The Winter Ecology of Dunlin (*Calidris alpina pacifica*) in the Fraser River Delta.

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Abstract

The Fraser River Delta is an important wintering area and migratory stopover site for waterfowl, raptors and shorebirds, including internationally important populations of Dunlin and Western Sandpipers (Calidris maurii). The health of the ecosystem has been adversely affected by industrial and human wastes and agricultural runoff, as well as by the pressures of a rapidly expanding local human population. Recent clean-up efforts have been successful, as other technical reports in this volume attest. Since the Fraser River Delta provides critical habitat for so many species of birds, fish, and other organisms, some of which are harvested for human consumption, it is important that we work to maintain it in a state of good health. This report examines the ecology of the local Dunlin population and discusses whether and how these birds can be used as a tool for monitoring the long-term health of the Fraser River Delta ecosystem.

Radio telemetry was used to study home ranges, habitat use, and activity budgets of male and female adult and juvenile Dunlin from three areas within the delta. There were significant differences in home range size between Dunlin from different banding sites, with home range size increasing as the adjacent marine sediment grain size increased. There were also significant differences in habitat use between Dunlin from different banding sites, as well as between males and females across sites. These differences may be due to variation in the quality of feeding habitat, variation in the availability of food and/or the social dominance hierarchy. There were few differences in activity budgets between groups of Dunlin. Recommendations for monitoring are outlined.

Résumé

Le delta du Fraser est une importante aire d'hivernage et une halte migratoire pour les oiseaux aquatiques, les rapaces et les oiseaux de rivage. Parmi ces derniers, on retrouve de grandes populations de bécasseau variable (*Calidris alpina*) et de bécasseau d'Alaska (*Calidris mauri*). Les déchets industriels et urbains, le lessivage des terres cultivées ainsi que les pressions exercées par l'accroissement rapide de la population humaine dans le delta ont gravement affecté l'écosystème. Comme l'indiquent d'autres rapports techniques du présent ouvrage, les récents efforts de dépollution ont connu du succès. Étant donné que le delta du Fraser constitue un habitat vital pour beaucoup d'espèces d'oiseaux, de poissons et d'autres organismes, dont certains sont prélevés pour la consommation humaine, il est important de travailler à le maintenir en bon état. Le présent rapport étudie l'écologie de la population locale de bécasseau variable et examine la possibilité d'utiliser ces oiseaux pour surveiller la santé à long terme de l'écosystème du delta du Fraser.

On a utilisé la radiotélémétrie pour étudier, dans trois endroits du delta, le domaine vital, l'utilisation de l'habitat et les bilans d'activité de bécasseaux variables mâles et femelles, adultes et juvéniles. On a d'abord noté des différences significatives dans l'étendue du domaine vital entre les bécasseaux variables des différents sites de baguage. En fait, le domaine s'élargissait au fur et à mesure qu'augmentait la granulométrie du sédiment marin adjacent. On a également trouvé que l'utilisation de l'habitat variait entre les bécasseaux variables des différents sites de baguage, et également entre les mâles et les femelles dans tous les sites. Ces différences résultent peut-être des variations dans la qualité de l'habitat d'alimentation, la disponibilité de la nourriture ou l'ordre social. Par ailleurs, on a observé peu de différences entre les bilans d'activité des groupes de bécasseaux variables. Des recommandations sur la surveillance sont présentées.

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1.0 Introduction

The Fraser River Delta is the largest estuary on Canada's Pacific coast and supports the country's highest densities of waterbirds, shorebirds and raptors in winter (Butler & Campbell 1987). It is also a key wetland stopover site for many species of migrant birds flying between breeding habitat in Canada, Alaska and Russia and wintering habitat in southern USA and Central and South America. Over one million shorebirds use the Fraser Delta annually, including internationally important populations of Dunlin and Western Sandpipers (Butler & Vermeer 1994). In recognition of this, Wildlife Management Area status has recently been awarded to key portions of the estuary, and work is under way to obtain official designation as a Western Hemisphere Shorebird Reserve Network site of hemispheric importance (R. Butler, pers. com).

Dunlin are calidrid sandpipers with a circumpolar breeding range, and there are six races worldwide. *Calidris alpina pacifica* is the locally distributed race (Figure 1), breeding in western Alaska, and wintering from B.C. down into Mexico (Hayman et al. 1986). During the non-breeding season, Dunlin are commonly found on coastal estuaries, intertidal flats, agricultural lands, and interior seasonal wetlands (Butler & Vermeer 1994; Warnock 1994; Warnock et al. 1995; Shepherd, unpublished data), and they are known to move regularly among sites within a season, responding to food availability, predation pressure, environmental conditions (especially rain), and water levels (Warnock 1994; Evenson & Buchannan 1995; Shepherd, unpublished data). The Fraser River Delta is a migratory stopover site for Dunlin, and is also the northernmost site within their winter range to support a significant number of birds. Dunlin begin to arrive here in October, and between 30 and 60 thousand remain until late March/early April when they migrate back up to their Alaskan breeding grounds.

Figure 1. Dunlin (Calidris alpina pacifica) foraging in the marine intertital habitat.

More than two thirds of western North America's wetlands have disappeared due to human disturbance, and many of those that remain have been irrevocably altered (National Wetlands Working Group 1988; Bildstein et al. 1991; Environment Canada 1991). The Fraser River Delta is presently experiencing a great deal of pressure due to the rapidly expanding human population around Vancouver and increases in housing, recreational, and industrial development. As well, the river carries agricultural runoff and effluent from sewage treatment plants, paper mills, and other industries out to sea via the delta. Recent clean-up efforts have been successful, as other technical reports in this volume attest. Since the Fraser Delta provides critical habitat for so many species of birds, fish, and other organisms, some of which are harvested for human consumption, it is important to maintain the ecosystem in a state of good health.

Bird populations have long been used as indicators of the health of riverine and estuarine ecosystems. Their position in the food chain makes them vulnerable to the effects of contaminant bioaccumulation, and fluctuations in their populations can be a first indication of problems within an ecosystem. Migratory shorebirds, and Dunlin in particular, have been used as indicators of environmental health in a number of studies (Goss-Custard 1979; Goede and DeBruin 1985a & 1985b; Burger 1986 & 1988; Goss-Custard and Moser 1988; Goss-Custard and Le V dit Durrell 1990; Hill et al. 1993). Survivorship in shorebirds is primarily related to ecological factors away from the breeding grounds, so fluctuations in population numbers can be related to events occurring on their migration and wintering grounds (Myers et al. 1987; Warnock 1994; Troy 1996; Hitchcock & Gratto-Trevor 1997). Despite its extensive geographical range, populations of several subspecies of Dunlin worldwide (including our local subspecies) appear to have declined in recent decades, in some cases severely. Research on European wintering grounds has related these declines to man-made changes to wetland habitats (Goss-Custard and Moser 1988). Warnock & Gill (1996) estimate the loss of *C. a. pacifica* wintering habitat at between 30-91%, a potential explanation for their declining numbers here in North America.

This project was initiated in 1995 to assess the usefulness of the local Dunlin population as an indicator of the health of the Fraser River Delta ecosystem, and is part of my ongoing PhD research. In order to determine whether the Dunlin was an appropriate indicator species and to design an effective monitoring scheme, we needed data on their ecology in the delta. The high visibility of Dunlin in the intertidal zone should make the implementation of a monitoring scheme relatively simple and cost-effective.

The specific objectives of this study are to use radio telemetry to examine home ranges, habitat use, and activity budgets of male and female adult and juvenile Dunlin in the Fraser River Delta. I am also working on other aspects of Dunlin winter ecology, including prey availability (invertebrates) and predation rates (raptors), and these data will be available upon completion of my thesis.

2.0 Study area

The study area included the marine intertidal habitat of Boundary Bay and Roberts Bank from Westham Island to the Tsawassen ferry terminal, and adjacent terrestrial/agricultural habitat (Figure 2). Three banding sites were chosen at the marine/terrestrial interface at either end and in the middle of the study area. Sixty-one permanent telemetry stations were set throughout the area, and their exact UTM locations (to within ± 2 m) were recorded using a GPS unit. All telemetry locations included in the analysis were collected from these stations.

Figure 2. **The study area, with banding sites and telemetry stations.**

3.0 Methods

3.1 Capture and marking

Dunlin were captured using mist nets at night, and a total of 47 were fitted with radio transmitters to assess their home ranges, habitat use, and activity budgets. Each individual Dunlin was measured and identified by sex, capture site, and capture season, and 24 were also identified by age. Dunlin are sexually dimorphic, with females generally larger than males. Page (1974) used museum collections of the *pacifica* subspecies of Dunlin to determine that birds with bills longer than 39.8 cm or shorter than 37.7 cm can be sexed by bill length with a minimum certainty of 70%. Juveniles can usually be distinguished from adults by retained buffy-edged inner medians until about mid-winter (Page 1974, Paulson 1993). Using these methodologies, 5 adult male Dunlin, 7 adult females, 6 juvenile males, and 6 juvenile females were fitted with radio transmitters in eastern Boundary Bay in early winter (December 1995). In late winter (February 1996), transmitters were placed on 6 males and 6 females in western Boundary Bay, 4 males and 6 females on Westham Island, and one Dunlin of unknown sex in eastern Boundary Bay. All but one bird that could not be reliably sexed were released without transmitters.

We used Holohil BD-2G radio transmitters with ranges of 4-10 km and 4 to 6 week battery lives. The range of each radio was tested, and the minimum range was used as the standard. The radios were 2 cm by .75 cm with a 15 cm long antenna, and weighed 1.45 grams, representing less than 3 % of a Dunlin's total body weight. Each radio contained a mercury activity switch, so that when the bird was feeding or flying, the pulse rate doubled. The accuracy of the activity switches in each radio was tested repeatedly before attachment. The best attachment location for and the accuracy of the activity switches were also tested on one captive Dunlin and one Dunlin observed in the field, and found to be 100%.

Once individual Dunlin had been identified, banded, and measured, a small oval the size of the radio was cut in the dorsal feather tract 1 cm above the uropygial gland, leaving 2 mm stubs of feather shafts behind for better radio retention. Titan bird glue was used to attach the transmitters to the skin and feather shafts, and the birds later preened the antennae into their tail feathers. To my knowledge, only one radio fell off before the battery died.

3.2 Radio telemetry

After a three-day adjustment period, a dual-Yagi van mast telemetry system (Warnock & Takekawa 1996) was used to locate and determine activity patterns of Dunlin within the study area (Figure 3). The first group of Dunlin fitted with radio transmitters were tracked from late December until early February, and the others from late February until early April. Location data were collected within 3 hours of both day and night high and low tides, 12 to 18 times per week, and 24 hours of activity data were collected each week. For location data, two compass bearings were taken on each Dunlin from consecutive telemetry stations, and the time between bearings was minimized and recorded for error calculation. A GIS computer program was designed to triangulate these bearings, incorporating the compass directions of the van at each station. The output was a UTM location for each individual Dunlin heard within the study area on each tracking run. Only one location was taken for each bird during each tracking run. Precision and accuracy tests were performed on the system, and error data were collected for each individual telemetry location. The dual-Yagi system decreases telemetry error considerably by pinpointing compass bearings to within 1-3 degrees under good weather conditions and 10-15 degrees under bad ones.

Figure 3. The van mast telemetry system used to collect location data.

Activity data were collected by recording the transmitter pulse rate and the general location of each Dunlin in a sample every 15 minutes, and precise locations were recorded every two hours as described above. I recorded activity data during all day time and night time hours (24 hours) during the course of each week. I collected the data from whichever telemetry station in the study area I could listen to the greatest number of individual Dunlin at that particular time. There were two categories of activity—feeding/flying and roosting/preening—denoted by the pulse rate of the transmitter.

3.3 Statistical analyses

3.3.1 Home ranges

I computed harmonic mean and weighted bivariate elliptical home ranges for each individual Dunlin from radio telemetry locations using Ackerman et al. (1990)'s Home Range program. This procedure eliminated outliers which may have exaggerated home range size. Home range size tends to stabilize with a location sample of approximately 20 (Anderson 1982). I computed home ranges for Dunlin with between 15 and 20 locations and those with 20 or more locations, and used a one-way ANOVA to test for differences between them. Since the range sizes were not significantly different, I included all of the birds with 15 or more locations in subsequent analyses. The sample of home ranges was not normally distributed, but since the medians matched very closely with the means for all groupings by site, sex, and age, I analyzed the untransformed data. I used two-way ANOVA's to compare home range size by sex and site together across sites, and by sex and age together for eastern Boundary Bay (SAS Institute Inc., 1993). Harmonic mean home ranges are the most appropriate for this study because the data can determine the shape and dimension as well as the size of the range. I also calculated weighted bivariate elliptical home ranges (which smoothes out the borders of the home range) so that I could compare my data to those of Warnock and Takekawa (1996). Warnock and Takekawa (1996) captured and radio-marked male and female adult and juvenile Western Sandpipers at three sites in San Francisco Bay to study home ranges and movement patterns.

3.3.2 Habitat use

Two habitat choices were available to Dunlin in the study area--marine intertidal or terrestrial/agricultural. Virtually all day time locations were recorded in the marine intertidal habitat (Figure 4), but night time locations were distributed through both habitats (Figure 5). I therefore calculated mean within-bird percentages of night locations spent in each habitat, weighted by the number of locations for each bird, and these were the data used in subsequent habitat choice analyses. I used two-way analyses of variance (ANOVA) to compare habitat use by sex and age together across sites, by sex and age together for the eastern Boundary Bay site, and by sex and site together (only Dunlin caught in eastern Boundary Bay were aged). I also used one-way ANOVAs to compare habitat use by sex within sites (SAS Institute Inc., 1993).

Figure 4. Daytime Dunlin telemetry locations.

Figure 5. Night time Dunlin telemetry locations.

In order to determine whether detection rates of Dunlin may have varied by sex, age, or site, I calculated the mean number of detections for each group and then used two-way ANOVAs to compare day, night, and ratio of day to night detections by sex and age for eastern Boundary Bay, and by sex and site for all three sites (Systat Inc., 1990). These tests were important to evaluate whether any differences in habitat use detected were ecological realities or sampling artifacts.

3.3.3 Activity budgets

I calculated mean within-bird percentages of time spent feeding/flying in each habitat type during both day and night. These data were used to calculate mean activity by sex, age, and site. I weighted the within-bird means by within-bird sample size and then performed two-way ANOVAs to compare activity by sex and site together across sites, and by sex and age together for eastern Boundary Bay. Separate two-way ANOVAs were done for marine intertidal habitat by both day and night and for terrestrial/agricultural habitat by night (since this habitat was rarely used during the day (Figure 4)) (SAS Institute Inc., 1993).

4.0 Results

Most of the Dunlin were located in the Fraser River Delta throughout the lives of their radio batteries, but not on all tracking bouts. Thirty-seven of the 47 Dunlin fitted with transmitters were located at least 10 times, and two others were located between 5 and 10 times. One radio fell off, three Dunlin were found dead (at least the radio was found in a pile of Dunlin feathers), and four others disappeared shortly after the three-day adjustment period and may have been predated. During the study, some Dunlin disappeared for a couple of days on occasion, and one was located near LaConner, WA in the middle of a three day absence from the delta. These birds were consistently relocated in the delta after periods of absence.

Table 1 Harmonic mean home ranges (km^2) ± SE of Dunlin by site, sex, and age (n = sample size).

Parameter	n	Home range ± SE
Site		
Eastern Boundary Bay	17	22.0 ± 2.5
Western Boundary Bay	8	50.4 ± 7.1
Westham Island	6	11.3 ± 1.4
Sex		
Males	12	27.7 ± 5.4
Females	19	27.0 ± 4.5
Age		
Adults	6	24.3 ± 3.7
Juveniles	9	20.0 ± 3.4

4.1 Home ranges

There was a statistically significant difference in home range size between sites when tested with sex (p=0.0001) (Table 1). There were no significant differences in harmonic mean home ranges between males and females when tested with site (p=0.4196) or with age (p=0.4216). Nor were there any differences between adults and juveniles when tested with sex (p=0.4880). None of the interaction terms in the two-way ANOVAs were statistically significant. The weighted bivariate home ranges were on average plus or minus 12.4% of the harmonic mean home ranges, so I will be comfortably able to make comparisons between my Dunlin data and Warnock and Takekawa (1996)'s data on Western Sandpipers.

4.2 Habitat use

There were statistically significant differences between the two sexes (p=0.0271) across sites in the use of marine intertidal versus agricultural/terrestrial habitat at night (Table 2). The sex effect was not statistically significant within western Boundary Bay (p=0.1654) or Westham Island (p=0.8293), and within eastern Boundary Bay, the sex (p=0.0771) and age (p=0.0529) differences were only marginally significant. There was a statistically significant difference in habitat use among sites (p=0.0190). None of the interaction terms in the two-way ANOVAs were significant, and there were no differences in detection rates between sexes, ages or sites (Table 3).

Table 2 **Mean proportions of within-bird night time Dunlin locations ± SE in the terrestrial/agricultural habitat, by site, sex, and age (n = sample size).**

Site	Age/Sex	n	Terrestrial/agricultural
Eastern Boundary Bay (late December - early February)	Males	11	41.3 ± 19.2
	Females	13	23.3 ± 16.5
	Adults	12	22.4 ± 13.6
	Juveniles	12	42.2 ± 21.0
Western Boundary Bay (late February - early April)	Males	4	67.5 ± 15.7
	Females	5	48.9 ± 30.6
Westham Island (late February - early April)	Males	2	50.0 ± 86.5
	Females	5	40.6 ± 37.4
All sites	Males	17	50.4 ± 16.8
	Females	23	34.4 ± 14.8

Table 3 Mean number and ratio of Dunlin telemetry locations by site, sex, and age.

Parameter	Day locations	Night locations	Day/Night ratios
Site			
Eastern Boundary Bay	12.6	6.2	2.1
Western Boundary Bay	18.7	9.7	1.9
Westham Island	15.4	5.3	2.9
Sex			
Males	14.8	7.2	2.1
Females	14.5	6.6	2.2
Age			
Adults	13.5	6.7	2.0
Juveniles	11.8	5.8	2.0

4.3 Activity budgets

Mean percentages of time spent feeding/flying by sex, age, and site for the marine intertidal habitat by both day and night and for the terrestrial/agricultural habitat by night are presented in tables 4 and 5. There were no statistically significant activity differences between sites or between males and females or adults and juveniles at the eastern Boundary Bay site. The two-way ANOVAs comparing activity by site and sex together were not significant in the marine intertidal habitat by day or in the terrestrial/agricultural habitat by night. There was however a statistically significant difference in activity between the sexes in the marine intertidal at night (p=0.0339), and the interaction between sex and site was also significant (p=0.0344).

Table 4 Mean percentages of time spent feeding/flying ± SE by sex and age in eastern Boundary Bay. Means are presented for marine intertidal habitat by day and night and for terrestrial/agricultural habitat by night (n = sample size).

Sex	Marine intertidal habitat		Terrestrial / agricultural habitat
	Day (n)	Night (n)	Night (n)
Adult males	61.9 ± 4.6 (5)	89.2 ± 3.7 (5)	68.8 ± 10.1 (5)
Adult females	60.4 ± 5.6 (5)	75.5 ± 7.9 (4)	76.2 ± 6.4 (5)
Juvenile males	69.1 ± 7.5 (6)	71.4 ± 16.1 (5)	63.2 ± 10.3 (5)
Juvenile females	56.4 ± 5.1 (6)	59.3 ± 11.4 (5)	35.4 ± 14.6 (3)

Table 5 Mean percentages of time spent feeding/flying ± SE by sex and site. Means are presented for marine intertidal habitat by day and night and for terrestrial/agricultural habitat by night (n = sample size).

Sex	Marine intertidal habitat		Terrestrial/agricultural habitat
	Day (n)	Night (n)	Night (n)
Eastern Boundary Bay			
Males	65.8 ± 4.5 (11)	80.3 ± 8.3 (10)	66.0 ± 6.9 (10)
Females	58.2 ± 3.6 (11)	66.5 ± 7.4 (9)	60.9 ± 9.6 (8)
Western Boundary Bay			
Males	86.3 ± 4.5 (4)	83.6 ± 8.1 (4)	74.8 ± 12.6 (3)
Females	88.9 ± 3.8 (5)	91.1 ± 4.5 (5)	70.7 ± 17.3 (4)
Westham Island			
Males	88.8 ± 3.3 (2)	56.7 ± 43.5 (2)	71.4 ± -- (1)
Females	85.4 ± 2.8 (5)	96.0 ± 4.0 (5)	10.8 ± 5.5 (3)
All sites			
Males	73.3 ± 4.3 (17)	78.2 ± 10.7 (16)	68.3 ± 7.6 (14)
Females	72.0 ± 3.1 (21)	80.7 ± 5.7 (19)	53.5 ± 10.8 (15)

5.0 Discussion

5.1 Home ranges

5.1.1 Site differences

There were significant differences in home range size between birds captured at different sites within the Fraser River Delta (Figures 6, 7, and 8). The average home range size of birds captured on Westham Island was 11.3 (± 1.4 SE) km^2; the average home range size of birds captured in eastern Boundary Bay was 22.0 (± 2.5 SE) km^2; and the average home range size of birds captured in western Boundary Bay was 50.4 (± 7.1 SE) km^2.

One possible explanation for this is that home range size may decrease with increasing marine invertebrate density and diversity. In the Fraser Delta, home range size increases with increasing grain size of the marine sediment (Sewell 1996), and marine invertebrate density and diversity tend to decrease with increasing grain size (Heck et. al. 1995; Sewell 1996). Dunlin in western Boundary Bay, where the marine sediment is sandy, may need to range farther to meet their energy requirements than birds from either eastern Boundary Bay or Westham Island, where the marine sediment is muddier. The Boundary Bay intertidal zone experiences approximately two to four hours more exposure time than the Roberts Bank intertidal zone, so Westham Island birds have less overall feeding time than Boundary Bay birds. This makes it all the more surprising that the Westham Island Dunlin have the smallest home ranges, and points to the likelihood that local prey availability is high enough to support this behaviour.

Spatial and temporal variations in the abundance of non-breeding shorebirds have been found by many researchers to be closely associated with variations in the abundance of their prey (Goss-Custard 1970, 1977, Goss-Custard et al. 1991; Hicklin & Smith 1984; Colwell 1993; Colwell & Landrum 1993), but to my knowledge there have been no other shorebird studies relating home range sizes to prey abundance. In order to examine the relationship between site/grain size and invertebrate density/diversity in the Fraser River Delta, I collected 270 invertebrate samples along three marine intertidal transects in January and February 1996 (between the two radio tracking bouts). One transect was in eastern Boundary Bay, one was in western Boundary Bay, and one on Roberts Bank just south of Westham Island. These samples are slowly being sorted and counted (one sample can take an entire day), and these data will be presented in my PhD thesis.

Figure 6. **Telemetry locations of Dunlin Banded in Eastern Boundary Bay.**

Figure 7. Telemetry locations of Dunlin Banded in Western Boundary Bay.

Figure 8. Telemetry locations of Dunlin Banded on Westham Island.

Another possible reason for the gradient of home range size from Westham Island to western Boundary Bay might be the proximity of intertidal foraging habitat to safe day time roost areas. Day time roost sites in Boundary Bay tend to be ephemeral because of the short distance between the marsh/mudflat interface and the dyke, making these birds more susceptible to disturbance from predators or people. Warnock and Takekawa (1996) postulated that the smaller home ranges at one site in San Francisco Bay were due to the fact that feeding and roosting areas were closest together there than at the other two sites.

5.1.2 Sex and age differences

There were no differences in home range size between sex or age categories in the Fraser River Delta. Western Sandpipers in San Francisco Bay showed no differences in home range size between the sexes either, but juveniles there had larger home ranges than adults (Warnock and Takekawa 1996). Warnock and Takekawa (1996) thought this may have been because adults were more efficient at locating and returning to profitable feeding areas, similar to Warnock's (1994) findings in his study of a colour-banded population of Dunlin in California. These findings, although they may not be reflected in the data on Fraser River Dunlin home ranges, may help to explain the differences in habitat use between age categories discussed below.

5.2 Habitat use

Dunlin foraged both by day and by night as expected, but one of the most interesting findings of this study was that they regularly used the agricultural fields in the delta at night (Figure 5). This was unexpected because a great deal more and a greater diversity of mudflat habitat was available at night than during the day, and because Dunlin were rarely located in the fields during the day (Figure 4). One reason the Dunlin may be foraging in the terrestrial/agricultural habitat is that rain on the mudflat surface reduces the availability of marine invertebrates by forcing them to burrow deeper in the sediment (Goss-Custard 1984, Pienkowski et al. 1984). Warnock (1994 & 1995) found that in years of heavy rainfall in California, more than 40% of local Dunlin populations disappeared from the coast and moved to inland agricultural habitats. As well, Townshend (1981) found that Curlews in Britain fed in fields when rain and cold reduced intertidal prey availability and increased the availability of worms in the fields. Since rainfall tends to bring terrestrial invertebrates up closer to the surface while it forces marine ivertebrates to burrow further away from the surface, it is difficult to say whether Dunlin leave the marine intertidal habitat to feed in the terrestrial/agricultural habitat because they are forced to do so or because they prefer to do so. Hopefully the prey availability data outlined below and ongoing field work will shed further light on this behaviour.

In order to relate Dunlin habitat use to the availability of their prey, I collected 270 invertebrate samples from each of the two habitat types. I collected 60 samples from each of three pairs of agricultural fields (2 in Boundary Bay and 1 on Westham Island). Each pair was made up of one field that was regularly used by Dunlin and one field that was not. In order to determine the effects of time of day and rain on invertebrate prey availability, I also collected 30 samples on a dry day, 30 on a wet day, 30 on a dry night, and 30 on a wet night within one of the fields used by Dunlin. The marine collections are described above, and also include samples collected on a dry day, a wet day, a dry night and a wet night along one of the transects. As mentioned above, the sorting and counting of these samples continues and the results will be reported in my PhD thesis.

5.3 Sex and age differences

The radio-tracking data for the Fraser Delta show a statistically significant difference in habitat use at night between male and female Dunlin (p=0.0271). Males spent less time than females in the marine intertidal habitat (Table 2), perhaps because of the effects of rain on the availability of marine invertebrates (Goss-Custard 1984, Pienkowski et al. 1984). It may be harder for shorter-billed males to meet their energetic requirements, and they may choose or be forced to move into the terrestrial/agricultural habitat to feed more often than longer-billed females.

The two-way ANOVA for eastern Boundary Bay (where it was possible to age birds) did not show statistically significant differences in habitat use by sex (p=0.0771) or age (p=0.0529), but these p-values were not far off from the 95% standard, especially for age. Studies of Dunlin and other shorebird species have shown that adults sometimes exclude juveniles from foraging areas (van der Have et al. 1984, Goss-Custard & le V. dit Durell 1987), and Warnock and Takekawa

(1996) thought this might be why juvenile Western Sandpipers had larger home ranges than adults. Warnock (1994) found significant spatial segregation between foraging adult and juvenile Dunlin in California, and concluded that this was because adults fed in areas they know from experience are safer from predation and where there was also sufficient food, while predator-naïve juveniles chose simply to forage wherever they could get enough food.

Dunlin here in the Fraser River Delta generally avoid the terrestrial/agricultural habitat during the day, maybe because there is a higher predation risk in this habitat at this time. It is much easier to detect attacking predators in advance from the open mudflat than from fields surrounded by hedgerows, trees, fences, etc. Predation risk probably decreases in both habitats at night since there are fewer night time than day time avian predators in the delta, but the risk likely remains higher in the terrestrial/agricultural habitat regardless of time of day. Owls forage on small mammals and rodents as well as shorebirds, so there is higher overall prey availability for them in the terrestrial/agricultural habitat than in the marine intertidal habitat. The fact that more juveniles than adults use the agricultural habitat at night may indicate that it is less preferred, and that males (shorter-billed) Dunlin are forced to feed there rather than preferring to do so.

5.3.1 Site differences

There was a statistically significant difference between sites (p=0.0190) in the proportion of time Dunlin spent in the terrestrial/agricultural habitat at night. Birds from western Boundary Bay and Westham Island, which were tracked from February to April, were located there more often than birds from eastern Boundary Bay, which were tracked from December to February. This difference was not due to improved ability in locating Dunlin in the terrestrial/agricultural habitat later in the field season (see below). The difference in field use between tracking bouts may be due to an increase in rainfall later in winter and/or the accumulation of freshwater on the terrestrial/agricultural habitat, which might affect invertebrate populations as described above. Colwell and Dodd (1997) found that the use of pastures by wintering Dunlin increased when it rained and also that the likelihood of pasture use increased when shorebirds used pastures the previous week. There may therefore be a learning aspect and/or an information center aspect to the increased use of fields later in the season in the Fraser River Delta.

Within the later tracking bout, birds from western Boundary Bay were located in the terrestrial/agricultural habitat more often than birds from Westham Island. If the marine intertidal habitat near Westham Island does prove to contain a higher density and diversity of invertebrates as expected, then perhaps that may also explain why they spend less time foraging in the terrestrial/agricultural habitat at night. You will recall they have significantly smaller home ranges than Dunlin from western Boundary Bay. The sandy intertidal sediment in western Boundary Bay may also be more permeable to fresh water than muddier sediment, causing marine invertebrates to burrow down farther and reducing invertebrate availability.

5.3.2 Detection rates

On average, I obtained almost the same number of telemetry locations for males and females, and only slightly fewer telemetry locations for juveniles than adults, although this was not a statistically significant difference. I obtained about the same ratio of day to night locations for all three sites (Table 3), which means that night time habitat choices seen in the data are real and not sampling artifacts.

5.4 Activity budgets

The only statistically significant difference in activity by time of day and habitat between any of the groups of Dunlin (by sex, age, and site) was that between the sexes in the marine intertidal habitat at night (p=0.0339). The interaction between sex and site was also significant (p=0.0344). Males in eastern Boundary Bay spent a greater proportion of their time feeding/flying in the marine intertidal habitat at night than did females, while in western Boundary Bay and on Westham Island, it was the females who fed/flew a greater proportion of the time than the males in this habitat at this time of day. Since female Dunlin have larger body sizes, they may require more feeding time to maintain themselves than males. Males may spend more time foraging on the flats at night early in the winter because their shorter bills may make it harder to obtain food as quickly/easily as females. By late winter, the males who were less successful feeding on the flats at night may be moving into the fields, and those that stay behind may be the more efficient or longer-billed Dunlin than their fellows.

The fact that the radio transmitters cannot distinguish between feeding and flying may confound the activity data. In order to remedy this, I am collecting observational activity budget data to determine what proportion of the day Dunlin spend flying. I will also attempt to do so at night using night vision equipment, but I will not be able to break the data down by sex or age.

The relationship between bill length and habitat choice/activity budget is also being further investigated this winter. Radios will be attached to eight Dunlin with short bills, eight Dunlin with short-medium bills, eight Dunlin with medium-long bills, and eight Dunlin with long bills. These birds will be sexed by blood using a technique developed in Dr. Tony Williams' lab at Simon Fraser University, and differences in habitat use and activity will be related to bill length as well as sex. This cannot be done with the data presented here since I excluded Dunlin with medium bill-lengths in order to be certain of the sex of each bird.

6.0 Summary

There were significant differences in Dunlin home range size between capture sites (p=0.0001), but not between sex or age groups. The average home range size of birds captured at Westham Island was 11.3 ($\pm$ 1.4 SE) km^2; of birds captured at eastern Boundary Bay was 22.0 ($\pm$ 2.5 SE) km^2; and of birds captured at western Boundary Bay was 50.4 ($\pm$ 7.1 SE) km^2. Home range size increased with increasing grain size of the marine sediment. This might reflect the fact that marine invertebrate density and diversity tend to decrease with increasing grain size, forcing Dunlin to range farther to meet their energy requirements. Most of the Dunlin were located in the Fraser River Delta throughout the lives of their radio batteries, but not on all tracking bouts.

Dunlin foraged both by day and by night as expected, but one of the most interesting findings of this study was that they regularly used the agricultural fields in the Delta at night. This was unexpected because a great deal more and a greater diversity of mudflat habitat was available at night than during the day. Dunlin were rarely located in the fields during the day, likely due to the high numbers of diurnal wintering raptors in the delta. There were statistically significant differences between males and females (p=0.0271) in the use of mudflat versus field habitat at night. Males were located in the fields on 50.4% of nighttime tracking bouts, whereas for females it was only 34.4%. As well, juveniles were located in the fields on 42.2% of nighttime tracking bouts, whereas for adults it was only 22.4%, but this difference was only marginally statistically significant (p=0.0529). All four groups used the field habitat for foraging.

The only significant difference in activity by time of day and habitat between any of the groups of Dunlin (by sex, age, and site) was that between the sexes in the marine intertidal habitat at night (p=0.0339). The interaction between sex and site was also significant (p=0.0344).

7.0 Recommendations

Based on the ecological results described above and the fact that shorebird survivorship is primarily related to migration and wintering factors (Myers et al. 1987; Warnock 1994; Troy 1996; Hitchcock & Gratto-Trevor 1997), I believe that the Dunlin would be an ideal indicator species to monitor the health of the Fraser River Delta ecosystem as a whole. Natural migration mortalities are usually related to weather events or predation at stopover sites, and natural winter mortalities are usually related to predation or starvation. This is the northernmost wintering ground to support a significant number of Dunlin, and one of their northernmost migratory stopover sites (Warnock & Gill 1996), so stopover site predation should not contribute significantly to mortality in the Fraser River Delta Dunlin population. Weather systems between here and the Alaskan breeding grounds can be easily monitored using satellite data available on the World Wide Web and could provide an index of expected migration mortality. An index of the previous year's winter mortality could be arrived at using the number and length of freezing events (from Environment Canada weather data) and the number of avain predators (falcons and owls) counted in the Fraser River Delta during the annual Christmas Bird Count. Any significant fluctuations in the numbers of Dunlin wintering in the delta that do not correlate with the indices of migratory mortality and the previous year's winter mortality should reflect changes in the health of the ecosystem (including both marine and terrestrial habitats).

Since Dunlin home ranges for the eastern Boundary Bay and Westham Island groups are consistently small, I recommend that monitoring take place at these sites (Figures 6 and 8). As well, since some of the radioed Dunlin were not heard on some days and may take short trips out of the area, single surveys would not necessarily reflect real population sizes. Instead, the average of two to three surveys done at the same tide height at five day intervals would give a more accurate estimate of population size at a particular point in time. Surveys such as these would not cost a great deal (in time or funds) and could easily be maintained over the long term.

As for using Dunlin as a tool for monitoring toxins in the Fraser Delta, the fact that they forage in terrestrial as well as marine habitats would likely make it difficult to determine the source of agricultural toxins. Lesley Evans-Ogden, a new PhD student in Wildlife Ecology at Simon Fraser University, is planning an experiment to measure stable isotope ratios in Dunlin gut contents. This will allow her to determine what proportion of their diet comes from marine versus terrestrial habitats (Alexander et al. 1996), and in combination with the habitat use and activity data outlined in this report, might still make it feasible to use Dunlin to monitor levels of agricultural toxins in Fraser River runoff. For toxins never found in agricultural habitat, adult females would be the best choice as indicators since they are the demographic group that spends the most time in marine habitats.

8.0 Literature cited

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