FINAL REPORT

Space Use and Habitat Selection by Wintering Dunlin in the Skagit River Delta

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I. Introduction

Understanding non-random patterns of habitat use by wildlife species and the ecological basis for these patterns provide the framework for most conservation efforts aimed at the maintenance of biodiversity and healthy ecosystems. For highly mobile species, such as shorebirds, both abiotic (e.g., time of day, tide stage) and biotic (e.g., food resources) factors can influence habitat use patterns (Rottenborn 1996, Colwell and Dodd 1997). Furthermore, variation in habitat selection can reflect differences based on individual classes of a population, such as sex and age, reflecting differences in morphology (bill length) and competitive exclusion, respectively (Shepherd and Lank 2004). Consequently, investigations of individuals through time and space are critical to reveal the species-specific patterns of habitat use necessary to guide conservation actions.

In the Skagit and Stillaguamish River deltas of western Washington State, many organizations and agencies are working to design and implement wetland restoration and wildlife conservation plans aimed at the conservation of coastal estuarine habitats and the species that depend upon them. Shorebirds in particular have received significant attention because of their population declines, their status as environmental indicators, and their conspicuousness. In this region, many shorebird species aggregate in large number during spring and fall migration to and from their breeding grounds and during their overwintering periods. In this critical period of their life cycle, however, they are generally restricted to an assortment of estuaries and associated nontidal wetlands, and thus habitat loss and degradation pose major threats. Indeed, declines in many shorebird species have been attributed to the loss of coastal wetland habitats (Drut and Buchanan 2000, Brown et al. 2001), and this is likely true in the Skagit and Stillaguamish River deltas.

Research indicates that shorebirds often use agricultural habitats in coastal ecosystems when intertidal habitats are inundated during high tides or flood events (Gerstenberg 1979, Colwell and Dodd 1995, 1997, Shepherd and Lank 2004). On the Fraser River delta, which lies 60 miles north of the Skagit River, Dunlin (*Calidrus alpina*) used agriculture habitats at night, and this led the authors to promote the conservation of agricultural lands, particularly soil-based agriculture, as an important step in shorebird conservation (Shepherd and Lank 2004, Evans Ogden et al. 2008). However, it remains unclear if shorebirds use habitats in the Skagit and Stillaguamish River deltas similarly to adjacent estuaries. This information gap presents a significant challenge to land managers and conservation organizations developing conservation strategies for shorebirds in the absence of information on habitat use patterns.

To address this information gap, we initiated a radio-telemetry project aimed at improving our understanding of habitat use patterns exhibited by Dunlin in the Skagit and Stillaguamish River deltas.

We selected Dunlin as our study species because: 1) the region supports a large population (30,000-60,000) of wintering Dunlin and they have been the focus of studies in nearby coastal communities (Evenson and Buchanan 1997, Evans Ogden 2002, Shepherd and Lank 2004); 2) the Pacific Coast subspecies of Dunlin (*C. a. pacifica*) is listed as a species of high concern (Drut and Buchanan 2000) due to long-term population declines attributed to a loss of wintering habitat (Warnock and Gill 1996); and 3) overwintering Dunlin exhibit site fidelity in the region (Warnock et al. 1995, Shepherd 2001), making them an excellent study subject for a radio-telemetry project.

This study was initially designed to extend two years with the goal of following 30 Dunlin in each year. Ecostudies Institute raised additional support, leveraging funds provided by Seattle City Light and other initial funders, from Washington Department of Fish and Wildlife and The Nature Conservancy to expand the project after the first year. These funds allowed us to increase the number of birds we radio-tagged from 30 to 70 individuals/year, implement more efficient aerial-tracking to locate radio-tagged dunlin, and expand the study length from two to three years. With collaborators, Dr. David Lank, Simon Fraser University, and Dr. Keith Hobson, Canadian Wildlife Service, we also obtained a grant to use stable isotope methods to quantify relative contributions of estuarine and terrestrial prey to diet of Dunlin. This component greatly enhanced the intensive radio-tracking habitat use component by adding to information on ("where birds eat") with habitat usage ("where birds are"). We will measure this by taking advantage of natural differences between marine and terrestrial environments in the proportions of stable isotope ratios of nitrogen (isotopes 14 versus 15) and carbon (isotopes 12 versus 13) proportions. Overall, our study had three objectives: 1) quantify space use by wintering non-territorial Dunlin; 2) determine habitat preferences of Dunlin; and 3) determine the proportion of Dunlin diet from estuarine and terrestrial sources.

II. Methods

Study area

The study was conducted in the Skagit River delta (48°19'N, 122°24'W) and the Stillaguamish River delta (48°12'N, 122°22'W), two adjacent estuaries ecologically linked via hydrodynamics (Fig 1). The Skagit River is the largest river flowing into Puget Sound and empties into Skagit Bay. Its delta extends over ~32,670 ha, and prior to Euro-American settlement (approximately 1860) included 5,620 ha of estuarine emergent marsh, 9,700 ha of scrub-shrub wetlands, and 2,410 ha of forested wetland (Collins 2000). Approximately, 15 km to the south, the Stillaguamish River, with a 4,330 ha delta, terminates into Port Susan Bay. Historically, the Stillaguamish River delta included 1,120 ha of estuarine emergent wetlands and 1,190 ha of scrub-shrub wetlands (Collins 2000). Both river deltas have experienced substantial loss of wetland habitat. More than 85% of emergent wetlands and nearly all scrub-shrub and forested wetlands have been lost, primarily for agricultural development. Remaining estuarine marsh and intertidal flat habitats are separated from agricultural, urban, and other terrestrial habitats by a system of dikes.

The Skagit River and Stillaguamish River deltas and the Fraser River Delta, 60 km to the north, support the northernmost populations of overwintering Dunlin. Skagit and Port Susan Bay qualify as regional sites of importance to migratory and overwintering shorebirds (>25,000 individuals in each; Ruth Milner [Washington Department of Fish and Wildlife], unpub. data, Evenson and Buchanan 1997).

Capture and radio-tagging

During the winter of 2006-2007, the first year of the study, trapping was restricted to the Skagit River delta. We captured Dunlin using mist nets at two sites (Fig 1), one agricultural (Goose Reserve) and one estuarine (King's Marsh), along the bayfront of Fir Island adjacent to Skagit Bay during the period from 19 December 2006 to 9 February 2007. Birds were captured within $\pm$ 2 hours of high tide at either dawn or dusk, a time when Dunlin were actively flying between intertidal and terrestrial habitats. After the first year of the study, we expanded trapping areas to include south Skagit Bay and Port Susan Bay. We captured Dunlin from four estuarine sites (Jenson Access, Big Ditch, West Pass, and Port Susan Bay) and one agricultural site (Goose Reserve) during the period 27 November 2007 to 7 February 2008 and 24 November 2008 to 21 January 2009 (Fig 1). We attempted trapping, without success, in other areas where use of agricultural fields by Dunlin appeared high. In addition to mist nets, we used a net gun to capture Dunlin during the 2nd and 3rd years of the study. The net gun was used exclusively in marsh habitats and was not effective in agricultural habitat.

Each individual was banded with a U.S. Fish and Wildlife band and the following measurements were taken: weight, natural wing cord, culmen length. Dunlin were sexed based on culmen length (males < 37.9 mm; unknown 37.9-39.7; females > 39.7; Shepherd 2001) and juveniles were distinguished from adults by the presence of buffy edges on inner median coverts (Paulson 1993). We attempted to balance radio-tagged individuals by sex and age groups. Individuals selected for radio-marking were fitted with a 1.3g radio-transmitter with a rated life span of 60-80 days (American Wildlife Enterprises, Tallahassee) using epoxy glue. This glue method allows the bird to fly normally and ensures that the radio will drop off when the birds molts and has been used successfully in other studies (Shepherd 2001, Slater 2001). This weight of the transmitter represented <3 percent of the mean body weight of all radio-tagged birds.

Radio-tracking

We began radio-tracking Dunlin after a 2-day post-attachment adjustment period. Dunlin were located from a combination of fixed and variable tracking stations that provided adequate coverage of suitable habitats within the study area. We established 32 fixed stations on the Skagit River delta, particularly focused around Fir Island, and 19 fixed stations on the Stillaguamish River delta (Fig 2). Stations were established on the raised dikes separating the marine and terrestrial habitats and on roads through agricultural habitats. An additional 16 points were placed in the LaConner Flats, but these were used infrequently following few detections of radio-tagged birds in that region. At low tides when intertidal habitats were exposed we located Dunlin from points along walking transects (variable tracking locations) in the estuary that were typically parallel to the tideline (See Fig 3 for location of all tracking stations). We conducted telemetry tracking bouts on a nearly daily basis within blocks stratified by area (Skagit River vs. Stillaguamish River deltas), time of day (night vs. day), and tide stage (high vs. low), aiming to cover agricultural and estuarine habitats similarly. Thus, each bout occurred in one area, during either the day or night, and at either a high or low tide. On occasions when tracking runs were conducted in both areas during a single day, they were conducted at different tide periods. We defined "day" as the period from 30 min before sunrise to 30 min after sunset and "night" as the remainder of the 24-hr cycle. High and low tides were defined as those periods between the midpoint of the day's high and low tide, thus each day had two low tide periods and two high tide periods. During each tracking bout, we visited as many tracking stations as possible (mean = 13, range = 1 - 35) within the time period, scanning for all active frequencies of radio-tagged Dunlin using a 3-element Yagi antennae and Communication Specialist R1000 or ATS R2000 Receiver. The location of each individual was derived from at least two compass bearings taken from consecutive telemetry stations; the second station usually being a variable tracking station that was selected to optimize the likelihood of successful bi- or triangulation. Time between bearings was generally less than 10 minutes. When birds were visually observed, we determined the bearing and estimated distance to the individual. Location data were determined using Location of a Signal software (LOAS, Ecological Software Solutions, LLC).

We supplemented ground-based tracking events with aerial surveys using fixed wing aircraft with wing-mounted Yagi antennae; this method allowed us to cover the entire study area within a single tracking run. In 2006-2007, we only conducted five aerial surveys, all at low tide. In the following two years we conducted aerial surveys approximately twice a week with flights stratified by day and tide. In the first and second year of the study, flights covered adjacent Padilla, and Samish Bays, but after few bird detections in that region, flights were primarily restricted to Skagit and Port Susan Bay in the third year. We occasionally used aerial flights to survey areas adjacent to the study area when individuals disappeared. Dunlin were tracked until mid-late March or until transmitters failed, except in 2007-2008 when we conducted five surveys in April. For each Dunlin location, we recorded the tide height based on tide calculations from http://tbone.biol.sc.edu for the LaConner tide station. On falling tides, Port Susan bay dewaters about 30 minutes earlier than Skagit Bay and the average offset of tide height is 0.15 m. Thus, we corrected Dunlin location collected in Port Susan Bay on falling tides by reducing the LaConner tide height value by 0.15 m. Tides in Skagit Bay and Port Susan Bay rise at similar times and thus we did not correct for locations collected on rising tides. We did not consider the effect of river stage or flow of the Skagit and Stillaguamish Rivers on tide heights, but acknowledge that both can influence relative tide heights.

Habitat Maps

We constructed habitat maps of the terrestrial environment in our study area during each year of the project because conditions on agricultural fields changed among years. We surveyed all areas of the floodplain where Dunlin were located and assigned terrestrial habitats into the following categories: bare soil, crop residue, pasture, cover crop (typically rye [*Lolium sp.*]), woody agriculture (nurseries, blueberries, and orchards), other agriculture (flooded fields, active growing crops; e.g., cabbage), and non-use habitat (i.e., forest and urban habitats). Habitat maps were created in ArcGIS 9.2. We also constructed a habitat map of the estuarine environment using aerial photographs, field surveys, and existing vegetation maps of Skagit Bay (McBride et al. 2006) and Port Susan Bay (Griffith 2005, Heatwole 2006). We categorized three estuarine habitats: tidal flat, high marsh, and low marsh that were separated by apparent differences in intertidal elevation and vegetation composition and density. Tidal flat included those areas at elevations unable to support marsh vegetation. Thus, they were generally unvegetated, except for the presence of eelgrass (*Zaponica sp*) in some areas. Low marsh was typified by sedges and bulrushes, including *Carex lyngbyei* (Lyngby's sedge), *Scirpus americanus* (American bulrush), and *Scirpus maritimus* (maritime bulrush). Vegetation density in this habitat was variable, and included unvegetated areas where vegetation died back to moderately dense stands of dead vegetation (approximately 25-50% vegetation cover). The transition between high and low marsh was denoted as the area where sedges and bulrushes of the low marsh transitioned to more dense stands (>50% vegetation cover) and vegetation communities became dominated by *Scirpus validus* (soft-stem bulrush), *Typha angustifolia* (cattail) and woody shrubs (e.g, sweetgale [*Myrica gale*], willow [*Salix sp.*]). We ground-truthed habitat ecotones in selected areas, and we validated habitat categories and their location using expert opinion from ecologists familiar with vegetation patterns in the region (Roger

Fuller, The Nature Conservancy, Justin Haug, Washington Department of Fish and Wildlife, Greg Hood, Skagit River System Cooperative, Ruth Milner, Washington Department of Fish and Wildlife). We merged each year's terrestrial map with the estuarine map to construct the final habitat for each year.

Task 1. Quantify space use by wintering non-territorial Dunlin

We quantified the use of space by Dunlin across the study area by determining the size and habitat composition of home ranges and comparing home range size among different classes of the population. We estimated fixed kernel 85% utilization distributions (UD) to represent home ranges of radio-tagged individuals. We selected the 85% UD following a comparison of the proportion of our habitat map contained within the UD of 30, 50, 75, 85, and 95% home ranges. Analysis of variance (ANOVA) indicated that the 85% UD was the largest UD without significant gaps in our habitat maps (mean coverage = 99%). In other words, the 95% UD contained a significantly larger area of unmapped habitats compared to the 85% UD. Home range estimates were determined using the Animal Movement extension (Hooge and Eichenlaub 1997) in ArcView GIS 3.2. We used least-squares cross validation to calculate the smoothing parameter (H) for each home range calculation and calculated home range estimates for each Dunlin with $\geq$ 14 locations. An evaluation of plots of individual UDs with successively larger set of points, chosen at random, indicated that UDs stabilized between 13-17 points. This range includes the number of locations, 15, which Shepherd and Lank (2004) used to calculate home ranges of Dunlin in the adjacent Fraser River delta. We decided to use 14 locations over 15 locations for determining UDs because correlation analysis indicated no relation between the number of locations and home range size and because our sample size was increased by 10 individuals. We used only 1 location per bird per day in all of the analysis. We compared log-transformed home range size of Dunlin among years using ANOVA. Post hoc tests to determine which means differed were conducted with the Bonferroni test based on the Student's *t* statistic. We used two-way ANOVA to compare home range-size among categories (sex, age sex*age). Means and 95% confidence intervals (CI) of 85% UDs were calculated with log values and back transformed (Limpert et al. 2001). Within each home range, we also determined the percentage of each habitat category.

Task 2: Determine habitat preferences of Dunlin

We used discrete-choice modeling to estimate a resource selection probability function detailing patterns of habitat use by Dunlin in our study area (Arthur et al. 1996, Cooper and Millspaugh 1999, McDonald et al. 2006). Discrete-choice modeling allows for separate definitions of habitat availability for each animal observation, a property that is desirable when availability of habitat changes among observations, as is the case for Dunlin where habitat availability varies due to tidal fluctuations (Buskirk and Millspaugh 2006). The set of parameters of this function sum to 1.0, and each index value reflects the probability that an individual would use a particular habitat type, assuming all types were equally available. If habitat types are all used randomly then the expected values of the function will be 1/H for each type, where H = the number of habitat types. This approach allows independent estimates of habitat selection indices for each observation and animal, which can be used to investigate the influence of additional variables that may affect habitat use, such as time-of-day, tidal height, age, and sex.

We investigated habit selection by comparing the proportion of habitat within a pooled UD for individuals from the same capture location in each year (I.e., available habitat), with individual Dunlin locations (i.e., used habitat). Therefore our analysis most closely resembles third-order, or local-scale, selection, as defined by Johnson (1980). We determined the overall choice set of available habit for each capture location in each year by merging 85% UDs for those individuals with $\geq$ 14 points, which resulted in a single pooled UD for each capture group in each year. Within this area, we calculated the proportion of each habitat. For each year we combined habitat categories containing < 2% of locations and classified them as "other habitat." We used pooled UDs of capture groups as the choice set rather than individual bird 85% UDs for several reasons. Dunlin are highly mobile, capable of covering large areas in a short period of time, and thus we believed that the actual amount of habitat available to Dunlin was larger than individual 85% UDs. Based on a review of locations, Dunlin also appeared to show some fidelity to the region they were trapped, and as such, many UDs within capture groups showed substantial overlap. Shepherd and Lank (2004) also found high fidelity in their study of Dunlin in the Fraser River delta. Finally, this method allowed us to include a large number of locations from individuals that did not have enough locations to calculate their own UD.

For every capture group, we determined the amount of available habitat, accounting for changing habitat availability with tide, using GIS. To do this, we first created an elevation model of intertidal habitats using lidar data in the form of GIS rasters for estuarine habitats in Skagit Bay and in Port Susan Bay. We transformed vertical datums (Skagit Bay, NGVD 29; Port Susan Bay, NAVD88) to MLLW, which is the same datum used by tide stations. We divided the full range of tidal elevations into four intervals, representing four distinct tidal conditions with respect to availability of estuarine habitats to Dunlin : 1) very low (-0.60 to 0.90 m) - nearly all intertidal habitats exposed, 2) low (0.91 to 2.30 m) - most intertidal habitats exposed, 3) transitional (2.31 to 2.90 m) – the midpoint of this range was the tide height where most intertidal habitats became fully inundated, 4) very high (2.91-3.70 m) – all intertidal habitats were inundated. We determined the habitat choice sets available to Dunlin for each of the four tide intervals by subtracting the amount of intertidal habitats lost with increasing tide (i.e., inundated habitat) from the corresponding overall choice set of the capture group. If for any occasion proportional habitat availability was < 1% but > 0, we made availability equal to 1% to prevent errors in computing selection indices.

We calculated habitat selection indices, b_j, of the resource selection probability function for observations of all birds pooled and for each individual bird. For each individual location, a paired measure of availability was determined according to the tide interval during which the bird was observed. We used every location of each individual bird, unless the location fell outside of the pooled home range for its capture group, in which case the location was excluded from the analysis. As described by Arthur (1996), we used a maximum likelihood approach to calculate selection indices. The basic form of the resource selection function ($\hat{w}_k$) is:

$$\hat{w}_k = \frac{\sum_{i=1}^{D} o_{ik}}{\sum_{i=1}^{D} \frac{A_{ik}}{\sum_{j=1}^{H} A_{ij}\hat{b}_j}}, \tag{1}$$

where $\hat{w}_k$ is the probability that habitat belonging to category k is chosen, o_{ik} is the proportional use of habitat type k on day i, j is the set of all habitat categories 1 to H, A_{ik} is the proportional availability of type k on day i, D is the number of days on which the animal was located, and H is the total number of habitat categories. The observed selection index, b_j, was calculated on an iterative basis, starting with a null model of no selection (proportional use is equal for all habitat types; b_j are set to equal 1/H) and solving Equation 1. We then solved the following equation:

$$\hat{b}_k = \frac{\hat{w}_k}{\sum_{j=1}^{H} \hat{w}_j}, \tag{2}$$

to calculate new values for b_j , which were inserted back into Equation 1. This process was repeated until $\hat{w}_j$ was equal to $\hat{b}_j$ for all habitat types.

We used likelihood ratio tests to determine whether the use of habitats by Dunlin was selective or random and to determine whether variation in selection differed among individuals. For each observation we estimated the likelihood of obtaining that observation with the equation:

$$\hat{P}_i = \frac{\sum_{i=1}^{H} A_{ij}\hat{b}_j o_{ij}}{\sum_{i=1}^{H} A_{ij}}$$

Likelihood values were calculated for each of the three models: no selection, where all $\hat{b}_j$ = 1/H; constant selection among individuals, where $\hat{b}_j$ = to those values generated from pooled observations; and individual selection, where $\hat{b}_j$ = to values estimated for individual birds. Deviance values (deviance = -2log$_e$(likelihood)) from each observation under these models were summed. We compared models by determining the difference between deviance values, which are expected to follow approximately a χ^2 distribution with degrees of freedom (df) equal to the difference in df between the two models (Manly et al. 1993). Tests were conducted in a stepwise fashion with the simplest (i.e., fewest parameter) models tested first. Hence, the first test compared a model assuming no selection and all animals pooled with a pooled model allowing for habitat selection. If significant, a second test was conducted comparing the pooled model allowing for habitat selection with the model containing variation among both habitat types and animals.

Where habitat use was non-random, we ranked habitats according to values of the selection index to ask: which habitats are used more or less than the other types? This analysis provides a measure of preference among the habitats used by Dunlin, after adjusting for differences in availability. We used univariate, paired *t*-tests to compare indices between habitats types, controlling for the familywise error rate by setting the critical level of individual comparisons to α=0.05 divided by the number of comparisons. We only used selection indices for those individuals with 10 or more points to reduce potential bias from individuals with only a few locations.

We compared differences in selection indices between years (2007-2008 and 2008-2009) and groups (adult vs. juvenile, night vs. day, and low tide vs. high tide) using Multi-Response Permutation Procedures (MRPP; Zimmerman et al. 1985). MRPP is a nonparametric procedure for testing the hypothesis of no difference between two or more groups of entities; the groups must be determined a priori. MRPP uses distance measures to calculate the similarity of observations for different groups. Although similar to parametric discriminant analysis procedures, MRPP has the advantage of not requiring certain assumptions (such as multivariate normality and homogeneity of variances) associated with parametric procedures and that are often difficult to meet with ecological community data. As with the paired *t*-tests, for comparisons, we only used selection indices for those individuals with 10 or more points to reduce potential bias from individuals with only a few locations. Because 2006-2007 had 2 fewer habitat categories and relatively few birds meeting the 10 location criteria compared to the other years (only 9 birds with 10 or more points), we conducted analyses with only data from 2007-2008 and 2008-2009. Where significant differences were found between groups using MRPP, we used ANOVA to compare selection of specific habitats by groups, implementing a Bonferroni adjustment for multiple comparisons. We divided $P = 0.05$ by the number of comparisons to obtain the corrected significance level.

Task 3. Determine the proportion of Dunlin diet from estuarine and terrestrial sources

During the winter of 2006-2007 and 2007-2008, we extracted whole blood samples, approximately 100-µL, from the brachial vein of captured Dunlin, as part of a study to estimate the relative proportion of Dunlin diet procured from estuarine vs. terrestrial sources. In year 1, we avoided both radio-tagging and bleeding individual birds, as we refined our trapping and radio-tagging techniques. In year 2, with refined techniques, we were able to both attach radios and bleed individuals quickly. Isotope analyses of whole blood indicate diet source over approximately 21 $\pm$ 1 d (Evans Ogden et al. 2004). Overwintering Dunlin arrive on their overwintering ground through October, and therefore we did not collect blood samples prior to 27 November to ensure results were indicative of diet within the greater Skagit delta. Collected blood samples were frozen until lab analyses.

Interpretation of stable isotope values requires obtaining "endpoint samples" of prey from the environment against which blood values can be scaled. We sampled both the terrestrial and estuarine environments, restricting sampling to within the boundary of Dunlin radio-tracking locations. To select sampling points within the agricultural environment, we first created two polygons of the primary agricultural regions used by Dunlin in the Skagit and Stillaguamish River deltas, respectively. Using Hawth's Tools (Beyer 2004), we randomly selected sampling points within each polygon with the criteria that points were > 500m apart (Fig 4). Within the estuarine environment we established two transects, parallel to the tide line, in each estuary (four total) (Fig 4). The rational for transect placement within the study area was to ensure transects were 1) within the region where Dunlin were located and 2) that they encompassed as much of a freshwater/salinity gradient as possible, with respect to both proximity to freshwater outflows and distance to shoreline. Thus, we established transects started near a freshwater outflow, with one transect close to the shoreline and the second transect approximately 1 km farther out on the tidal flat. Transects were approximately 2-3 km long, and we collected prey samples every 175 m by either collecting items off the surface of the estuary (i.e., annelids) or digging a shallow hole and collecting invertebrate prey (shrimp, mollusk, etc). We only collected samples presumed to be prey of Dunlin. Invertebrate samples were stored frozen until sent to the lab.

In the lab, blood samples were freeze dried and powdered. Invertebrate samples were cleaned with distilled water, freeze dried, and powdered. Invertebrates were then subjected to a lipid extraction step using a 2:1 chloroform:methanol soak and rinse. These samples were then dried in a fume hood for 48h. The samples were tested for the presence of carbonates by applying a few drops of 0.1N HCl. Samples showing any bubbling were then treated with this solution without rinsing. Treated powdered samples were weighed (1.0±0.1mg) into tin cups and analyzed using a Costech ECS4010 elemental analyzer coupled to a Delta V mass spectrometer with Conflo IV interface. Results were expressed in standard delta (δ) notation in parts per thousand deviation from the international standards VPDB ($\delta^{13}C$) and Atmospheric AIR ($\delta^{15}N$). We placed one internal laboratory standard (egg albumin for high N samples and a Peagrain standard for low N samples) between every 5 unknowns in each analytical run to correct for instrument drift. Using these within-run replicate measurements of standards, we estimate measurement precision to be of the order of ± 0.1‰ for $\delta^{13}C$ and ± 0.25‰ for $\delta^{15}N$. All analyses were conducted at the Stable Isotope Laboratory of the Department of Soil Science, University of Saskatchewan, Canada.

To quantify the relative proportion of Dunlin diet from agricultural vs. estuarine habitats, we first averaged all prey samples falling within sampled zones (terrestrial, estuarine) and used these as endpoint values in our mixing model. Next, dunlin isotope values and endpoints were used in a Bayesian mixing model with isotope values (MixSIR; Semmens and Moore 2008) to quantify relative nutrient inputs to diets. This approach required the application of diet-blood isotope discrimination values derived previously for this species (Evans-Ogden **; $\Delta^{13}C$: 1.3‰, $\Delta^{15}N$: 2.9‰).

III. Results

We radio-tagged 29 Dunlin during the winter of 2006-2007, including 17 adults and 12 juveniles; 13 were females, 14 were males, and 2 were of unknown sex (Table 1). We conducted 74 tracking runs from 26 December 2006 – 21 March 2007, obtaining 260 Dunlin locations (mean/individual = 9.6; range/individual = 1-25) from 27 radio-marked individuals (Table 2, Fig 5,). We radio-tagged 69 individuals during the winter of 2007-2008, including 25 adults, 43 juveniles, and 1 of unknown age; 32 were females, 32 were male, and 5 were of unknown sex (Table 1). During the period from 30 November 2007 – 29 April 2008, we obtained 1,128 Dunlin locations (mean/individual = 17.4; range/individual = 1-41) from 65 radio-marked individuals on 101 tracking runs (Table 2, Fig 6,). Four individuals were not detected after tagging. In the final year of the study, we radio-tagged 70 dunlin, including 34 adults and 36 juveniles; 28 were females, 38 were males, and 4 were of unknown sex (Table 1). Ninety-one tracking bouts from 4 December 2008 – 17 March 2009 yielded 1,101 Dunlin locations (mean/individual = 16.4; range/individual = 2-33) from 67 individuals (Table 2, Fig 7).

Task 1. Quantify space use by wintering non-territorial Dunlin

Ninety-five Dunlin had sufficient locations ($\geq$ 14) to calculate 85% UDs (See Fig 8 for example). Preliminary analysis of residual plots detected 4 outliers, 2 with extremely large UDs and 2 with extremely small UDs. These individuals were removed from subsequent home range analyses. Dunlin home range sizes differed by year ($F_{2,88}$ = 17.55, P < 0.001). Dunlin captured in 2006-2007 had significantly smaller UDs (11.1 km^2; 95% CI = 5.6-22.1, N = 7) than Dunlin in 2007-2008 (t = -1.35, P < 0.001; 42.7 km^2; 95% CI = 35.0-52.1, N = 38) or in 2008-2009 (t = -1.68, P < 0.001; 59.5 km^2; 95% CI = 47.3-74.8, N = 46). We omitted 2006-2007 data from further home range analyses because of concerns that estimates of home range size estimates were biased low. Few aerial surveys were conducted in 2006-2007, and as a result the effective search area from which Dunlin were sampled was apparently limited. Dunlin home ranges size in 2007-2008 did not differ from 2008-2009 (t = -0.33, P=0.10), and we subsequently pooled these two years' data for comparisons of age and sex. Home range size did not differ with respect to sex (F = 0.24, P = 0.63), age (F = 0.14, P = 0.71), or the interaction between sex and age (F = 1.12, P = 0.29; Fig 9).

Every Dunlin home range estimated in the study contained both estuarine and agricultural habitats. Estuarine habitats comprised a larger proportion of the home range (mean = 0.57, range = 0.53 – 0.62) than agricultural habitats (mean = 0.39, range = 0.33 - 0.44; Table 3). Tidal flat made up the largest proportion (mean = 0.38) of estuarine habitat followed by low marsh (mean = 0.15) and high marsh (mean = 0.04). Within agricultural habitats, cover crop comprised the largest proportion of dunlin home ranges (mean = 0.18), followed by bare soil (mean = 0.12). All other habitats made up < 0.06 of home ranges.

Task 2: Determine habitat preferences of Dunlin

In all 3 years of the study, the majority of Dunlin locations were recorded in estuarine habitats (2006-2007: 0.59, 2007-2008: 0.76, 2008-2009: 0.66; Table 3). The majority of locations were recorded in tide flat (mean = 0.32) and low marsh (mean = 0.31). Dunlin were recorded less frequently in agricultural habitats (2006-2007: 0.40, 2007-2008: 0.23, 2008-2009: 0.33). Within agricultural habitats cover crop (range = 11.5 – 14.9) and bare soil (6.8 – 23.7) habitats were the highest ranking habitats in which Dunlin were recorded; no other habitats averaged > 5% of locations.

In 2007, the choice set of habitat availability consisted of five habitat categories (bare soil, low marsh, tidal flat, winter cover crop, and other habitats), and in 2008 and 2009 a total of seven habitat types were categorized (bare soil, crop residue, high marsh, low marsh, tidal flat, winter cover crop, and other habitats). Proportional habitat availability changed with tide height for each capture group in each year of the study (See Appendix A). As the tide rose, the availability of tidal flats and low marsh showed substantial decreases, while the availability of terrestrial habitats increased. In general, the availability of bare soil and winter cover crops were the terrestrial habitats that showed the largest proportional increase.

In each year, likelihood-ratio tests showed similar results. The model with all observations pooled showed greater fit than the nonselection model ($P < 0.001$), and the model treating each individual independently showed greater fit than the pooled model (2006-2007: $P < 0.01$; 2007-2008 and 2008-2009: $P < 0.001$; Tables 4, 5, 6). In 2006-2007, the selection model with habitat and individual variation indicated tidal flat, low marsh and bare soil were selected at greater probabilities (index values: 0.35, 0.35, and 0.25, respectively) than if use was nonrandom (index value: 0.20), whereas the pooled selection model indicated only tidal flat and low marsh (index values: 0.61, 0.32) were selected at greater probabilities than random. We suspect that the individual model in 2006-2007 is biased due to the small number of observations for most individuals. Twenty of the 29 birds used in the analysis had less than 10 locations and 11 of those had less than 5 locations.

Selection indices in 2007-2008 and 2008-2009 for the models showing variation in habitat and individuals were nearly identical across all 7 habitat categories (Tables 5, 6). Tidal flat (index values: 0.55, 0.50, respectively) and low marsh (index values: 0.31, 0.37, respectively) were the only habitats in which the probability of use was greater than the probability of use assuming equal availability (i.e., index value: 0.14). Selection indices for high marsh and agricultural habitats were all less than 0.04, indicating the probability of habitat use was much lower than if use was random.

Selection indices, for individuals with $\geq$ 10 locations, did not differ between 2007-2008 and 2008-2009. Accordingly, we pooled values from each year for subsequent analyses. Paired t-tests (with bonferroni adjustment, P=0.05/21= 0.0024) comparing mean differences among habitat selection indices indicated habitat use of tidal flat (mean = 0.55, 95%CI: 0.51 to 0.59) was significantly preferred over low marsh (mean = 0.32, 95% CI: 0.29 to 0.35; P<0.001), which was significantly preferred over all other habitats (P<0.001). Selection indices for high marsh (mean = 0.03, 95% CI: 0.02 to 0.04), bare soil (mean = 0.03, 95% CI: 0.02 to 0.04), cover crop (mean = 0.03, 95% CI: 0.02 to 0.05), and crop residue (mean = 0.03, 95% CI: 0.02 to 0.04) did not differ, indicating a lack of preference by Dunlin among these habitats; all habitat types were used significantly more than the other habitat (mean = 0.01, 95% CI: 0.01 to 0.02) category.

We did not find significant differences in selection indices between males and females (A = -0.00063473, $P = 0.42$), but differences among age groups were significant (A = 0.00788316, $P = 0.008$). One-way ANOVA, after Bonferroni adjustment, indicated that the only difference between adults and juveniles was in the selection of tidal flats, where adults used tidal flats more often than juveniles ($F = 8.78$, d.f. = 1, 97, $P = 0.004$). The relatively low p-value associated with crop residue ($P = 0.04$) suggested that juveniles used crop residue more often than adults, but the result was not significant following Bonferroni adjustment (Table 7).

Habitat selection indices differed significantly between low (<2.4 m) and high tides ($\geq$ 2.4 ft; T = -22.43, A = 0.1424, $P < 0.0001$). We found that selection indices for crop residue and low marsh were significantly higher during high tide ($F = 10.56$; df = 1, 98; $P = 0.0016$ and $F = 41.73$; $p < 0.0001$ respectively), and that selection for all tidal flat and low marsh habitats was greater during low tide ($F = 42.38$, $P < 0.0001$) (Table 8).

Habitat selection indices also differed significantly and between night and day (T = -20.95, A = 0.1265, $P < 0.0001$). Selection indices for bare soil, crop residue, and winter cover crops were significantly higher at night and selection indices for tidal flats and low marsh were significantly higher during the day (Table 9).

Task 3: Determine the proportion of Dunlin diet from estuarine and terrestrial sources

We obtained blood from 39 individuals in 2006-2007 and 79 individuals in 2007-2008. Fifty-six blood samples were obtained from adults and 62 were obtained from juveniles. Blood samples were evenly distributed among males (N = 49) and females (N = 42); twenty-seven samples were from individuals of unknown sex.

The distribution of Dunlin locations, derived from radio-tracking, allowed us to narrow the inclusion of sampling points in the terrestrial environment for consideration in our model. We omitted sampling points PSB01, 02, 15, 16, Fir02, 03, 08, and LaConner01 and 03 since these were apparently not used. In the estuary, we averaged prey values across the four transects, essentially defining the marsh/marine region to -16.4±2.1‰ for $\delta^{13}C$ (range -20.6 to -11.3‰, n=45) and 9.8±1.0‰ (range 7.7 to 14.6‰) for $\delta^{15}N$. We identified two isotopically distinct terrestrial endpoints. High ^{15}N agriculture was defined as -22.7±0.8‰ for $\delta^{13}C$ (range -23.6 to -22.1‰, n=3) and 13.8±2.4‰ (range 11.1 to 15.7‰) for $\delta^{15}N$. Low ^{15}N agriculture was defined as -24.8±1.9‰ for $\delta^{13}C$ (range -27.2 to -21.3‰, n=26) and 7.0±2.2

(range 2.2 to 10.3‰) for $\delta^{15}N$. This pattern with regions of both high and low $\delta^{15}N$ values for terrestrial prey indicates different land-use practices, namely the application of fertilizer.

We used a two-isotope 3-source mixing model, with assumed error in isotopic discrimination factors of ± 0.2‰, to estimate relative inputs of these sources to dunlin. Using MixSIR , the model estimated a 19.8% input of high ^{15}N agriculture (95% CI: 17.5 to 22.0%), a 14% input of low ^{15}N agriculture (9.7 to 44.3%), and a 66.2% (63.7 to 69%) input of marsh/marine-derived nutrients. This corresponded to 33.8% dietary input from agricultural lands and 66.2% input from the estuary.

IV. Discussion and Management Implications

In the Skagit and Stillaguamish River deltas, habitat use by Dunlin was non-random, and Dunlin exhibited a strong preference for two intertidal estuarine habitats, tidal flat and low marsh, over all other habitats measured in this study. Estuarine habitats, primarily tidal flat and low marsh, also comprised a major proportion of individual home ranges. Home range size did not differ among age and sex classes, but adults used tidal flats significantly more than juveniles. Although agricultural habitats, the dominant feature on the terrestrial side of the estuary, were much less preferred than estuarine habitats, they made up nearly 40% of an individuals' home range, and, equally important, Dunlin apparently received 33.8% of their diet from the terrestrial environment. The importance of agricultural habitats to Dunlin was further illustrated by their increased use when tide heights were high and at night.

Tidal flat and low marsh habitat selection indices were ranked first and second, respectively, compared to other habitats. Selection indices were nearly identical in 2007-2008 and 2008-2009, years in which data were sufficient for rigorous analysis, showing the consistency in which the habitats were selected. Due to their high energy needs, shorebird habitat use is driven primarily by the rate at which they can forage (Goss-Custard 1984). We suspect that foraging efficiency was likely highest for dunlin in estuarine habitats in both the Skagit and Stillaguamish River deltas, as tidal flats in nearby regions have been shown to support high densities of shorebird prey (Baldwin and Lovvorn 1994, Shepherd 2001). We observed the highest concentrations of foraging dunlin in tidal flat habitats characterized by finer sediments, such as south Skagit Bay, an area downstream of the largest remaining area of estuarine marsh in the Skagit River delta. Tidal flat and marsh habitats were also the highest ranked habitats selected by Dunlin in the adjacent Fraser River delta (Shepherd and Lank 2004). Open estuarine habitats may allow high foraging efficiency because they are relatively "safe", as aerial predators (e.g., falcons) are detected more easily due to the lack of cover and distance from shore (Pomeroy 2006).

Marsh habitat followed tidal flat in importance to Dunlin, but habitat selection was primarily restricted to low marsh habitats. Dunlin were regularly observed foraging in low marsh substrates in areas where vegetation had died back or in areas where both vegetation cover and height was low and bare patches of mud were present. Some of the heavily used marsh habitats appeared to contain sediments with a greater proportion of organic matter and finer-grained particles than areas of tidal flats that were apparently avoided. For example, Dunlin were regularly observed foraging in marsh habitats along the bayfront of Fir Island, but rarely ventured beyond the marsh edge where tidal flat substrates were dominated by sand.

In addition to providing foraging opportunities for Dunlin, marsh habitats also served as roost sites for Dunlin. The use of low marsh habitat increased substantially during high tide periods and we attribute this pattern to Dunlin roosting behavior. We observed two general roost behaviors that varied with respect to tide and time of day. Dunlin were regularly observed congregating on pieces of large woody debris in marsh habitats during high tide events during the day. Roost sites were above the marsh area and likely were selected to provide an open horizon in which to detect diurnal predators. We also observed Dunlin using marsh habitats as roost sites at night during low tides. In these situations, Dunlin were flushed from dense patches of marsh vegetation during tracking runs and trapping periods. Dunlin appeared to be evenly dispersed within areas of the marsh and typically were found alone or with one or two other birds. We suspect that Dunlin choose dense vegetation patches in marsh habitats at night as a mean to avoid aerial predators, such as short-eared owls (*Asio flammeus*), which are relatively common during the winter.

The importance of marsh habitats to Dunlin in the estuarine environment likely extends beyond simply providing habitat for foraging or roosting. Marsh habitats are a primary driver of food webs in the estuarine environment, contributing large amounts of detritus as vegetation dies back annually. Tidal flats are the recipients of this influx of productivity, and the quality of tidal flat habitats to species like Dunlin and other shorebirds may be driven, in part, by the amount of intact marsh habitat. If so, estuaries with large areas of intact marsh should have higher quality tidal flats that support greater numbers of individuals. In the Skagit and Stillaguamish River deltas, the area of tidal flats has remained stable while marsh habitats have been severely reduced in area due to diking and drainage for human development. Consequently, we suggest that marsh restoration activities will contribute significantly to the conservation of Dunlin and other shorebird species both directly, by providing foraging and roosting habitat, and indirectly, by increasing habitat quality of adjacent tidal flat habitats.

Many studies have noted the noted the importance of agricultural habitats to Dunlin as high-tide foraging and refugia habitats in coastal habitats, particularly at night (Colwell and Dodd 1997, Shepherd 2001, Evans Ogden 2002, Conklin and Colwell 2007). Although agricultural habitats were much less preferred than tidal flat and low marsh habitats, several lines of evidence point to the importance of agricultural habitats to Dunlin in the Skagit and Stillaguamish River deltas. First, the proportion of Dunlin locations in agricultural habitats was > 23% in each year of the study, and all individuals had home ranges that included some agricultural habitats. Second, the use of agricultural habitats increased significantly at night. Increased use of agricultural habitats at night may be a function of lower predation risk from diurnal predators, such as falcons that are present during the winter. In general, most agricultural use by Dunlin was close to the estuary and few locations were found > 6 km from the shoreline. Finally, stable isotope ($\delta^{13}C$, $\delta^{15}N$) measurements of whole Dunlin blood and their prey revealed that while dunlin used primarily estuarine habitats, they also depended to a large degree on adjacent agricultural lands. These findings are similar to those found for dunlin wintering on the Fraser River Estuary, Canada, and are consistent with several studies of shorebirds using estuaries in Europe (reviewed in Evans-Ogden et al. 2005).

The precise habitat features that Dunlin prefer in agricultural habitats remains unclear. Dunlin used bare soil, winter cover crop, and crop residue habitats in similar proportion; use of pasture, other agriculture and woody agriculture was extremely rare. The use of multiple agricultural habitats in similar proportions may reflect the flexibility of Dunlin habitat use or may reflect the similarity in habitat structure between these three habitat types. Each of the habitat types is similar in that they generally have a low percentage of vegetation cover at short heights early in the winter. However, both cover and vegetation height increase during the latter part of the winter. In general, habitat use of agricultural lands was similar to that found in other studies except that pasture was found to be the most preferred agricultural habitat (Colwell and Dodd 1997, Shepherd and Lank 2004, Conklin and Colwell 2007). The lack of pasture use in this study may reflect low availability of this habitat type, as few dairy farms remain in the region.

Perhaps the most apparent feature of agricultural fields associated with use by wintering Dunlin is the presence of saturated soils. In general, observations of Dunlin using agricultural habitats were infrequent until winter precipitation resulted in saturated soils and patches of standing water on fields. Different agricultural crops and various physical conditions may contain features that offer different trade-offs between energy intake and expenditure and predation risk for Dunlin (Shepherd and Lank

2004). Consequently, a mix of agricultural field types may provide the greatest benefit to Dunlin and other wintering shorebird species, offering them multiple habitat types from which to choose.

We found no sex or age specific differences with respect to home range sizes, but adult and juvenile dunlin differed in their habitat selection. Selection indices for tidal flat habitats were significantly higher for adults than juveniles. Juveniles selected other marsh and agricultural habitats in greater proportions than adults, with crop residue, high marsh, and bare soil habitats approaching significance. Increased selection of tidal flats by adults may reflect behavioral or morphological differences that provide a competitive advantage to adults over juveniles for the preferred tidal flat habitats (Goss-Custard et al. 1982, Goss-Custard and Le V.dit Durell 1983). Juveniles may also be less efficient feeding in tidal flats, limiting their ability to obtain sufficient nutrients from tidal flats during the periods they are available (Marchetti and Price 1989).

We believe differences in home range size between the first year of the study and the following two years was likely due to how Dunlin location data were collected. During the first year of the study, most of our ground-based tracking was restricted to the Skagit River delta, and aerial surveys were used on only five occasions, all at low tides. Aerial surveys allowed us to reach areas inaccessible with ground-based surveys in both terrestrial and estuarine habitats. Due to their increased efficiency and coverage, we increased aerial surveys in subsequent years. The increase in our search area resulted in detecting bird movements over a larger area which likely translated to greater home range sizes. In the second and third years of the study, Dunlin home range estimates were similar to those found in the Fraser River delta (Shepherd and Lank 2004).

We found no evidence that radio-tagged Dunlin used any of the three agricultural fields participating in a research study where fields are flooded to attract shorebirds (Slater and Lloyd 2010). The lack of use corresponds with low numbers of Dunlin detected during avian surveys conducted at these fields during the winter. We attribute the low use of flooded fields by Dunlin to the generally high availability of other agricultural fields with saturated soils. During the winter, precipitation is generally high in the Pacific Northwest and farming activity is negligible, resulting in an abundance of fields with saturated soil or standing water that are likely attractive to dunlin. Farming for Wildlife fields may also have been less attractive to Dunlin due to their distance from the estuary; fields were > 3 km to tidal flats. However, during winters of low precipitation, flooded fields may be important to Dunlin as high-tide refugia. Although there is no way to predict winter field conditions, the presence of flooded fields may serve as a safeguard for those years when precipitation is low. Dunlin may also prefer larger fields with greater areas of open space, which likely translates to lower predation risk from aerial predators (Shepherd and Lank 2004).

Overall, this study reinforces the importance of both marsh and agriculture habitats, and suggests that different strategies may need to be encouraged for each region. Restoration of estuarine habitats will likely provide the greatest benefit to Dunlin by creating new habitat and by increasing the quality of existing habitats. However, under the current landscape, agricultural habitats remain important as alternative foraging and refugia sites, particularly those fields that are adjacent to the estuary. Results from this study suggest that saturated agricultural fields with bare ground or low levels of vegetation cover are important habitat features for wintering Dunlin, but additional research to identify the specific characteristics that dunlin favor are needed to refine conservation strategies on agricultural land.

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VII. Publications

We anticipate completing two journal articles in the upcoming months.

1 Where estuaries meet agriculture: evaluating habitat selection by Dunlin in northern Puget Sound using discrete choice models. Authors: Gary Slater, Ruth Milner, Rena Borkhateria. To be submitted: Journal of Wildlife Management. Expected submittal: August 2011.

2) Tracking winter habitat use of Dunlin (*Calidris alpina*) at an agro-estuarine complex: Deciphering feeding sources using stable isotope ($\delta^{13}C$, $\delta^{15}N$) measurements. Authors: Keith A. Hobson, Gary Slater, David B. Lank, R.L. Milner and R. Gardiner (order to be determined). Expected submittal: Nov. 2011.

We are also considering two additional manuscripts using data from this project. The first is evaluating individual variation in Dunlin diet using carbon, nitrogen, and sulfur isotopes. Authors would include: Keith A. Hobson, Gary Slater, David B. Lank, R.L. Milner and R. Gardiner. We are currently trying to find funding for additional analyses of blood and to pay a Master's student, Rachel Gardiner, to complete this work. The second manuscript under consideration would describe a habitat model predicting the occurrence of Dunlin intertidal habitat on tidal based on spatially-explicit (mappable) parameters of the environment, including sediment properties (e.g. grain size, organic content), tidal elevation, and proximity to ecologically important coastal features (e.g. tall vegetation harboring potential predators).

Tables

Table 1. Number of Dunlin radio-tagged by age and sex classes at trapping locations in Skagit and Stillaguamish River deltas. Trapping locations shown in Figure 1.

			Adult			Juvenile			Unknown
Location	Habitat	Total	Female	Male	Unknown	Female	Male	Unknown	Male
2006-2007									
Goose Reserve	Ag	17	7	2	0	5	2	1	0
Goose Reserve	Marsh	1	0	0	0	0	0	1	0
King's Marsh	Marsh	11	1	7	0	0	3	0	0
2007-2008									
Goose Reserve	Ag	11	4	5	0	1	1	0	0
Jensen Access	Marsh	26	2	4	0	9	10	0	1
Big Ditch Access	Marsh	21	2	1	1	7	7	3	0
West Pass	Marsh	7	5	0	0	2	0	0	0
Port Susan Bay	Marsh	4	0	0	1	0	3	0	0
2008-09									
Goose Reserve	Ag	9	2	4	0	0	2	1	0
Jensen Access	Marsh	24	5	4	1	4	8	2	0
Big Ditch Access	Marsh	10	1	3	0	5	1	0	0
West Pass	Marsh	15	5	3	0	2	5	0	0
Port Susan Bay	Marsh	12	2	4	0	2	4	0	0
TOTAL		168	34	37	3	37	46	8	1

Table 2. Summary of tracking runs conducted in the Skagit River and Stillaguamish River deltas during the winters of 2006-2007, 2007-2008, and 2008-2009.

		Day		Night	
Tracking Run	Total	Low tide	High tide	Low tide	High tide
2006-2007					
Skagit River delta	61	15	22	11	13
Stillaguamish River delta	8	4	2	2	0
Aerial	5	5	0	0	0
2007-2008					
Skagit River delta	41	10	13	8	10
Stillaguamish River delta	34	14	11	6	3
Aerial	26	7	8	7	4
2008-09					
Skagit River delta	36	12	10	9	5
Stillaguamish River delta	27	9	9	6	6
Aerial	25	7	7	5	6

Table 3. Mean percentage of habitat within dunlin home range and mean percentage of dunlin radio locations found in each habitat in the Skagit and Stillaguamish River deltas.

Habitat	2007		2008		2009	
	Home Range	% of locations	Home Range	% of locations	Home Range	% of locations
	N = 7	N = 262	N = 38	N = 1132	N = 46	N = 1105
Estuarine Habitats						
Tidal Flat	0.34	0.29	0.44	0.35	0.38	0.33
Low Marsh	0.18	0.31	0.14	0.35	0.13	0.29
High Marsh	0.02	0.00	0.05	0.5	0.05	0.05
Agricultural Habitats						
Cover Crop	0.22	0.12	0.13	0.12	0.17	0.15
Bare Soil	0.17	0.24	0.12	0.08	0.07	0.07
Crop Residue	0.02	0.02	0.05	0.03	0.06	0.08
Pasture	0.02	0.02	0.02	0.01	0.03	0.02
Other Agriculture	0.01	0.01	0.01	0.01	0.06	0.02
Woody Agriculture	0.01	<0.01	<0.01	<0.01	0.01	<0.01
Other						
River	<0.01	0.01	0.01	0.01	0.02	0.02
Urban and Forest	0.02	0.00	0.04	0.00	0.05	0.00

Table 4. Selection indices for habitat categories under used by Dunlin in the Skagit and Stillaguamish river deltas in 2006-2007. Note: Analysis and table were modeled after (Arthur et al. 1996).

	Habitat categories							
Model	Tidal Flat	Low Marsh	Bare Soil	Winter Cover Crop	Other Habitat	Deviance	Df	*P*
Null	0.20	0.20	0.20	0.20	0.20	858.40	0	
Pooled	0.61	0.32	0.04	0.02	0.01	588.71	4	
Individual	0.35	0.35	0.25	0.05	0.01	432.14	116	
Difference, null model vs. selection, pooled model						269.69	4	<0.001
Difference, selection, (pooled) vs. selection (individuals)						156.57	112	<0.01

Table 5. Selection indices for habitat categories used by Dunlin in the Skagit and Stillaguamish river deltas in 2007-2008.

	Habitat categories									
Model	Tidal Flat	Low Marsh	High Marsh	Bare Soil	Crop Residue	Cover Crop	Other Habitat	Deviance	Df	*P*
Null	0.14	0.14	0.14	0.14	0.14	0.14	0.14	4961.1	0	
Pooled	0.58	0.31	0.04	0.02	0.02	0.02	0.01	3054.4	6	
Individual	0.55	0.31	0.04	0.04	0.02	0.04	0.01	2457.5	336	
Difference, null model vs. selection, pooled model								1906.7	6	<0.001
Difference, selection, (pooled) vs. selection (individuals)								597.0	330	<0.001

Table 6. Selection indices under for habitat types used by Dunlin in the Skagit and Stillaguamish river deltas in 2007-2008.

	Habitat categories									
Model	Tidal Flat	Low Marsh	High Marsh	Bare Soil	Crop Residue	Cover Crop	Other Habitat	Deviance	Df	*P*
Null	0.14	0.14	0.14	0.14	0.14	0.14	0.14	5465.6	0	
Pooled	0.57	0.32	0.03	0.02	0.04	0.02	0.01	3533.1	6	
Individual	0.50	0.37	0.03	0.02	0.04	0.02	0.01	3006.1	414	
Difference, null model vs. selection, pooled model								1932.5	6	<0.001
Difference, selection, (pooled) vs. selection (individuals)								526.9	408	<0.001

Table 7. Mean habitat selection indices and ANOVA results for the comparison of adults vs. juveniles. Significance is based on the Bonferroni corrected *P*-value where *P* = 0.05/7 (significant if *P*-value < 0.0071).

Habitat Category	Adult (*N* =47)		Juveniles (*N* =52)		F	*P*	Significance
	Mean	SE	Mean	SE			
Tidal Flat	0.61	0.03	0.49	0.03	8.78	0.004	*****
Low Marsh	0.30	0.02	0.34	0.02	1.84	0.18	
High Marsh	0.02	0.005	0.04	0.008	3.26	0.07	
Bare Soil	0.02	0.005	0.04	0.011	3.07	0.08	
Winter Cover	0.02	0.005	0.04	0.012	1.90	0.17	
Crop Residue	0.02	0.004	0.04	0.006	4.29	0.04	
Other	0.01	0.002	0.01	0.004	0.56	0.46	

Table 8. Mean habitat selection indices and ANOVA results for the comparison of high vs. low tide. Significance is based on the Bonferroni corrected *P*-value where *P* = 0.05/7 (significant if *P*-value < 0.0071).

Habitat Category	High Tide (*N* = 66)		Low Tide (*N* = 34)		F	*P*	Significance
	Mean	SE	Mean	SE			
Tidal Flat	0.37	0.031	0.69	0.034	42.38	<.0001	*****
Low Marsh	0.47	0.027	0.21	0.025	41.73	<.0001	*****
High Marsh	0.04	0.007	0.03	0.010	0.61	0.437	
Bare Soil	0.04	0.009	0.03	0.017	0.15	0.697	
Winter Cover	0.04	0.008	0.02	0.008	1.25	0.266	
Crop Residue	0.04	0.006	0.01	0.005	10.56	0.002	*****
Other	0.01	0.002	0.01	0.005	0.18	0.671	

Table 9. Mean habitat selection indices and ANOVA results for the comparison of day vs. night. Significance is based on the Bonferroni corrected *P*-value where $P = 0.05/7$ (significant if *P*-value < 0.0071).

Habitat Category	Day (*N* =75)		Night (*N* = 17)		F	*P*	Significance
	Mean	SE	Mean	SE			
Tidal Flat	0.66	0.020	0.30	0.056	51.81	<.0001	*****
Low Marsh	0.28	0.015	0.3765	0.0629	5.02	0.028	
High Marsh	0.01	0.004	0.03	0.013	3.74	0.056	
Bare Soil	0.01	0.006	0.09	0.030	16.76	<.0001	*****
Winter Cover	0.01	0.004	0.10	0.021	44.50	<.0001	*****
Crop Residue	0.02	0.003	0.08	0.030	16.97	<.0001	*****
Other	0.00	0.001	0.02	0.015	5.81	0.018	*****

Figures

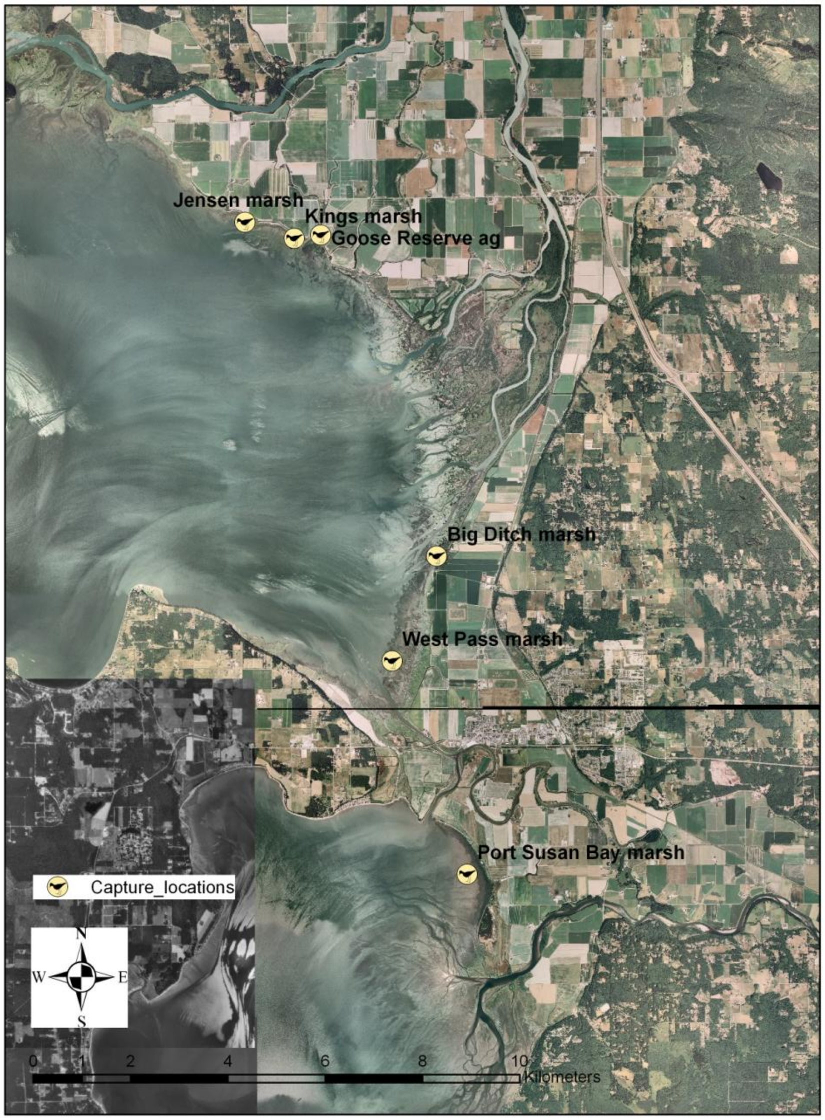


Figure 1. Map of the Skagit and Stillaguamish River deltas, noting locations where Dunlin were trapped including during the winters of 2006-2007, 2007-2008, and 2008-2009.

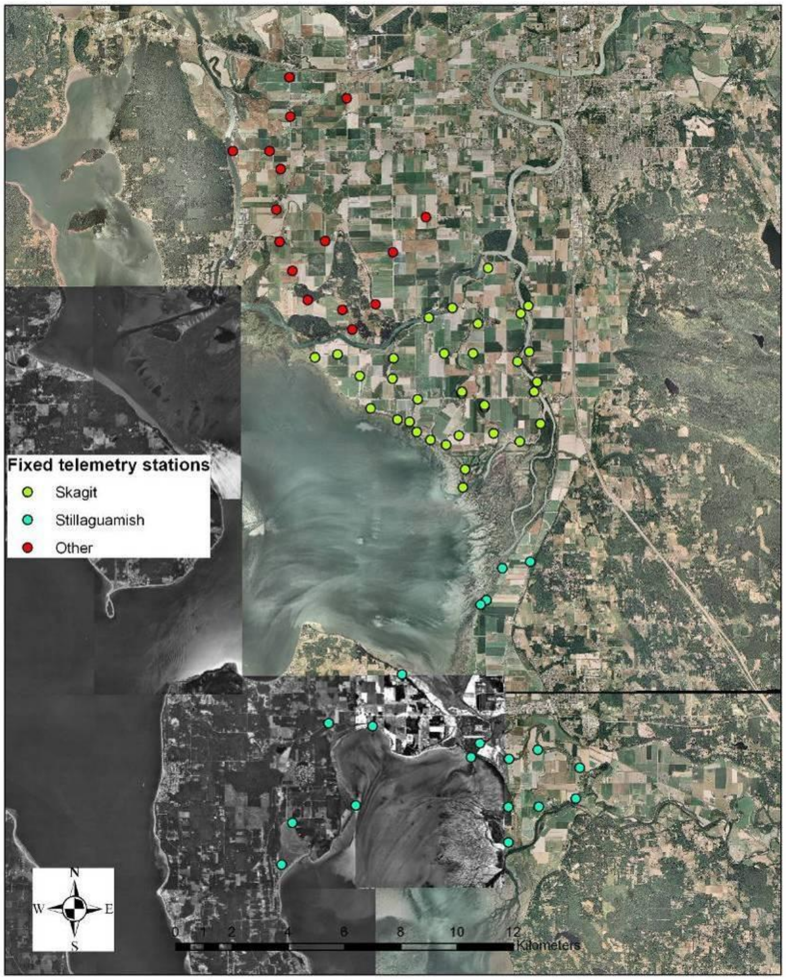


Figure 2. Map of fixed tracking stations in the Skagit and Stillaguamish River delta.

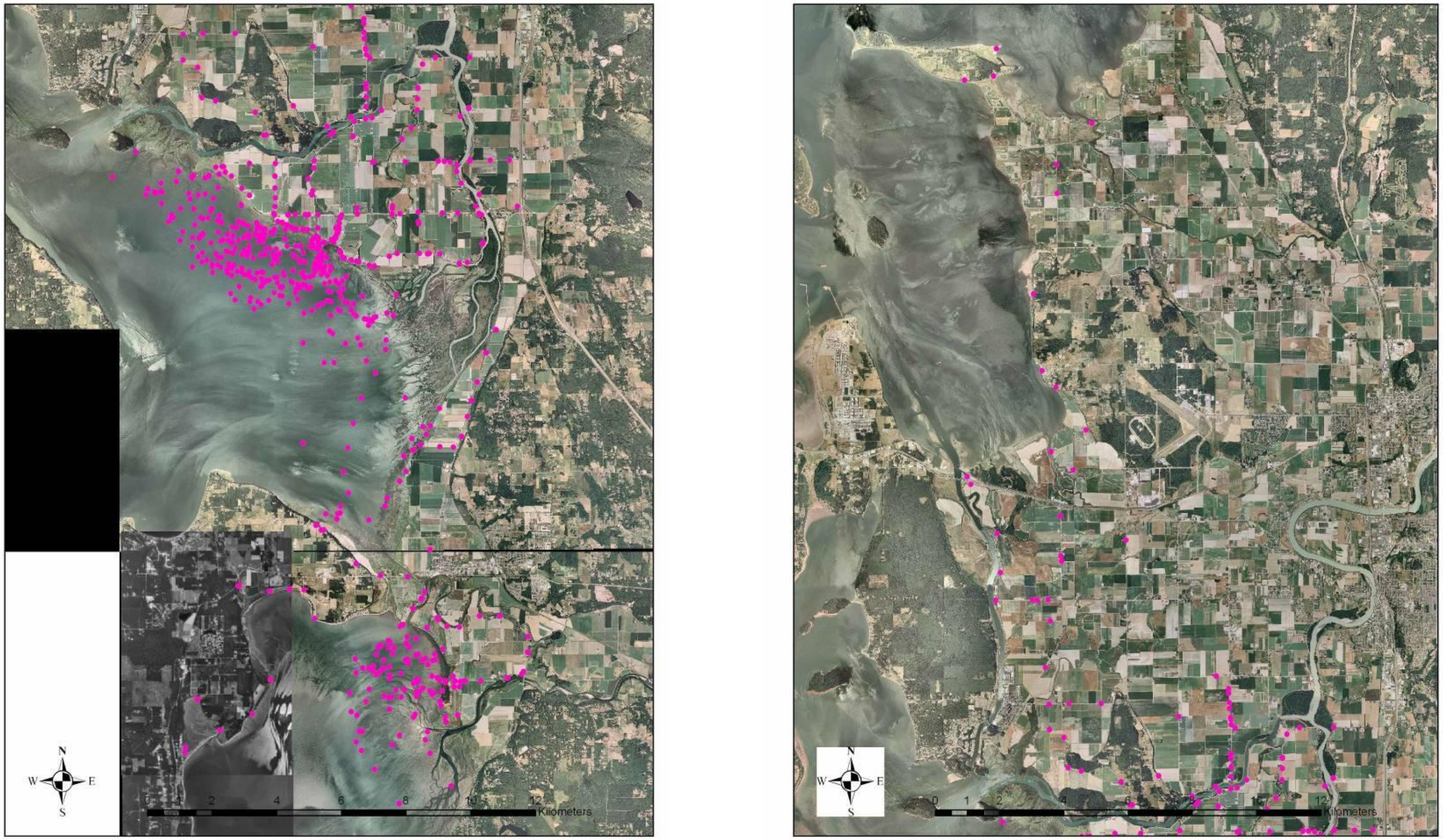
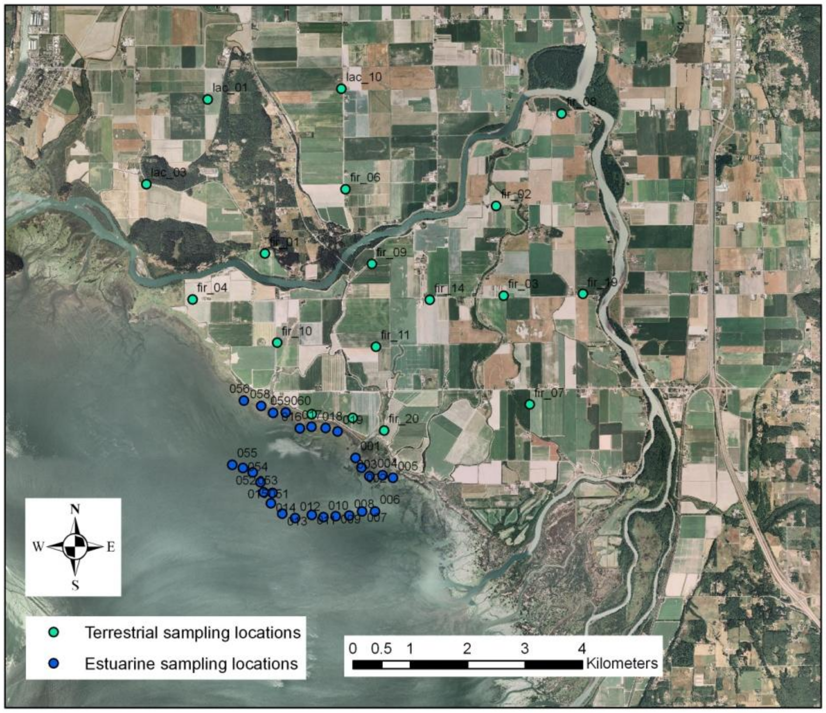


Figure 3. Map of all tracking stations used in the study. Primary tracking location in the Skagit and Stillaguamish River deltas are on the left figure, and rarely used tracking locations in Padilla Bay and Samish Bay are on the left.



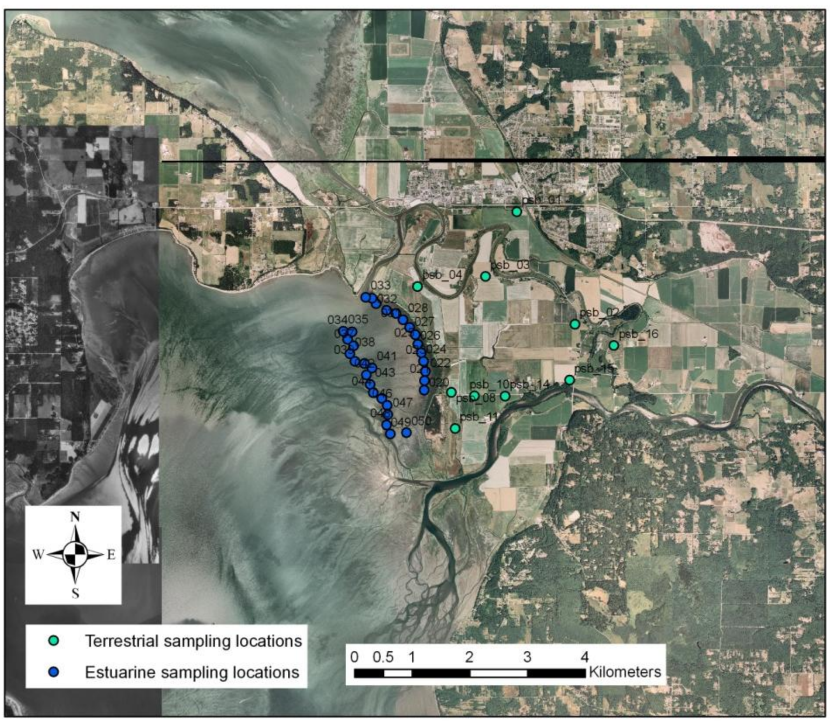


Figure 4. Sampling locations for invertebrate endpoint in agricultural and estuarine regions of the Skagit River delta (upper) and Stillaguamish River delta (lower).

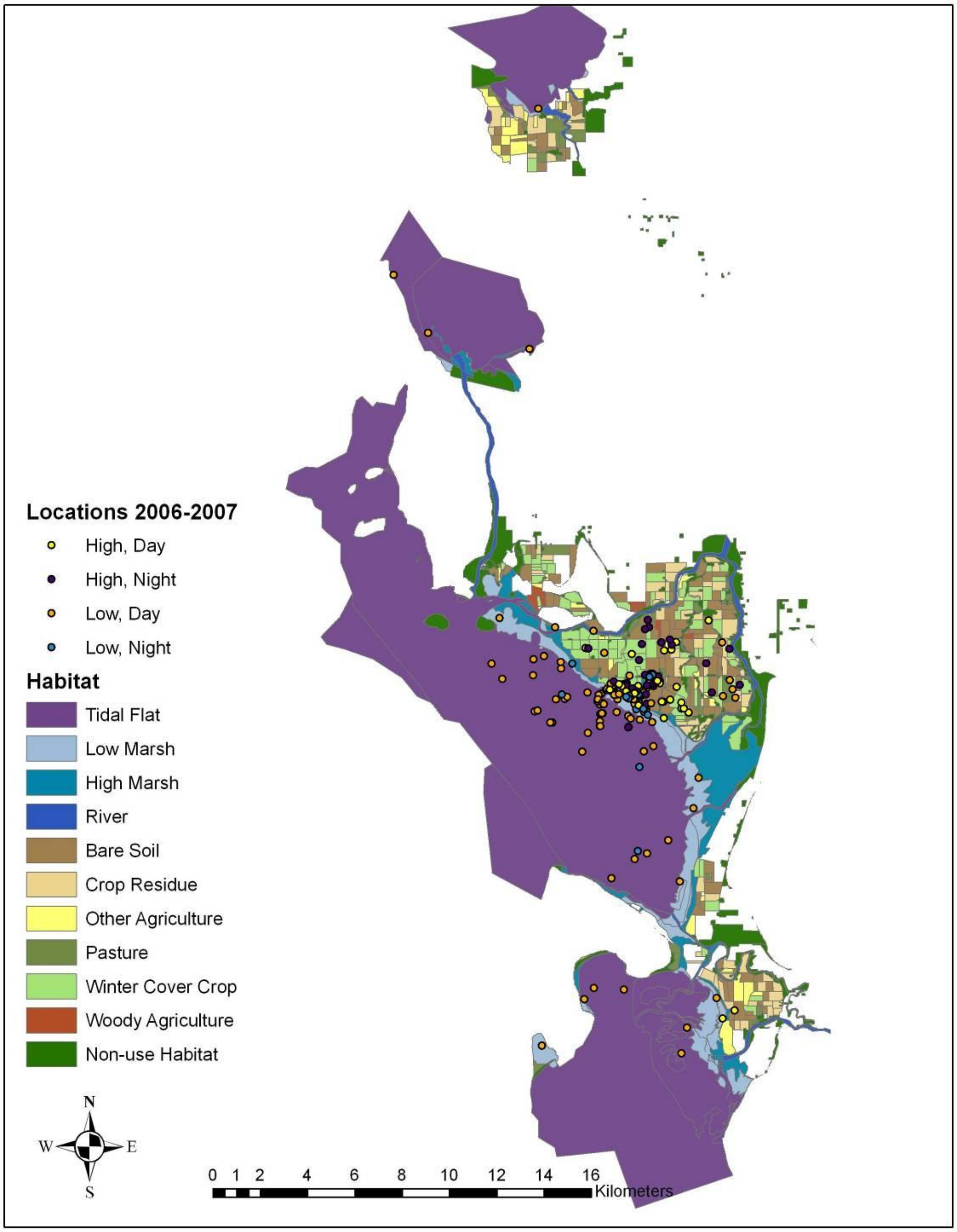


Figure 5. Dunlin locations collected from ground-based and aerial tracking events during the winter of 2006-2007 in the Skagit and Stillaguamish River delta, WA.

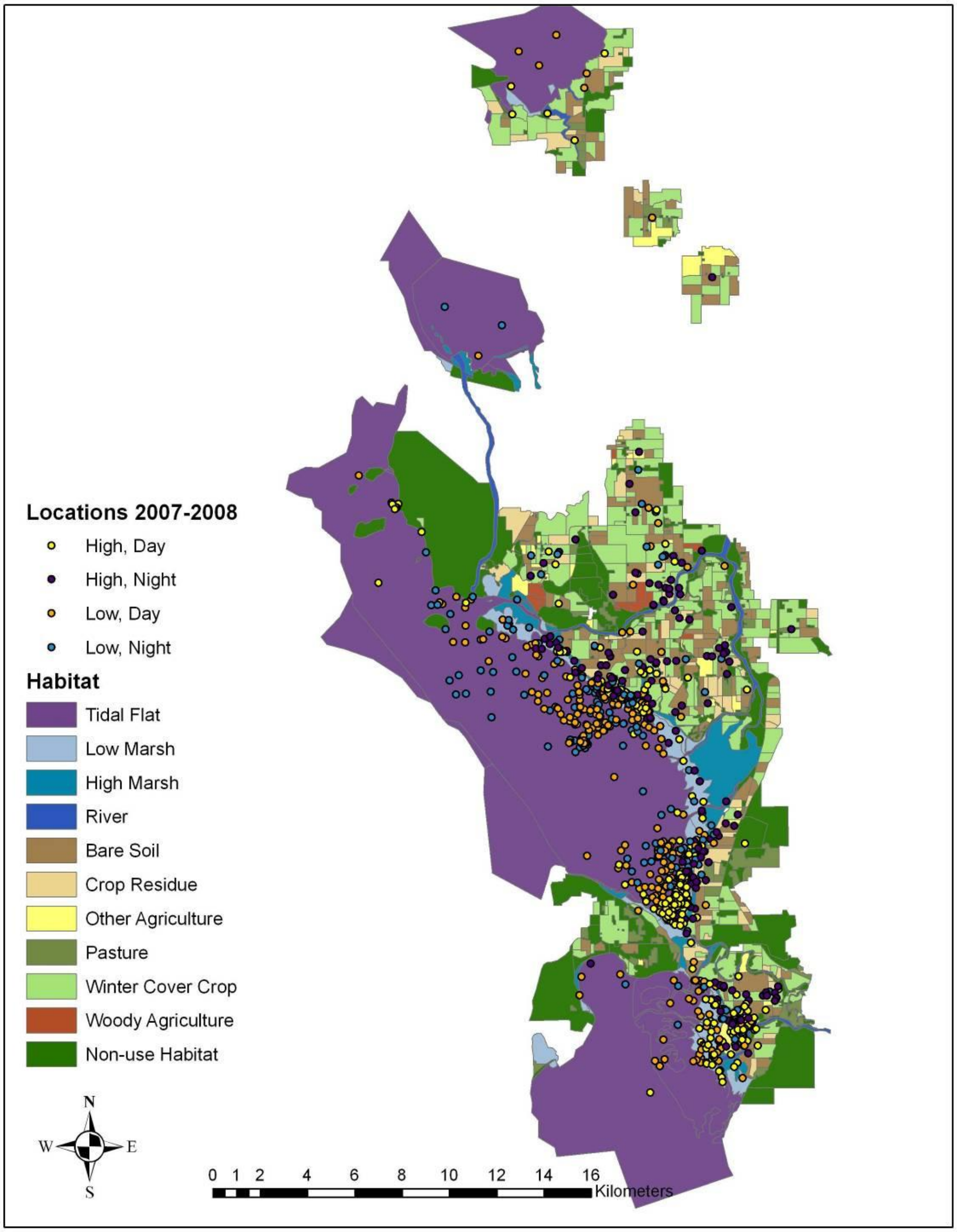


Figure 6. Dunlin locations collected from ground-based and aerial tracking events during the winter of 2007-2008 in the Skagit and Stillaguamish River delta, WA.

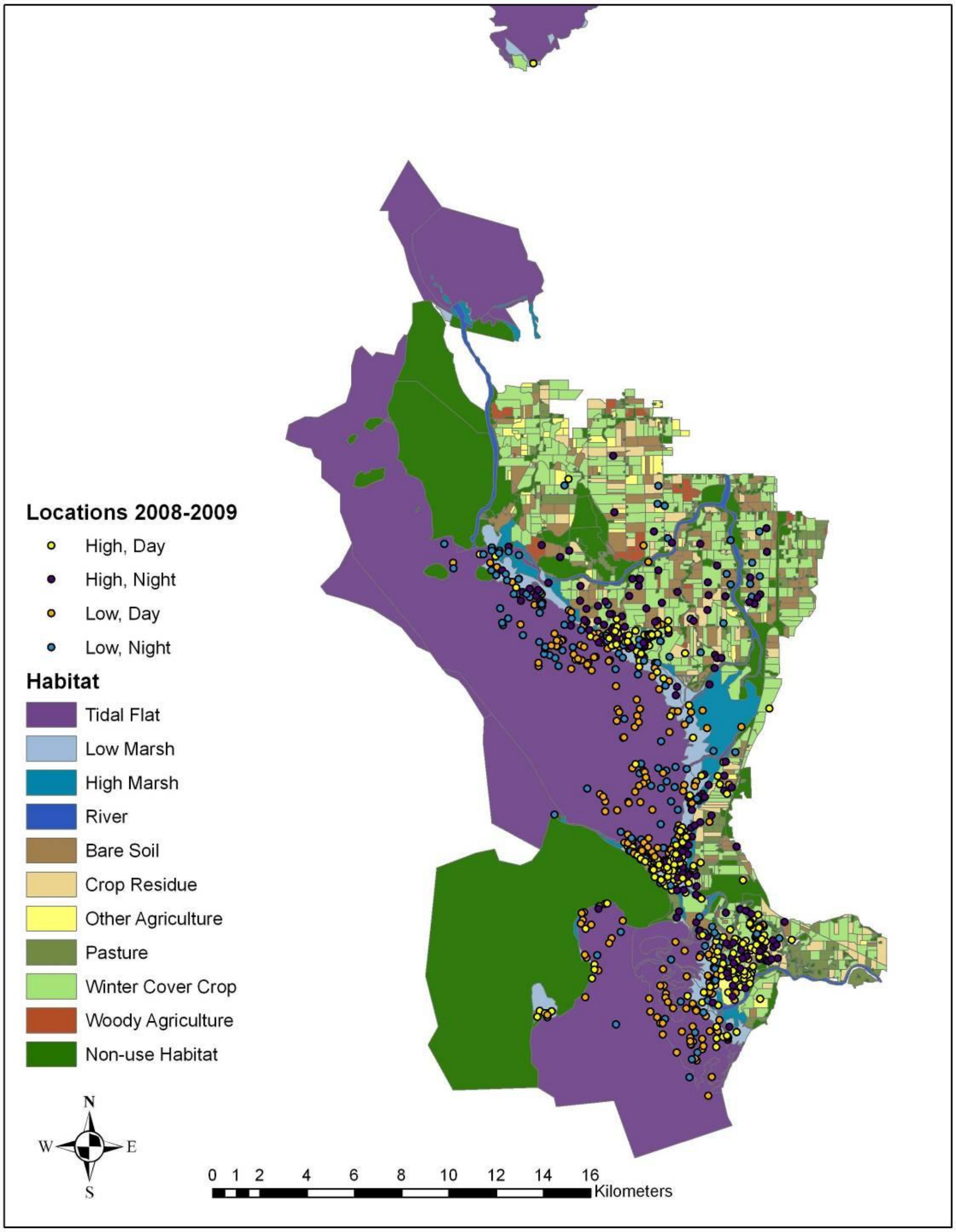
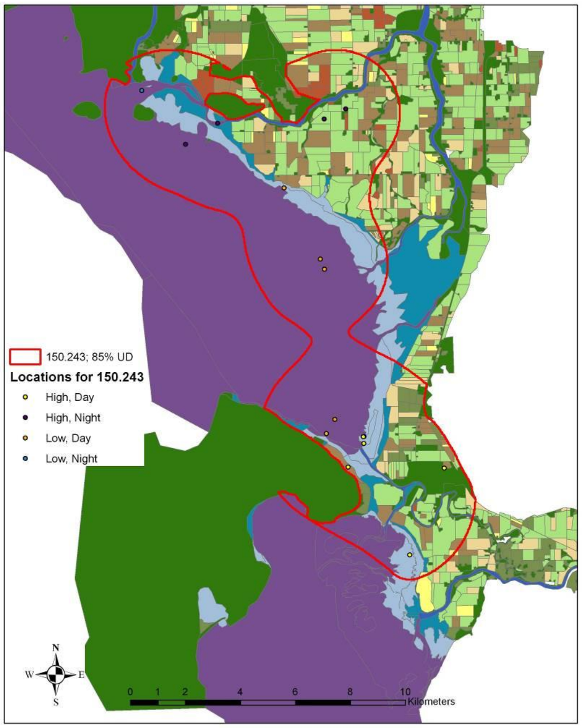


Figure 7. Dunlin locations collected from ground-based and aerial tracking events during the winter of 2008-2009 in the Skagit and Stillaguamish River delta, WA.



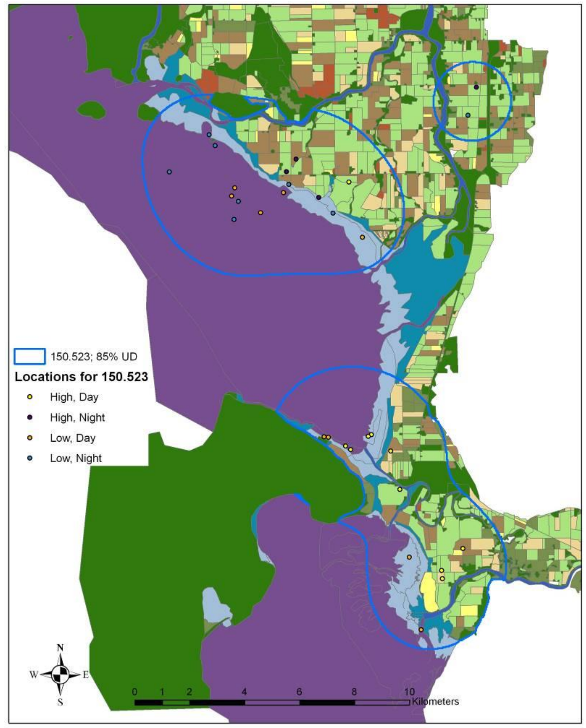


Figure 8. Dunlin locations and home range estimates (85% UD) for individuals radio-tagged 150.243 (left) and 150.523 (right).

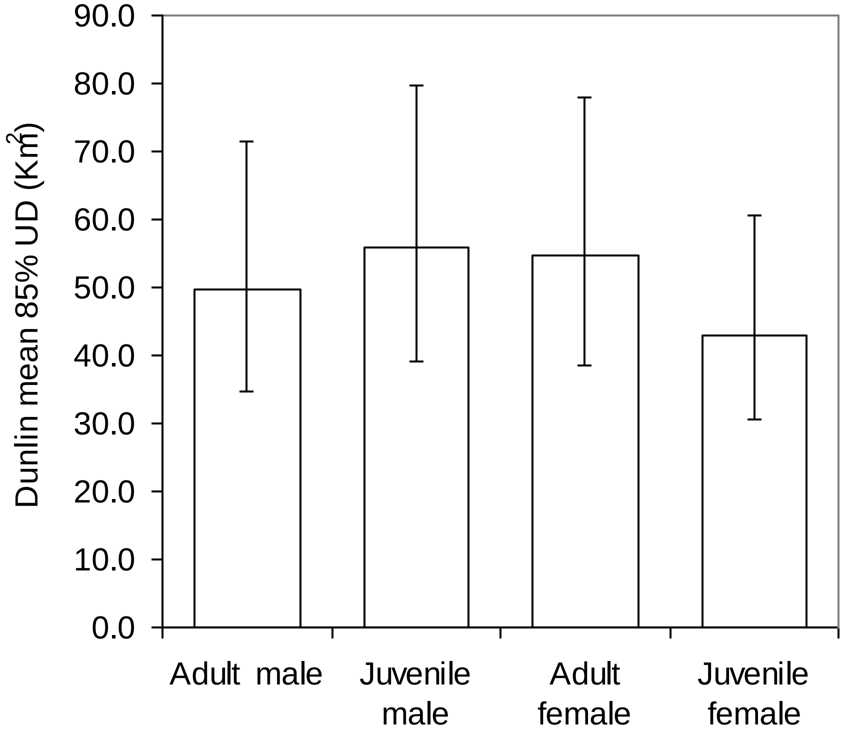


Figure 9. Dunlin mean 85% UD (Km2; 95% CI) by age and sex for individuals captured in winter 2007-2008 and winter 2008-2009; adult male, N = 20, juvenile male, N = 19; adult female, N = 18; juvenile female, N = 20.

Appendix A.

Tables of habitat availability and their proportional change due to tide height variation for pooled 85% UD of Dunlin captured at individual sites.

Table A-1. Proportional change in habitat availability with tide height for birds captured in 2006-2007 at the Goose Reserve Agricultural site.

Habitat	% available by tide height				% change
	-0.6-0.90	0.91-2.3	2.31-2.9	2.91-3.7	
Bare Soil	16.20	43.66	51.42	56.56	40.36
Crop Residue	0.07	0.20	0.23	0.26	0.18
High Marsh	1.49	3.67	4.02	3.18	1.69
Low Marsh	12.37	20.51	11.78	4.52	-7.85
Non-use Habitat	1.10	2.96	3.49	3.83	2.74
Other Agriculture	0.43	1.17	1.38	1.52	1.08
Pasture	0.85	2.30	2.71	2.98	2.12
River	0	0	0	0	0
Tidal Flat	59.73	4.61	0.35	0.07	-59.66
Winter Cover Crop	7.68	20.69	24.37	26.80	19.13
Woody Agriculture	0.08	0.22	0.26	0.29	0.20

Table A-2. Proportional change in habitat availability with tide height for birds captured in 2006-2007 at the Kings Access marsh site.

Habitat	% available by tide height				% change
	-0.6-0.90	0.91-2.3	2.31-2.9	2.91-3.7	
Bare Soil	24.16	34.43	36.33	37.46	13.3
Crop Residue	4.14	5.89	6.22	6.41	2.28
High Marsh	2.09	2.86	2.86	2.05	-0.04
Low Marsh	8.54	7.15	2.94	0.83	-7.71
Non-use Habitat	3.76	5.36	5.66	5.83	2.07
Other Agriculture	1.01	1.44	1.52	1.57	0.56
Pasture	2.79	3.98	4.2	4.33	1.54
River	1.05	1.5	1.58	1.63	0.58
Tidal Flat	26.74	0.75	0	0	-26.74
Winter Cover Crop	24.02	34.23	36.13	37.25	13.23
Woody Agriculture	1.7	2.42	2.55	2.63	0.93

Table A-3. Proportional change in habitat availability with tide height for birds captured in 2007-2008 at the Goose Reserve agricultural site.

Habitat	% available by tide height				% change
	-0.6-0.90	0.91-2.3	2.31-2.9	2.91-3.7	
Bare Soil	12.67	21.44	24.09	26.49	13.82
Crop Residue	5.07	8.58	9.64	10.60	5.53
High Marsh	4.03	6.60	6.90	4.04	0.01
Low Marsh	11.23	13.67	6.49	1.14	-10.09
Non-use Habitat	6.51	11.01	12.37	13.60	7.09
Other Agriculture	1.36	2.30	2.59	2.85	1.48
Pasture	1.65	2.79	3.14	3.45	1.80
River	1.74	2.94	3.31	3.64	1.90
Tidal Flat	39.86	3.80	1.30	1.02	-38.84
Winter Cover Crop	14.59	24.68	27.73	30.49	15.91
Woody Agriculture	1.29	2.18	2.44	2.69	1.40

Table A-4. Proportional change in habitat availability with tide height for birds captured in 2007-2008 at the Jensen Access marsh site.

Habitat	% available by tide height				% change
	-0.6-0.90	0.91-2.3	2.31-2.9	2.91-3.7	
Bare Soil	12.98	18.69	19.98	21.04	8.07
Crop Residue	5.41	7.80	8.34	8.78	3.37
High Marsh	5.23	7.35	7.52	6.00	0.78
Low Marsh	7.64	8.00	3.70	0.78	-6.86
Non-use Habitat	9.58	13.80	14.75	15.54	5.96
Other Agriculture	1.56	2.25	2.41	2.53	0.97
Pasture	1.70	2.44	2.61	2.75	1.06
River	2.05	2.96	3.16	3.33	1.28
Tidal Flat	30.44	3.00	1.48	1.29	-29.15
Winter Cover Crop	22.36	32.20	34.43	36.26	13.90
Woody Agriculture	1.05	1.51	1.61	1.70	0.65

Table A-5. Proportional change in habitat availability with tide height for birds captured in 2007-2008 at the Big Ditch Access marsh site.

Habitat	% available by tide height				% change
	-0.6-0.90	0.91-2.3	2.31-2.9	2.91-3.7	
Bare Soil	10.47	20.16	23.61	27.24	16.77
Crop Residue	4.87	9.37	10.97	12.66	7.79
High Marsh	6.12	11.31	12.56	8.74	2.62
Low Marsh	14.14	18.83	9.13	1.47	-12.67
Non-use Habitat	3.97	7.64	8.95	10.33	6.36
Other Agriculture	0.74	1.43	1.68	1.93	1.19
Pasture	1.83	3.51	4.11	4.75	2.92
River	1.61	3.10	3.63	4.19	2.58
Tidal Flat	45.54	4.03	1.22	0.85	-44.70
Winter Cover Crop	10.71	20.61	24.14	27.85	17.14
Woody Agriculture	0.00	0.00	0.00	0.00	0.00

Table A-6. Proportional change in habitat availability with tide height for birds captured in 2007-2008 at the South Skagit Bay/West Pass marsh site.

Habitat	% available by tide height				% change
	-0.6-0.90	0.91-2.3	2.31-2.9	2.91-3.7	
Bare Soil	13.23	21.93	24.85	27.64	14.40
Crop Residue	3.66	6.06	6.87	7.64	3.98
High Marsh	5.25	8.45	9.08	6.51	1.27
Low Marsh	12.71	15.30	7.84	1.54	-11.17
Non-use Habitat	5.23	8.66	9.81	10.92	5.69
Other Agriculture	0.56	0.92	1.04	1.16	0.61
Pasture	1.31	2.17	2.46	2.73	1.42
River	1.20	1.99	2.26	2.51	1.31
Tidal Flat	38.14	3.50	0.63	0.26	-37.89
Winter Cover Crop	18.14	30.05	34.06	37.87	19.74
Woody Agriculture	0.58	0.97	1.09	1.22	0.63

Table A-7. Proportional change in habitat availability with tide height for birds captured in 2007-2008 at the Port Susan Bay marsh site.

Habitat	% available by tide height				% change
	-0.6-0.90	0.91-2.3	2.31-2.9	2.91-3.7	
Bare Soil	14.74	24.39	29.37	32.79	18.04
Crop Residue	4.79	7.92	9.54	10.65	5.86
High Marsh	0.00	0.00	0.00	0.00	0.00
Low Marsh	19.20	22.79	11.54	1.92	-17.27
Non-use Habitat	4.70	7.78	9.37	10.46	5.75
Other Agriculture	0.49	0.81	0.98	1.09	0.60
Pasture	2.33	3.85	4.63	5.17	2.85
River	2.58	4.26	5.13	5.73	3.15
Tidal Flat	37.27	5.20	1.73	1.26	-36.01
Winter Cover Crop	13.91	23.00	27.70	30.93	17.02
Woody Agriculture	0.00	0.00	0.00	0.00	0.00

Table A-8. Proportional change in habitat availability with tide height for birds captured in 2008-2009 at the Goose Reserve agricultural site.

Habitat	% available by tide height				% change
	-0.6-0.90	0.91-2.3	2.31-2.9	2.91-3.7	
Bare Soil	9.12	13.82	14.95	15.92	6.80
Crop Residue	5.79	8.78	9.50	10.11	4.32
High Marsh	4.77	7.00	7.17	5.24	0.47
Low Marsh	8.39	9.22	4.26	0.77	-7.62
Non-use Habitat	8.19	12.42	13.43	14.30	6.11
Other Agriculture	2.74	4.15	4.49	4.78	2.04
Pasture	3.23	4.90	5.30	5.64	2.41
River	1.45	2.19	2.37	2.52	1.08
Tidal Flat	33.65	3.16	1.35	1.15	-32.50
Winter Cover Crop	21.60	32.73	35.41	37.70	16.10
Woody Agriculture	1.07	1.63	1.76	1.87	0.80

Table A-9. Proportional change in habitat availability with tide height for birds captured in 2008-2009 at Jensen Access marsh site.

Habitat	% available by tide height				% change
	-0.6-0.90	0.91-2.3	2.31-2.9	2.91-3.7	
Bare Soil	10.25	16.28	17.85	19.26	9.01
Crop Residue	5.91	9.38	10.29	11.11	5.20
High Marsh	7.24	11.22	11.73	9.54	2.30
Low Marsh	9.38	10.82	5.14	1.11	-8.28
Non-use Habitat	0.00	0.00	0.00	0.00	0.00
Other Agriculture	1.61	2.56	2.81	3.03	1.42
Pasture	3.07	4.88	5.35	5.78	2.70
River	2.22	3.52	3.86	4.16	1.95
Tidal Flat	36.53	3.55	1.52	1.29	-35.24
Winter Cover Crop	22.39	35.57	39.01	42.09	19.70
Woody Agriculture	1.40	2.22	2.44	2.63	1.23

Table A-10. Proportional change in habitat availability with tide height for birds captured in 2008-2009 at Big Ditch Access marsh site.

Habitat	% available by tide height				% change
	-0.6-0.90	0.91-2.3	2.31-2.9	2.91-3.7	
Bare Soil	5.44	8.92	9.95	10.89	5.45
Crop Residue	4.40	7.22	8.06	8.81	4.41
High Marsh	6.19	9.80	10.33	7.63	1.44
Low Marsh	12.00	13.26	6.14	1.42	-10.58
Non-use Habitat	8.00	13.13	14.65	16.03	8.02
Other Agriculture	1.47	2.42	2.70	2.95	1.48
Pasture	5.05	8.28	9.24	10.11	5.06
River	1.86	3.05	3.41	3.73	1.87
Tidal Flat	36.97	3.41	1.46	1.16	-35.81
Winter Cover Crop	18.50	30.33	33.86	37.04	18.54
Woody Agriculture	0.11	0.18	0.20	0.22	0.11

Table A-11. Proportional change in habitat availability with tide height for birds captured in 2008-2009 at South Skagit Bay/West Pass marsh site.

Habitat	% available by tide height				% change
	-0.6-0.90	0.91-2.3	2.31-2.9	2.91-3.7	
Bare Soil	10.51	15.25	16.36	17.25	6.75
Crop Residue	5.98	8.68	9.31	9.82	3.84
High Marsh	4.22	5.97	6.09	4.46	0.24
Low Marsh	8.20	8.51	3.86	0.86	-7.34
Non-use Habitat	9.57	13.89	14.91	15.72	6.15
Other Agriculture	2.13	3.09	3.32	3.50	1.37
Pasture	3.09	4.49	4.82	5.08	1.99
River	1.80	2.61	2.81	2.96	1.16
Tidal Flat	30.26	2.35	0.77	0.55	-29.71
Winter Cover Crop	22.73	32.98	35.40	37.33	14.60
Woody Agriculture	1.51	2.18	2.34	2.47	0.97

Table A-12. Proportional change in habitat availability with tide height for birds captured in 2008-2009 at Port Susan Bay marsh site.

Habitat	% available by tide height				% change
	-0.6-0.90	0.91-2.3	2.31-2.9	2.91-3.7	
Bare Soil	10.69	15.90	17.19	18.35	7.67
Crop Residue	5.29	7.88	8.51	9.09	3.80
High Marsh	4.17	6.01	6.08	3.99	-0.18
Low Marsh	8.48	9.27	4.45	0.79	-7.68
Non-use Habitat	10.30	15.32	16.56	17.69	7.39
Other Agriculture	1.37	2.03	2.20	2.35	0.98
Pasture	2.81	4.18	4.52	4.83	2.02
River	2.22	3.31	3.58	3.82	1.60
Tidal Flat	32.22	2.68	0.80	0.53	-31.69
Winter Cover Crop	21.31	31.70	34.27	36.59	15.29
Woody Agriculture	1.14	1.70	1.84	1.97	0.82