expertise must be reached to maximize data acquisition while using volunteer and staff time efficiently.

Data collected

Additional data collected varies widely. Many protocols collect some basic information about the weather. Habitat type is also frequently noted, though the description of habitat types vary widely. Many protocols utilize a numerical code for habitat type. However, this introduces potential bias in coding habitat. If utilizing volunteers tt is suggested that observers should make detailed descriptions of the habitat types present in the site, which can later be verified by satellite image and numerically coded by Birds Canada's or other experts. . Additional data collected depends on minimizing effort and focusing study goals. Birds Canada aims to conduct habitat-use related monitoring in the context of disturbance. The Migratory Shorebird Project has proposed seven hypotheses concerning the factors affecting shorebird land use and migration[18] which can inform the additional data collected by Birds Canada:

1. The increase in the abundance of predators results in changes in the use of wintering site and possible changes in migratory behaviour of shorebirds
2. Shorebirds will be more abundant in coastal areas with fewer predators
3. The diminishing available habitat will result in changes to shorebird distribution
4. Anthropogenic disturbance in wintering sites will reduce the time available to shorebirds to accumulate fat for migration and can impact survival and productivity
5. Shorebirds accumulate industrial and urban pollution at wintering sites that are subsequently released in sudden high doses as fat is burned during migratory flights that then disrupt their ability survive and reproduce.
6. Increasing temperatures will provide more available winter food resources in northern coastal estuaries and non-coastal agricultural habitats.
7. Increased storm severity and sea-level rise in estuaries / bays will result in reduced habitat availability for shorebirds.

Many of the protocols examined collect some information on human disturbance. The method for quantifying human activity varies, from counting the number of people, cars, and dogs present within the survey site to quantifying anthropogenic noise. I suggest that data on total disturbance be collected, with observers providing a scale of anthropogenic disturbance from 1-5 with additional notes on the type of disturbance. This should include the presence of people, noise, cars, dogs, and high levels of anthropogenic debris/garbage. Data on predator presence should also be collected.

Data reporting and integration with other existing datasets

[18]http://migratoryshorebirdproject.org/wp-content/uploads/2019/10/Peru_2014Wkshp_12_HipotesisTomaDesicionesMReiter.pdf

Data reporting methods and integration with existing datasets are critical for ensuring the utility of data produced from monitoring programs. Many monitoring programs make use of online data reporting systems. Frequently used were eBird and NatureCounts. These app-based reporting tools are widely accessible and user-friendly. A few protocols explicitly mentioned aiming for integration with other existing datasets, specifically the International Shorebird Survey (ISS.) However, International Shorebird Survey methods are so broad that they were not included in this comparison. The results from nearly any of the protocols reviewed here could be submitted to the ISS. The breadth of the ISS is intentional, in order to collect the greatest quantity of data possible. The ISS also utilizes data entry via eBird to increase accessibility. When considering integration with other datasets, a balance must be reached between quality and quantity of data. Additionally, the monitoring program's specific goals must be kept in mind.

Environment and Climate Change Canada has conducted shorebird monitoring at Roberts Bank, the Tofino Mudflats, and Sidney Island. While select data from these surveys is published in journals[19],[20],7 raw data and specific monitoring protocols are available on request. Since scientific journal articles are often inaccessible to local stakeholders, data should be communicated in a more accessible way to be understood by local communities and decision-makers.

Foraging Rate and Behaviour

Many studies use defecation rate as a proxy for shorebird foraging rate. However, this method assumes that the rates of these processes are equal between individuals, and fails to provide information about the contents of shorebird diets. Mathot et al (2010)[21] investigated the stomach contents of Dunlin and Western Sandpipers at Roberts Bank and found that invertebrates constituted <25% of Dunlin stomach contents and <10% of Western Sandpiper contents. These were primarily molluscs, annelids and arthropods. Sediment, which contains critical biofilm, represented >40% of the stomach contents of Dunlin and >75% for Western Sandpipers. These findings suggest that when conducting studies of shorebird foraging in the Fraser River Delta, foraging of both biofilm and invertebrates must be investigated.

Lourenço et al[16] combined analysis of fecal contents with analysis of foraging behaviour. Analysis of feces to visually identify prey can aid in understanding of species niche. However, this method is laborious, requires extensive expertise, and may not provide sufficient information for the Fraser River Delta, where shorebirds have been shown to consume high proportions of biofilm. While the bacterial and archaeal microbiota of the shorebird gut and feces can be studied, fecal analysis of diatoms, which are a

[19] Hope, D. D., Drake, A., Shervill, D., Lemon, M. J., & Drever, M. C. (2021). Correlates of Annual Stopover Counts in Two Species of Arctic-Breeding Shorebirds: Roles of Local, Breeding, and Climatic Drivers. *Waterbirds*, *44*(1), 13-29.
[20] Canham, R., Flemming, S. A., Hope, D. D., & Drever, M. C. (2021). Sandpipers go with the flow: Correlations between estuarine conditions and shorebird abundance at an important stopover on the Pacific Flyway. *Ecology and evolution*, *11*(6), 2828-2841.
[21] Mathot, K. J., Lund, D. R., & Elner, R. W. (2010). Sediment in stomach contents of Western Sandpipers and Dunlin provide evidence of biofilm feeding. Waterbirds, 33(3), 300-306.

critical biofilm-based food source for shorebirds[22], has not been attempted and may be difficult due to vertebrate digestion processes. As such, study of the diatom composition of intertidal biofilm should be conducted in order to estimate shorebird diatom feeding rates[23]. Previous studies[15] examined foraging behaviour using a spotting scope. While this method is accessible and requires less time for video analysis, it limits in-detail study of foraging behaviour.

Kuwae et al (2008)[24] examined foraging behaviour of Western Sandpipers using video recordings and found that biofilm foraging behaviour is distinguishable from pecking and probing behaviour. During grazing, the sandpiper advances more slowly than during pecking or probing. The sandpiper first collects surface biofilm with a bill opening of ~3mm, then closes the bill to ~1mm, and with a bolus of biofilm in the bill, raises the head and repeatedly opens and closes the bill with repeated throat motions, and finally swallows the bolus. Chains of double impressions are visible afterwards on the sand. In order to effectively capture foraging rates, pecking, probing, and grazing behaviours must all be recorded. This study also found differences between diurnal and nocturnal foraging behaviours. Dependent on access to thermal imaging equipment, data should be collected during both day and night to provide a complete picture of shorebird foraging behaviour.

In this paper, droppings were also analyzed for carbon and nitrogen stable isotopic ratios. The authors compared $\partial^{13}C$ and $\partial^{15}N$ ratios of biofilm, biofilm+small invertebrates, small invertebrates, large polychaetes, droppings, and stomach contents to estimate the sources of carbon and nitrogen present in the sandpipers' stomach and droppings. However, due to metabolic rerouting, this type of analysis is not always an accurate representation of shorebird diet, and is likely a more accurate representation of the source of dietary protein only[25].

Hobson et al (2022)[25] performed isotopic analysis on the breath and liver of western sandpipers and dunlin to estimate the percent contribution of biofilm to the birds' energy budget. The authors argue that analysis of the breath is more representative of all dietary macromolecules than of the stomach or droppings. They compared the ratio of $\partial^{13}C$ in the breath and $\partial^{13}C$ and $\partial^{15}N$ in the liver to measured ratios in biofilm, amphipods, gastropods, bivalves, crabs, and surface sediment to calculate the approximate percentage of each of these as a portion of the birds' diet. This approach requires the use of a mass spectrometer, but provides useful estimates on the sources of energy to shorebirds.

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[22] Kuwae, T., Elner, R. W., Amano, T., & Drever, M. C. (2021). Seven ecological and technical attributes for biofilm-based recovery of shorebird populations in intertidal flat ecosystems. Ecological Solutions and Evidence, 2(4), e12114.

[23] Protocol forthcoming

[24] Kuwae, T., Beninger, P. G., Decottignies, P., Mathot, K. J., Lund, D. R., & Elner, R. W. (2008). Biofilm grazing in a higher vertebrate: the western sandpiper, Calidris mauri. Ecology, 89(3), 599-606.

[25] Hobson, K. A., Kuwae, T., Drever, M. C., Easton, W. E., & Elner, R. W. (2022). Biofilm and invertebrate consumption by western sandpipers (Calidris mauri) and dunlin (Calidris alpina) during spring migratory stopover: insights from tissue and breath CO2 isotopic (δ 13C, δ 15N) analyses. Conservation physiology, 10(1), coac006.

I recommend a combined approach, in which fecal frequency data is collected on a smaller spatial and time scale, and video recording of feeding behaviours is acquired for later analysis by experts and breath samples are taken during all Motus tagging activities for further analysis.

Conclusions

The overall goal for this review is to provide Birds Canada with a set of recommendations that transitions from abundance-related monitoring to habitat-use related monitoring. This protocol should examine the hypothesis that by introducing freshwater flows into areas of fine sediment on banks through human development, shorebird foraging will increase. While the migratory shorebird project protocol collects essential data, it provides little intrasite information. While this protocol should certainly still be utilized on the Fraser River Delta, I suggest utilizing an additional protocol to collect more intrasite and habitat-use information. My suggestions for such a protocol are as follows.

1. People developing monitoring birds should integrate that data into their design and separate procedures for site level.
2. One of the ways to link these is by focusing on the same species, another is to look at the hypothesis and look at where alteration of freshwater flows fits into the hypothesis. What else do we want to measure that supplements MSP data?

Study Design

A control site, or the closest possible site to an undisturbed site, such as the mudflats in front of Reifel Migratory Bird Sanctuary, should be identified and used for comparison. The studies examined in this review suggest that transects and point counts are variably effective depending on the site. As such, I suggest conducting a pilot study as in Verner et al (1985)[17]. A pilot study should be conducted at Iona, Brunswick Point, and a chosen control site. In some environments, such as long, unobstructed beach or mudflat, transects may be a more accurate method of covering the habitat in use by shorebirds. For others, multiple random point counts may better cover the area. If point counts are chosen as the more accurate method, a mixed-cluster point count should be used.

Abundance Monitoring

The scale of abundance monitoring will depend on the availability of volunteer effort. Monitoring should take place at a minimum of once per month. Both methods and scale for abundance-related monitoring will depend on season. Approaches for migrating, breeding, and overwintering shorebirds should vary. With each observation of birds or a group of birds, an approximation of habitat use should be recorded (e.g. whether birds are feeding, at rest, etc.) If sex is able to be determined, this should be recorded as additional information. Species recorded should follow the BC Coastal Waterbird survey, which includes shorebirds, crows, ravens, kingfishers, and raptors. Both a spotting scope and binoculars should be utilized. Flyovers should be recorded separately.

Feeding Behaviour Monitoring

Feeding behaviour data should be collected on the same day as abundance data. Measurements of feeding should take a combined approach between video monitoring and fecal counts. Fecal counts should roughly follow the Simon Fraser University Centre for Wildlife Ecology method, in which $1m^2$ quadrats are placed in the survey area and shorebird droppings counted and distinguished by size. In order to reduce survey effort, only five quadrats should be counted. In addition, at the start of the survey day, cameras should be set up in order to record shorebird foraging methods. Footage should be analyzed by trained Birds Canada staff in order to differentiate species as well as pecking, probing (random or not), and biofilm grazing behaviours. If resources allow, nocturnal feeding video recording should also be conducted and analyzed for a total period of 24 hours.

Additional Data Collected

The following data are recommended to be collected alongside abundance and feeding behaviour data:

- Temperature
- Wind
- Precipitation
- Cloud Cover
- Sea Conditions
- Tide state and movement
- Anthropogenic disturbance
    - Ranking from 1-5, with notes on the cause for disturbance (e.g. cars, dogs, beachgoers)
    - Excess pollution and trash should be noted
- Detailed habitat description with each bird observation–linked to location for later verification via satellite imagery

Data Reporting and Accessibility

Ease of data reporting can increase volunteer engagement and information collected. Shorebird abundance observations and environmental data should be collected and reported using the NatureCounts app. Optimal data storage and sharing can increase stakeholder and general public knowledge of conservation issues while maintaining data integrity. To enable distribution of data across multiple research initiatives, Birds Canada has used the standard structure of data collection and sharing among bird monitoring efforts. Birds Canada collects and stores data based upon this standard, which allows us to share with researchers across platforms. Data is housed in NatureCounts, a national database that compiles data across multiple surveys. Birds Canada is currently building tools that allow for fine-scale queries of that dataset. Currently, data can be exported by region or method, but not by species. This feature is currently in development. While this is useful for researchers, it's less accessible to the general public. Recommended to develop tools to allow the public to explore datasets.

Local Benefits of a Community Based Monitoring Approach

In 2013, Vancouver City Council and the Vancouver Park Board requested City staff to develop a bird strategy for the city. This was updated in 2020. The five goals of this strategy are to support habitat, reduce threats, improve access, enhance awareness, and grow tourism. The city specifically identified research and monitoring as one of five key action areas. This proposal supports the city's goals, and

effective mobilization and accessibility of resulting data could specifically support the city's goals to support habitat, reduce threats, and enhance public awareness of the plight of Metro Vancouver's shorebirds. The proposed methods of monitoring would be especially impactful in gauging the effects of development on the Fraser River Delta on shorebirds.

Methods for Monitoring Shorebird Abundance and Foraging on the Fraser River Delta

Background and Objectives

As identified in the shorebird review section monitoring of shorebirds is occurring across multiple scales seeking to answer multiple different hypotheses. Within the Canadian Impact Assessment and environmental permitting process monitoring is focused on project specific impacts within a Local Assessment Area or Regional Assessment Area. There are few examples where a proponent is instructed to work with other projects in the Regional Assessment Area on cumulative effects monitoring related to the overall condition of a specific value. There are at least 6 large projects proposed for the Fraser River Delta that may have either a negative or positive impact on shorebirds habitat. To date these projects have not collaborated on the development of a monitoring protocol to inform the cumulative impacts of their respective projects on shorebirds and shorebird habitat. This project is intended to provide Birds Canada with recommendations for a collaborative citizen science based shorebird monitoring protocol that could inform understandings of cumulative effects on shorebirds reliant on the Fraser River Estuary Key Biodiversity Area. This protocol will be further refined through engagement with community and local experts. This protocol is intended to provide fine-scale resolution and as such, will likely need to be adjusted by site after pilot testing.

As bird species are relatively easy to identify and count, data on their numbers and activities has been gathered over decades around the world. Unfortunately, in North America, data shows a net loss of 3 billion birds since 1970, or 29% of the total bird population[26]. This global trend applies to shorebirds[27], birds of the order Charadriiformes which commonly wade in the intertidal zone to forage. Shorebirds are critical indicators of mudflat ecosystem ecology, but are understudied in this regard[28]. The exact reasons for shorebird decline are unknown, but migration and breeding behaviour are correlated with rates of decline[29].

This staggering loss has spurred efforts at habitat restoration, but how successful have these efforts been? This question requires further monitoring and an adjustment of monitoring practices to appropriate species and spatial scale. Among California Least terns, for example, vegetation and habitat changes have been shown to impact nest location at both fine and large scales[30]. This highlights the

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[26] Rosenberg, K. V., Dokter, A. M., Blancher, P. J., Sauer, J. R., Smith, A. C., Smith, P. A., ... & Marra, P. P. (2019). Decline of the North American avifauna. *Science*, *366*(6461), 120-124.
[27] Donaldson, G., Hyslop, C., Morrison, R.I.G., Dickson, H.L. & Davidson, I. (2000). Canadian shorebird conservation plan. Ottawa: Canadian Wildlife Service.
[28] Mathot, K. J., Piersma, T., & Elner, R. W. (2018). Shorebirds as integrators and indicators of mudflat ecology. In *Mudflat ecology* (pp. 309-338). Springer, Cham.
[29] Thomas, G. H., Lanctot, R. B., & Székely, T. (2006). Can intrinsic factors explain population declines in North American breeding shorebirds? A comparative analysis. *Animal Conservation*, *9*(3), 252-258.
[30] Jesu, J. A. (2015). *The role of fine scale habitat features on nest placement and nest fate within California Least tern (Sternula antillarum browni) colonies* (Doctoral dissertation, San Diego State University).

importance of considering scale in the design of monitoring protocols. On the Fraser River estuary, river output, wind conditions, and tidal conditions have been found to affect sandpiper counts[31]. Monitoring in estuarine habitat necessitates special consideration of collection of weather and habitat data. Disturbance due to human activity also affects shorebirds in British Columbia[32], which prompts us to consider human population density and activity in data collection as well. The BC Coastal Waterbird Survey has successfully incorporated the use of citizen science, which increases the amount of data collected but balances these against the level of effort that can be fairly asked of volunteers. Current literature highlights the many variables affecting shorebird counts and behaviour and researchers must carefully consider the level of effort that goes into how and when to collect data on these variables when monitoring these birds.

Ecological monitoring can be used for many purposes. Lindenmayer and Likens (2010)[33] detailed some of these:

- Documenting and providing baselines against which change or extremes can be evaluated
- Evaluating ecological responses to natural or experimental disturbance
- Detecting and evaluating changes in ecosystem structure and function
- Guiding evidence-based environmental legislation
- Generating new and important questions about ecological dynamics

The aims of a monitoring program should be taken into account in its design. Lindenmayer and Likens also suggest four principles for the design of good monitoring programs:

1) Good questions.
(2) A conceptual model of an ecosystem or population.
(3) Strong partnerships between scientists, policymakers and managers.
(4) Frequent use of data collected.

An additional design challenge occurs when the monitored ecosystem experiences a disturbance, anthropogenic or natural. One common study design used to monitor disturbance is Before-After, Control-Impact (BACI.) In this design, a time series is performed on an impacted site before and after the disturbance. An additional “control” site is monitored to attempt to distinguish environmental change from disturbance-caused change. A distinction must be made between control sites vs. reference sites. Control sites are identical to the site being assessed, except for the disturbance, and are often in the vicinity of the assessed site. Reference sites are considered truly pristine sites, and while ideal for

[31] Canham, R., Flemming, S. A., Hope, D. D., & Drever, M. C. (2021). Sandpipers go with the flow: Correlations between estuarine conditions and shorebird abundance at an important stopover on the Pacific Flyway. *Ecology and evolution*, *11*(6), 2828-2841.

[32] Drever, M. C., Beasley, B. A., Zharikov, Y., Lemon, M. J., Levesque, P. G., Boyd, M. D., & Dorst, A. (2016). Monitoring migrating shorebirds at the Tofino Mudflats in British Columbia, Canada: Is disturbance a concern?. *Waterbirds*, *39*(2), 125-135.

[33] Lindenmayer, D. B., & Likens, G. E. (2010). The science and application of ecological monitoring. Biological conservation, 143(6), 1317-1328.

analysis, are difficult to find[34]. Additionally, some scholars have questioned the validity of analyses using only one "control" site[35].

Several groups have convened to coordinate large-scale monitoring of shorebirds in the Pacific. The Migratory Shorebird Project, founded in 2011 and coordinated by Point Blue Conservation Science, coordinates monitoring of migratory shorebirds from Alaska to South America. The Migratory Shorebird Project aims to study shorebird migration and land use in non-breeding seasons, evaluate which environmental factors affect shorebirds the most, and make recommendations for shorebird conservation and shoreline protection at the scale of the Pacific Flyway.

This protocol has two objectives:

1. To transition from abundance-related monitoring to a more holistic monitoring program that includes land use and foraging behaviour
2. To collect data useful for both intersite and intrasite comparisons

Sampling Design

As shorebirds utilize a variety of habitats on the Fraser Delta, different sampling techniques may need to be used to measure abundance. For example, line transects may be more useful on beaches and mudflats, but point counts may be more accurate in vegetated areas. There has been debate[36] over the accuracy of line transect and point count methods to measure bird abundance. With this in mind, a pilot study should be conducted (Appendix 1) comparing line transects and point count methods. Included in this study should be line transects (across beach,) simple point counts, and mixed-cluster point counts. In a mixed-cluster point count, a point is placed at the center of the sampling location, another point is randomly selected at a fixed distance from the second point, and five additional points selected at random within a fixed distance from the second point. These methods should be compared on a minimum of three sampling days. While it is difficult to quantitatively compare these methods in a field setting, the data should be examined and ease of method considered to choose a final sampling design.

Species examined should include Black-bellied Plover, Snowy Plover, Semipalmated Plover, Killdeer, Black Oystercatcher, Black-necked Stilt, American Avocet, Spotted Sandpiper, Greater Yellowlegs, Lesser Yellowlegs, yellowlegs spp., Willet, Whimbrel, Long-billed Curlew, Marbled Godwit, Curlew/Godwit, Ruddy Turnstone, Black Turnstone, Red Knot, Sanderling, Western Sandpiper, Least Sandpiper, Dunlin, Western/Least, Western/Least/Dunlin, dowitcher spp., and Wilson's Snipe to include all shorebird species surveyed on the Fraser River Delta as determined in the monitoring protocol review. Raptors,

[34] Queensland Government (2018). Environmental Protection (Water) Policy 2009 - Monitoring and Sampling Manual

[35] Underwood, A. J. (1992). Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. *Journal of experimental marine biology and ecology*, *161*(2), 145-178.

[36] Verner, J., & Ritter, L. V. (1985). A comparison of transects and point counts in oak-pine woodlands of California. The Condor, 87(1), 47-68.

crows, and ravens should also be noted, as well as Great Blue Herons due to the threatened status of the resident population at Roberts Bank[37] Sites should include Brunswick Point, Iona Beach Regional Park, and one control site on the Delta identified to have the least anthropogenic disturbance and impact. Sampling should occur a minimum of once monthly.

In order to examine shorebird land use and foraging behaviour, fecal counts (see appendix) and video recordings should also be conducted.

Field Methods

Surveys should be conducted within two hours of low tide, during a rising tide, when possible. It is recommended data be collected using the NatureCounts for ease and accessibility. Upon arrival in the field, volunteers/staff should first conduct abundance counts. Following the chosen abundance count sampling design, volunteers should conduct point counts or line transects at several points throughout the site. In NatureCounts, volunteers should select “Fraser River Delta Shorebird Monitoring.” Duration of count and GPS coordinates of point count or start and end point of line transect should be recorded. Volunteers should fill out the pre-survey questions including[38]:

- Names and roles of Observers
- Precipitation
    - None
    - Rain
    - Snow
    - Rain and Snow
    - Hail
    - Thunderstorm
    - Fog
- Cloud Cover
    - 0 (clear) - 10 (very overcast)
- Sea Conditions
    - Calm
    - Rippled
    - Wavy
    - Choppy
    - Rough
    - Stormy
- Tide State
    - Low
    - Mid-Low
    - Mid

[37] https://www.ibacanada.ca/site.jsp?siteID=BC017

[38] Note that many of these environmental variables have been adapted from the BC Coastal Waterbird Survey for greater integration

    - Mid-High
    - High
- Tide Movement
    - Falling
    - Rising
    - Slack
- Visibility
- Habitat Description (please describe the habitat types present in the survey area and any relevant notes)
- Anthropogenic Disturbance (please describe the presence of humans, dogs, vehicles, anthropogenic noise, and anthropogenic debris)
- Notes (please describe any additional relevant information)

The observer and partner should then begin the survey. To enter data, the recording partner should click the relevant species, add location on the map including number of individuals, and add any relevant information on sex or behaviour that can be attained in the details section. Separate checklists should be created for each line transect or point count conducted.

Due to higher levels of equipment and expertise required for habitat-use and feeding monitoring, these surveys should be conducted by highly trained Birds Canada staff or other recognized experts. On days when feeding monitoring is conducted, the surveyor should also complete abundance monitoring as described above before moving on to collect feeding data as described below.

After collecting abundance data, surveyors should conduct fecal counts[39]. If using a point count method, $1m^2$ quadrats should be placed near each point count location. If line transects are utilized, quadrats should be placed in a T-shape, with one line along the transect and the other perpendicular to it, for a total of six quadrats. The location of quadrats should be noted and counts of shorebird droppings conducted. After conducting fecal counts, the surveyors should set up a video camera for recording feeding behaviour[40]. Cameras should be set in a secure location, obscured from the view of as many passers-by as possible, but with sufficient view of mudflats as to record feeding behaviour. If resources allow, video recording should also be conducted at night using a thermal camera. If night time feeding behaviour is recorded, fecal counts should be conducted in the morning upon retrieval of the camera to supplement the lower-quality footage.

Data Management and Analysis

Shorebird survey data should be collected through NatureCounts. Fecal count and video data should be sent to Birds Canada staff for processing. Data should be aggregated and shared with relevant

[39] Adapted from methods developed by Simon Fraser University Centre for Wildlife Ecology

[40] Adapted from Kuwae, T. (2007). Diurnal and nocturnal feeding rate in Kentish plovers Charadrius alexandrinus on an intertidal flat as recorded by telescopic video systems. Marine Biology, 151(2), 663-673.

stakeholders annually at a minimum. All data collected should be submitted to the International Shorebird Survey. Birds Canada should produce an annual report of monitoring data for sharing internally and with relevant stakeholders. Estimations of abundance over time should be calculated. Relationships between abundance and other variables such as weather, anthropogenic disturbance, and presence of predators should be analyzed. Correlation between these environmental variables and feeding behaviour and defecation rate should also be examined, in addition to the correlation between feeding rates and defecation rates.

Training for volunteers

Volunteers should attend a training session on binocular and spotting scope usage, bird identification, and usage of the NatureCounts app. A simplified version of this document should be provided to volunteers for reference

Quality control

Surveyors should examine dropping data and abundance data for any anomalies immediately after survey and report any to Birds Canada. Birds Canada staff should review data submitted. Data submitted from different observers, should be compared, especially between Birds Canada staff and volunteers, to ensure consistency. Spatial and habitat information should be reviewed and confirmed by Birds Canada staff, and rating of anthropogenic disturbance by surveyor description should be done by multiple staff members to minimize bias.

Appendix 1. Protocol for Sampling Design Pilot Study

Sampling design should be tested at both Iona Beach Regional Park and Brunswick Point. Testing should occur on at least three days during the migration season. Testing should occur during a rising tide, within two hours of low tide. Data should be recorded via NatureCounts as described above, including pre-survey data. Sampling design type should be noted in the additional information section.

Simple Point Counts

To conduct a simple point count, surveyors should choose a minimum of three points within the survey area that provide good views of the sampling area. Observers should stand in one point, record the GPS coordinates of the point, and after recording pre-survey data, begin the count. One experienced observer should identify species, approximate numbers, distance, and direction for recording on the map via NatureCounts. Start and end time of each point count should be recorded and should occur for no more than 12 minutes. Observer should slowly turn 360º in order to record the area around them according to maximum visibility, taking care not to double-count birds. The observer and recorder should then repeat this process with the remaining two to four points, attempting not to double-count where the survey area from two points overlaps.

Figure 1. Diagram depicting simple point counts at Iona Beach Regional Park. Here, three points have been chosen along the beach to maximize viewing of the tidal mudflat (red points.) Transparent red circles show approximately 400m visibility coverage of sampling.

Line Transect

In a line transect, lines of pre-determined length (e.g. 200 or 400m,) are walked by the observers. The primary observer notes any birds visible from their location along the transect and the recorder records.

Transects should be placed to maximize survey area and minimize overlap. Start and end times and GPS coordinates should be recorded. This method provides good coverage of the survey area, but takes more time than point counts, as the observer must slowly walk the length of the transect until the survey is complete.

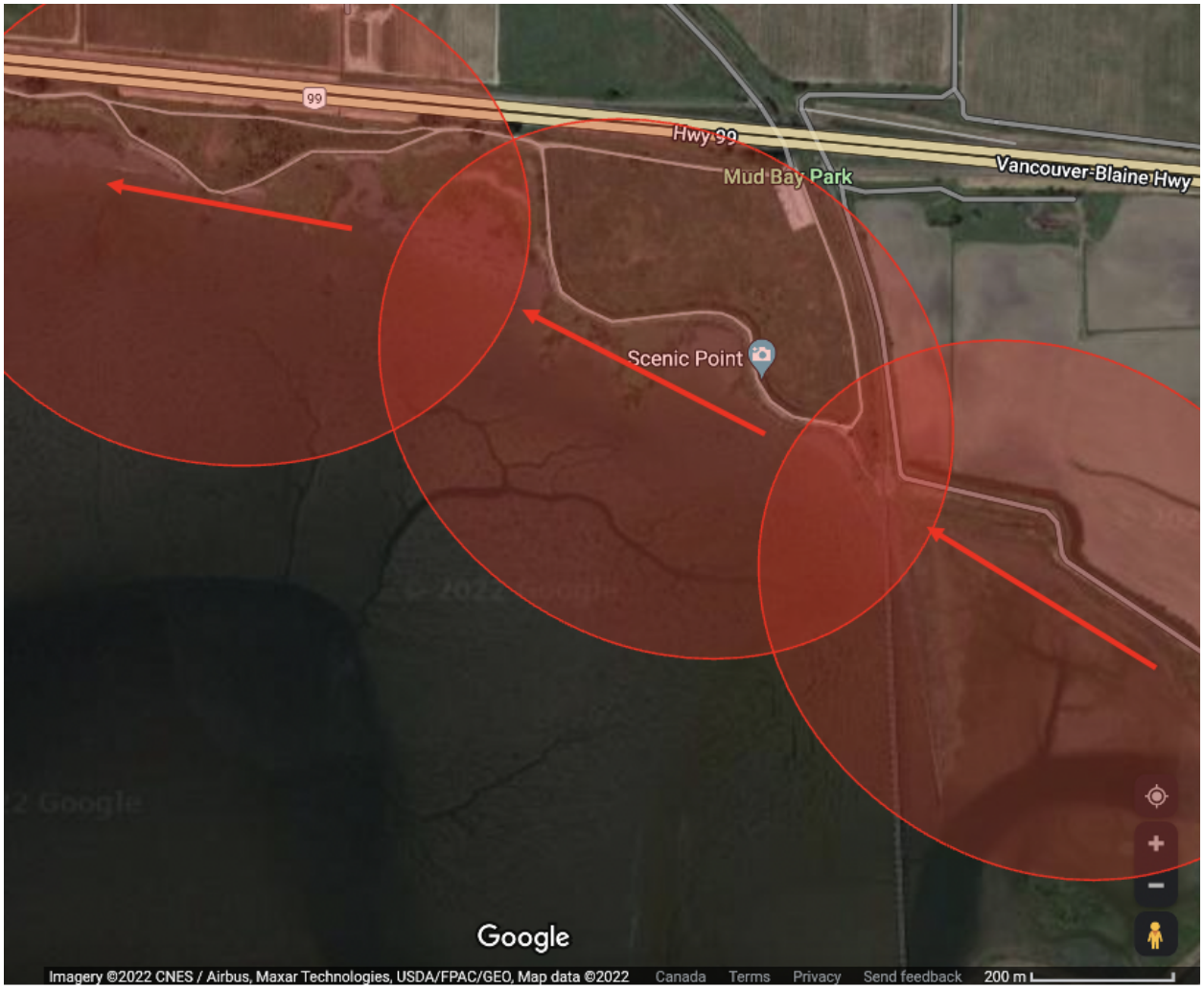

Figure 2. Diagram depicting line transects at Mud Bay Park in Boundary Bay. Transects (red arrows) were chosen to maximize visibility of tidal mudflats. Transparent ovals depict survey coverage with approximately 400m visibility.

Mixed-Cluster Point Counts

In a mixed-cluster point count, a point is randomly chosen and then a minimum of three other points are chosen at random distances from the first point (Figure 3) within a chosen area. While this method minimizes surveyor bias, it can create gaps in the survey area and high levels of overlap, which can increase the likelihood of double-counting birds. This method was identified as effective for measuring

bird abundance by Rempel and Kushneriuk (2003)[41]. Survey methods for this design should resemble those of simple point counts.

Figure 3. Diagram depicting mixed-cluster point counts at Brunswick Point. A central point (red triangle) is chosen within a given area (blue shape) and four additional points are chosen at random distances from the central point, constrained by the blue shape. Transparent red circles represent survey area with approximately 200m visibility.

[41] Rempel, R. S., & Kushneriuk, R. S. (2003). The influence of sampling scheme and interpolation method on the power to detect spatial effects of forest birds in Ontario (Canada). *Landscape Ecology*, *18*(8), 741-757.

Focused Transect

Figure 4. Diagram depicting path of observer (red arrow) and approximate area counted(between red arrow and blue line) for focused transect method.

In a focused transect method, the observer walks the length of the shore, counting only birds present in the intertidal area, as far as visibility allows. This method maximizes coverage of the intertidal zone and minimizes survey area overlap, but ignores shorebirds that may be utilizing habitat types other than the intertidal zone. This may be particularly important in Iona Beach Regional Park, where shorebirds often utilize neighbouring sewage ponds. This design was utilized by the Roberts Bank Terminal 2 Technical Data Report. Using this study design increases the potential for integration with this important dataset. The primary observer should walk the shoreline and observe birds as far out into the intertidal zone as visibility allows with the recorder entering data into NatureCounts. The survey should stop when observers are physically obstructed from completing the survey, but should otherwise follow no time limit. Start and stop time of survey should be recorded as well as start and stop coordinates.

Appendix 2. Sample Data Sheet for Fecal Counts

Shorebird Fecal Count Data Sheet

Birds Canada

Updated August 2022

Primary Observer_____ Date _____

Secondary Observer_____ Survey Location_____

Recorder _____ Start Time_____ End Time _____

Quadrat	Coordinates	Fecal Count	Notes
1			
2			
3			
4			
5			