

**MIGRATORY SHOREBIRD AND VEGETATION EVALUATION
OF CHICKALOON FLATS,
KENAI NATIONAL WILDLIFE REFUGE, ALASKA**

by

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A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Master of Science in Wildlife Ecology

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ABSTRACT

I conducted my research on Chickaloon Flats, Kenai National Wildlife Refuge, which is a tidal mudflats located along the northern part of the Kenai Peninsula in upper Cook Inlet, Alaska, 2009–2010. It is a protected coastal estuary stopover area along the Pacific Flyway, covering 7% of the total estuarine intertidal area of Cook Inlet and Prince William Sound. Almost one-third (23 of 73) of shorebird species recorded in Alaska use this stopover during spring and/or fall migrations. My objectives included 1) creating a current vegetation classification map and quantify vegetation changes from 1975 to 2005, 2) identify the driving factors of ephemeral pool presence, 3) document avian use of Chickaloon Flats during migration periods, and 4) conduct a multi-isotopic approach to estimate probable breeding and/or wintering origins of six species of shorebirds using Chickaloon during spring and fall migration of 2009 and 2010.

I analyzed Hydrogen (δD), Carbon ($\delta^{13}C$), and Nitrogen ($\delta^{15}N$) isotopes from feathers and performed a likelihood-based assignment to inform North American (NA) and South American (SA) origins of six shorebird species. Only lesser yellowlegs feathers (*Tringa flavipes*) indicated wintering (n=4, coastal SA) and breeding (n=26, central Alaska) ranges. Estimated wintering ranges for least sandpipers (*Calidris minutilla*, n=13) occurred in southern NA to northern SA, long-billed dowitchers (*Limnodromus scolopaceus*, n=8) occurred in Mexico, and pectoral sandpipers (*Calidris*

melanotos, n=11) occurred in northeastern SA. Estimated breeding ranges for greater yellowlegs (*Tringa melanoleuca*, n=67) occurred in southwest Alaska, and short-billed dowitcher (*Limnodromus griseus caurinus*, n=26) occurred in south-central Alaska. The analysis of stable isotopes to infer molt origins of birds is a useful and important tool in migration and conservation studies. I determined probable origins of long-distance shorebird migrants, some of high conservation concern, using an Alaskan stopover site, which identified habitats and previously unknown areas used by Alaskan breeding shorebirds.

I observed 95 bird species throughout the spring and fall of 2009 and 2010, with 26 of those species breeding on Chickaloon. I observed several pulses of total birds during spring migration, and a more protracted fall migration with variable smaller pulses of birds. Estimated maximum daily shorebird numbers are 5,638 during spring migration, and 20,297 during fall migration.

I created a recent vegetation classification of 7 vegetation types on Chickaloon Flats using 2005 Landsat TM imagery. I also quantified change of 3 mud/vegetation cover types from 1975–2005. The vegetated community type remained relatively stable over the 30-year period, while the mud and mixed mud/vegetation cover types closest to Cook Inlet showed a relatively-small amount of change over time. The greatest change was an increase in mud area, indicating that the vegetated areas of Chickaloon may be slowly converting to a less productive mud community type.

My research highlights the overall importance and value of Chickaloon Flats as a stopover and breeding grounds for a diversity of avian species, and long-distance migrant shorebirds in particular.

Chapter 1

STABLE ISOTOPES INFER GEOGRAPHIC ORIGINS OF SHOREBIRDS USING AN ALASKAN ESTUARY DURING MIGRATION

Introduction

Determining the locations of migratory birds during their annual cycle is increasingly important to developing conservation strategies (Hobson 1999*a*, Hebert and Wassenaar 2005, Webster and Marra 2005). For long-distance migrants, like many shorebirds, strategic stops rich in food are imperative for successful migration and subsequent nesting success (Castro and Myers 1993, Atkinson et al. 2005, O'Brien et al. 2006, Alaska Shorebird Group 2008, Yerkes et al. 2008). Therefore, identifying high-quality stopover sites along migration corridors aids in local habitat conservation and management (Rocque et al. 2006, Hobson and Wassenaar 2008, Alaska Shorebird Group 2008). There are gaps in our knowledge of avian migratory movement patterns, particularly at relatively discrete stopover sites and for small-bodied species that have not been researched using tracking devices or other extrinsic markers (Inger and Bearhop 2008). In order to better recognize and respond to global-scale threats to shorebirds and to identify critical habitats that need protection, understanding movements within and among landscapes is crucial (Alaska Shorebird Group 2008).

One relatively new technique to trace wildlife migration and identify important stopover areas is stable isotope analysis. An advantage of this methodology is it can

effectively provide migratory information associated with relatively-small stopover areas that would have low sample sizes using traditional methods of band returns or telemetry. Although numerous isotopic studies have been conducted on waterfowl migration, less is known about shorebirds (see Yerkes et al. 2008 for review of previous research). The use of stable isotopes is an intrinsic technique that does not require a previous capture to infer migratory origins (Inger and Bearhop 2008). Animals absorb isotopes from food and deposit them in body tissues. The most commonly used tissues for stable isotope analysis of avian migrations are feathers, muscle, and blood (Bearhop et al. 2003). Metabolically inert tissues, such as feathers, maintain a signature that corresponds to what was eaten during the relatively short period of synthesis (Rubenstein and Hobson 2004, Hobson and Wassenaar 2008) and can infer origins of feather molt (Chamberlain et al. 1997, Marra et al. 1998, Hobson 1999a, Caccamise et al. 2000, Rocque et al. 2006) as well as habitat information of the corresponding molt location (Atkinson et al. 2005). This allows individuals to be sampled in one season (i.e., summer) to estimate origin of feather growth during another season (i.e., winter).

Three stable isotopes are primarily used in isotopic analysis and have different functions in identifying habitat use: stable-carbon isotope ($\delta^{13}\text{C}$), stable-nitrogen isotope ($\delta^{15}\text{N}$), and stable-hydrogen isotope or deuterium (i.e., $^2\text{H}/^1\text{H}$ measured as δD) (Hobson and Wassenaar 2008). Although there has been concern over using single stable isotopes to estimate geographic origin (δD , Smith et al. 2009), the accuracy of geospatially distinct selected habitats can be improved by evaluating a multi-isotopic spectrum ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and δD together). For example, Atkinson et al. (2005) used stable isotope ratios of

carbon and nitrogen in red knot flight feathers to identify at least three discrete wintering areas in eastern North and South America.

Large-scale gradients in stable-carbon isotopes ($\delta^{13}\text{C}$) can also delineate habitat use of wildlife because of global differences in plant tissue with different photosynthetic pathways (C3 vs. C4 or Crassulacean acid metabolism (CAM; Kelly 2000) as well as between terrestrial freshwater and marine food webs (Fry and Sherr 1989, Hobson and Sealy 1991, Korner et al. 1991, Hobson 1999*a, b*). Stable-carbon isotope values of $\leq -20\text{‰}$ indicate freshwater and $>-20\text{‰}$ marine (coastal) values (Fry and Sherr 1989, Hobson and Sealy 1991). Plants using the C4 and CAM pathways grow in arid environments and have higher $\delta^{13}\text{C}$ values than C3 plants that tend to grow in cooler, wet areas (Atkinson et al. 2005). Additionally, C3 plants in hotter conditions use water more efficiently and therefore become more enriched in $\delta^{13}\text{C}$ than those in cooler conditions (Marra et al. 1998, Hobson and Wassenaar 2008). The different photosynthetic pathways of plants can be used to distinguish the North American isoscapes, and animal movements can be tracked across these isoclines. Alisauskas et al. (1998) identified migratory populations of lesser snow geese (*Chen caerulescens*) by examining $\delta^{13}\text{C}$ signatures consistent with C4 corn habitat used by residents versus C3 non-corn habitat used by migrants.

The mapping of spatial variation in plant stable-nitrogen isotopes ($\delta^{15}\text{N}$) has received less attention than $\delta^{13}\text{C}$ (Amundson et al. 2003). The plant nitrogen isoscapes show that plant $\delta^{15}\text{N}$ is related to the nitrogen cycle and negatively correlated with precipitation (Austin and Vitousek 1998, Handley et al. 1999) and positively correlated

with temperature (Amundson et al. 2003). Studies have shown that dietary $\delta^{15}\text{N}$ of kangaroos (Murphy and Bowman 2006) and warblers (Chamberlain et al. 2000) is linked to climate, likely through the openness of the nitrogen cycle. Stable nitrogen isotopes can provide information on agricultural influences; however, higher $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are also found in marine systems and enriched at higher trophic levels. Lower $\delta^{15}\text{N}$ values (<9‰) in feathers are associated with nonagricultural areas compared to feathers collected in C3 agricultural areas (Hebert and Wassenaar 2001, 2005). There are predictable changes in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ between terrestrial and marine environments. Marine environments are enriched in carbon and nitrogen, meaning $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values increase with salinity (Hobson 1999a). $\delta^{15}\text{N}$ values in intertidal habitats may depend upon several things, including: large-scale gradients of the marine environment, degree of influence of terrestrial and freshwater habitats, and anthropogenic inputs (Atkinson et al. 2005).

Hydrogen isotope ratios (δD) in feathers correlate with the δD of local precipitation patterns where the feathers were grown (Atkinson et al. 2005). Deuterium values in North American precipitation show a continent-wide pattern with a latitudinal gradient of enriched values in the Southeast to more depleted values in the Northwest (Hobson and Wassenaar 2008). Deuterium base maps provide a spatial reference to help detect migratory patterns, and therefore can be a potentially powerful tool from a science and conservation standpoint. Deuterium has been used to identify natal, wintering, and molting areas of waterfowl (Hobson 1999a, 2005, Rubenstein and Hobson 2004, Hebert and Wassenaar 2005, Clark et al. 2006, Yerkes et al. 2008) and numerous other bird and

invertebrate species (Hobson and Wassenaar 1997, Dunn et al. 2006, Hobson et al. 2006, Hobson et al. 2007, Perez and Hobson 2007, Hobson and Wassenaar 2008).

The accuracy and precision of using stable hydrogen isotopes to examine migration questions are dependent upon the accuracy and precision of the precipitation (δD_p) maps. It is important to consider the limitations associated with deuterium base maps and apply practical expectations of the accuracy of the origin prediction (Farmer et al. 2008). There are three factors involved with the decoupling of modeled deuterium map values and observed tissue isotopic signatures at a given location, including: 1) fractionation in feathers may occur during the assimilation of isotope signatures, 2) local biogeochemical processes, like evaporation, can modify surface and ground water, which would incorrectly reflect isotope precipitation values, and 3) the value of δD_p from a single year can vary around the 40-year mean (Farmer et al. 2008). Inter-annual variation in δD_p , however, is an underlying source of uncertainty involved in all systems and with all isotopic geographic assignments, and can be considered a baseline of isotopic signature variability in feathers (Farmer et al. 2008). Uncertainty in geographic assignment in stable isotope studies will always be present, and is something that must be dealt with (Farmer et al. 2008). Several studies (Hobson et al. 2001, Wunder et al. 2005, Szymanski et al. 2007) indicate that deuterium signatures do not allow for assigning origins below a resolution of 5°–9° latitude, but adding $\delta^{13}C$ and $\delta^{15}N$ can increase assignment precision.

Using stable isotope data of individuals caught on stopover sites can provide information on both breeding and wintering grounds of migrating birds. Alaska's huge

size and northern latitude make it a critical region for migrating and breeding birds (Alaska Shorebird Group 2008). Alaska hosts one-third (73) of the world's species of shorebirds (Alaska Shorebird Group 2008), and as much as 50% of all shorebirds (7–12 million) in North America (Lanctot 2003). Not only is it important as breeding grounds, there are five Western Hemisphere Shorebird Reserve Network recognized shorebird migration stopover and staging sites within Alaska. The Kenai National Wildlife Refuge (Kenai NWR), located in south-central Alaska, is qualitatively known as an important migratory stopover and breeding grounds for many shorebird species and poses a potential bottleneck (Isleib 1979) where birds pass through both spring and fall. Chickaloon Flats along the northern Kenai NWR is recognized as a valuable waterfowl habitat, where thousands of waterfowl annually use the marsh for nesting, feeding, and resting (Alaska Department of Fish and Game et al. 1972). Of the 73 shorebird species recorded in Alaska, there are 37 common shorebird breeding species (Alaska Shorebird Group 2008). Almost two-thirds (23 of 37) of those species use Chickaloon during spring and/or fall migration, with 7 being confirmed breeders (pers. obs). More than one-third of the 73 shorebird species have an annual roundtrip migration route of $\leq 30,000$ km (Alaska Shorebird Group 2008).

The movement of individuals between summer and winter populations, as well as stopover sites, is described by migratory connectivity (Webster et al. 2002). Using stable isotopes, patterns of migratory connectivity have been established for various bird species (Pain et al. 2004, Norris et al. 2006, Hobson et al. 2010). Webster et al, (2002) proposed a qualitative measure of migratory connectivity, with 'strong' connectivity when most

individuals from a breeding population move to the same wintering location and ‘weak’ connectivity when individuals from a breeding population spread throughout several wintering sites, For most species, the degree of connectivity will lie between ‘strong’ and ‘weak’ designations (Webster et al. 2002).

My objective was to use stable isotope (δD , $\delta^{13}C$, and $\delta^{15}N$) analyses of 6 shorebird species to determine broad spatial scale breeding and wintering origin and habitat use of migrating shorebirds using Chickaloon as a stopover site during both spring and fall (Quimby 1972) including greater yellowlegs (*Tringa melanoleuca*), lesser yellowlegs (*Tringa flavipes*), least sandpiper (*Calidris minutilla*), pectoral sandpiper (*Calidris melanotos*), short-billed dowitcher (*Limnodromus griseus caurinus*), and long-billed dowitcher (*Limnodromus scolopaceus*).

Study area

Chickaloon Flats is a tidal mudflat located along the northern part of the Kenai Peninsula (Figure 1.1). Tidal range in this area is 9.2 m, which is the second greatest in the world behind Bay of Fundy (11.7 m) (Mulherin et al. 2001). The area of vegetation is 6,894 ha (10,974 ha including mud) at high tide, and entails about 1% of the 773,759 ha Kenai NWR. Chickaloon has a high diversity of plant species due to the overlap of arctic and temperate species (Vince and Snow 1984), and the patterns of vegetation are largely due to saltwater and freshwater interactions, land subsistence from 1964 earthquake, and tides (Neiland 1971, Quimby 1972, Committee on the Alaska Earthquake 1973).

The flats support a diverse but low abundance of avian species during migration and breeding periods (see Chapter 2). Chickaloon Flats, located in upper Cook Inlet, is a relatively-small protected coastal estuary stopover site along the Pacific Flyway compared to other Alaskan estuary areas (e.g., Yukon-Kuskokwim River Delta, Copper River Delta, Kvichak Bay). As an estuary, this area can provide predictable tidal habitats and a reliable (compared to interior wetlands) source of abundant resources (Colwell 2010). Cook Inlet provides high-latitude migratory birds with the last considerable area of ice-free littoral habitat before reaching their breeding grounds (Gill and Tibbitts 1999).

Methods

Feather sampling

During the spring and fall migration periods of 2009 and 2010, I collected shorebirds primarily with drop nets (Doherty 2009); but occasionally with Coda net-gun or lethal collection. Sampling occurred at various sites across the study area, primarily in tidally influenced areas with mixed mud and vegetation. Most sampling took place directly east of Pincher Creek, with a couple of sites near Big Indian Creek and west of Pincher Creek. Individuals were banded with a United States Fish and Wildlife Service aluminum band and aged by plumage characteristics. Five structural variables (exposed culmen, nares, tarsus, wing chord, and tail) were measured to the nearest 0.1 mm and body mass to the nearest 0.1 g. The first primary feather and ~350 μ L blood (for dietary study) were taken from every individual. If bird was older than a hatch-year, a rectrice,

and/or tertial were collected depending on molt. All trapping and handling techniques were approved by the University of Delaware Animal Use and Care Committee (#1191).

Stable Isotope Analysis

Prior to analysis, I cleaned all feathers following a standard two-step method using both detergent and a 2:1 chloroform: methanol solution (Partitte and Kelly 2009). Choice of cleaning solvents affects stable-isotope ratios of bird feathers, and order of use may influence variation in data (Partitte and Kelly 2009). Therefore, I first cleaned all feathers with 1:30 solution of Fisher Versa-Clean detergent: deionized water, then rinsed three times with deionized water and put in fume hood to dry for 24 hours. Feathers were then placed in a sealed jar containing a 2:1 chloroform: methanol solvent and shaken for 45 seconds under the fume hood. Feathers were removed from solvent and dried for at least 24 hours under a fume hood.

I used the same part of each feather for analysis (Smith et al. 2009) and excluded the rachis (Wassenaar and Hobson 2006). For $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, I weighed 1.1 ± 0.2 mg of feather material into a tin capsule (Costech; #041061) and weighed $350 \mu\text{g} \pm 10\mu\text{g}$ into a silver capsule (Costech; #041066) for δD .

Isotopic ratios are expressed as per mil (‰) deviation from the standard using the delta (δ) notation:

$$\delta \text{ isotope} = \left[\left(\frac{R_{\text{sample}}}{R_{\text{standard}}} \right) - 1 \right] \times 1000 \quad (1)$$

where δ isotope is the sample isotope ratio (i.e. D, ^{13}C , or ^{15}N) relative to a standard, and R is the ratio of heavy to light isotopes ($\text{D}/^1\text{H}$, $^{13}\text{C}/^{12}\text{C}$, $^{15}\text{N}/^{14}\text{N}$) in the sample standard.

Isotope ratios are expressed in δ notation as parts per thousand (‰) relative to deuterium, $\delta^{13}\text{C}$, and $\delta^{15}\text{N}$ reported as ‰ deviation from the international reference standards Vienna Standard Mean Ocean Water Standard Light Antarctic Precipitation (VSMOW-SLAP) scale, Vienna Pee Dee Belemnite, and AIR, respectively.

Carbon and nitrogen isotopic analyses were performed at both the U.S. Environmental Protection Agency Atlantic Ecology Division laboratory and Colorado Plateau Stable Isotope Laboratory. Analysis at the U.S. Environmental Protection Agency Atlantic Ecology Division laboratory was performed using a Carlo-Erba NA 1500 Series II Elemental Analyzer interfaced with an Elementar Optima isotope ratio mass spectrometer. Samples were combusted (1020°C, chromic oxide catalyst) sending CO_2 and N_2 to the mass spectrometer for the measurement of carbon and nitrogen isotope ratios, respectively. Two internal laboratory standards (dogfish muscle) were used for every 10 unknowns in sequence. The internal standard had a running average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ measurement precision (standard deviation) of $\pm 0.17\text{‰}$ and $\pm 0.16\text{‰}$, respectively. Based on the assessment of the reproducibility of tissue sampled $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ measurements in this study, and propagating the measurement precision of the internal standard, reported tissue $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ measurements had measurement precisions of $\pm 1.00\text{‰}$ and $\pm 0.41\text{‰}$, respectively. Carbon and nitrogen stable isotope analysis at the Colorado Plateau Stable Isotope Laboratory was performed using a Carlo Erba NC2100 Elemental analyzer interfaced to a Thermo Electron Delta Plus Advantage stable isotope ratio mass spectrometer. An internal laboratory standard (NIST 1547 - peach leaves) was used for every 10 unknowns in sequence. The internal standard has a running average

$\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ measurement precision (standard deviation) of $\pm 0.10\text{‰}$ and $\pm 0.20\text{‰}$, respectively. $\delta^{13}\text{C}$ values were normalized on the VPDB scale using IAEA-CH6 (-10.45‰) and IAEA-CH7 (-32.15‰). $\delta^{15}\text{N}$ values were normalized on the AIR scale using IAEA-N1 (0.43‰) and IAEA-N2 (20.41‰).

Hydrogen stable isotope analysis was performed only at the Colorado Plateau Stable Isotope Laboratory using a Thermal Conversion Elemental Analyzer (TC/EA) interfaced with a Thermo Electron Delta Plus XL stable isotope ratio mass spectrometer. Stable-hydrogen isotope measurements were performed on H_2 from high temperature (1400°C) flash pyrolysis. Measurement precision based on replicate measurements of within-run standards of three keratin laboratory reference materials (Spectrum Chemical keratin: $\delta\text{D} = -117.5\text{‰}$, Bowhead Whale Baleen (BWB): $\delta\text{D} = -108\text{‰}$, and Cow Hoof Standard (CHS): $\delta\text{D} = -187\text{‰}$), resulted in accurate and precise \pm SD values of $\pm 2.2\text{‰}$ ($n=18$), $\pm 1.9\text{‰}$ ($n=6$), and $\pm 2.3\text{‰}$ ($n=6$), respectively. The control keratin reference standards yield a long-term SD of $\pm 3\text{‰}$.

Statistical analysis

Before assigning feather samples to feather deuterium isoscapes, I used $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values to classify samples as agricultural or nonagricultural and freshwater or marine (Yerkes et al. 2008). Using the $\delta^{15}\text{N}$ values, feathers $\geq 9\text{‰}$ were considered to come from an agricultural area, whereas all others were from nonagricultural sources (Yerkes et al. 2008). Using $\delta^{13}\text{C}$ values, samples were classified as freshwater if $\leq -20\text{‰}$ and marine if $> -20\text{‰}$ (Fry and Sherr 1989, Hobson and Sealy 1991, Hobson 1999a, Yerkes et al. 2008). If samples indicated evidence of marine inputs, I made no attempt to assign origin

based on δD of feathers (hereafter δD_f) because assigning origin based on δD_f is unreliable when influenced by marine inputs (Larson and Hobson 2009). Using $\delta^{13}C$ values to inform on marine versus terrestrial inputs before assigning samples to feather deuterium isoscapes is the most useful use of a multi-isotope dataset like this (Larson and Hobson 2009), although it is not preferred by some (e.g., Rocque et al. 2009). Additionally, the remaining measured δD_f values cannot be directly assigned to deuterium isoscapes without consideration of possible sources of error. To incorporate estimates of uncertainty in geographic assignment, I used a likelihood-based assignment (Royle and Rubenstein 2004, Ashley et al. 2010). To create a δD_f isoscape for both breeding and wintering ranges I first converted a GIS-based model of the δD in precipitation ((δD_p) , 20' x 20' resolution; Bowen et al. 2005) into a δD_f isoscape using the equation (Clark et al. 2006):

$$(\delta D_f = -30.44 + 0.93 \delta D_p) \quad (2)$$

Clark et al. (2006) found 88% of δD_f variance from known-origin songbird and scoup was explained by δD_p . For breeding molt origins, a growing-season δD_p was used, while an annual δD_p was used for assigning wintering molt origins because a winter season δD_p was not available. With the new δD_f isoscape, I categorized values into 1‰ bands to help with assignment. Using a Normal probability density function (Equation 1):

$$f(y^* | \mu_b, \sigma_b) = \left(\frac{1}{\sqrt{2\pi\sigma_b^2}} \right) \exp \left[-\frac{1}{2\pi\sigma_b^2} (y^* - \mu_b)^2 \right] \quad (3)$$

each individual bird of a given species was evaluated on the likelihood that a given isotope band (b) within the isoscape represented a potential geographic origin (y^*). The probability that potential origin is represented by a given band is represented by $f(y^*|\mu_b, \sigma_b)$. The expected mean δD_f for that band is shown by μ_b . The expected deviation (σ_b) of δD_f between individuals molting feathers at the same location was estimated to be 12.8% using the standard deviation of the residuals from Equation 3 (Ashley et al. 2010). The probabilities (Equation 3) were then normalized to estimate the probability of geographic origin:

$$\pi_b = \frac{f(y^* | \mu_b, \sigma_b)}{\sum_{b=1}^B f(y^* | \mu_b, \sigma_b)} \quad (4)$$

Isoscape classification

Individual birds for each of the six shorebird species were assigned to the δD_f isoscape by using a 2:1 odds ratio that the assigned geographic origin (1‰ band) was correct relative to incorrect. The isotopic bands in the upper 67% of estimated probabilities of origin (Equation 4) were used to sum results for each individual assignment across all individuals of the same species. Based on the odds ratio, this resulted in an individual bird being assigned to multiple isotopic bands representing probable geographic origins for that bird. Prior to mapping origins, ArcGIS v.10 Spatial Analyst (ESRI 2011) was used to clip the δD_f isoscape to breeding and/or wintering ranges (Ridgely et al. 2007) of

each of the six species. Species range data was provided by NatureServe in collaboration with Robert Ridgely, James Zook, The Nature Conservancy - Migratory Bird Program, Conservation International - CABS, World Wildlife Fund - US, and Environment Canada - WILDSPACE. To portray probable origins, the odds ratio results were put onto both an unaltered map and the species range-clipped δD_f isoscape using Spatial Analyst to reclassify the overall isoscape based on number of individuals designated to each of the 1‰ isotopic bands.

Bird Conservation Regions (BCRs) from the North American Bird Conservation Initiative (NABCI; U.S. NABCI Committee 2000*a, b*) and the ecological regions (ecoregions; descriptions in Gallant et al. 1995) of Alaska are used as basic conservation units to further discuss breeding origins of Alaskan shorebird species migrating through Chickaloon Flats. Description of BCRs and ecoregions related to Alaskan shorebirds are found in the Alaska Shorebird Conservation Plan (Alaska Shorebird Group 2008). To help describe the wintering origins of these shorebirds, I used the terrestrial ecoregions of the world (descriptions in Olson et al. 2001).

Results

Greater yellowlegs

Of the 69 individuals captured during the spring and fall migrations of 2009 and 2010, only 3 were after-hatch year (AHY) birds. Two AHY birds captured during spring migration were classified as marine in origin ($\delta^{13}C$ values $>-20‰$) and were not assigned to origins using the δD_f isoscape. These two birds had $\delta^{15}N$ values $\geq 9‰$, and are

classified as from an agriculture source. The remaining AHY would provide inference on wintering areas, however a likelihood-based assignment was not completed with a single sample. None of the hatch year (HY) birds (n=66) were classified as marine in origin, and only one was from an agricultural source (Table 1.1, Appendix Aa).

Stable hydrogen analyses of first primary feather of migrating HY greater yellowlegs examined on Chickaloon Flats during fall migration indicated that migrant greater yellowlegs bred in southwestern Alaska (Figure 1.2). The highest numbers of probable origins lie in Western Alaska BCR2 and to a lesser extent in the Northwestern Interior Forest BCR4 and North Pacific Rainforest BCR5 (Appendix B). This included 11 Alaska ecoregions, with highest numbers in Subarctic Coastal Plains, Ahklun and Kilbuck Mountains, Bristol Bay-Nushagak Lowlands, Alaska Peninsula Mountains, Interior Forested Lowlands and Uplands, and Interior Bottomlands.

Lesser yellowlegs

Of the 34 individuals captured, 6 were AHY birds. Two AHY birds (33%) were classified as marine in origin ($\delta^{13}\text{C}$ values $>-20\text{‰}$) and were not assigned to origins using the δD_f isoscape. Of the remaining four, two indicated influences from agriculture sources (Table 1.1, Appendix Ab). None of the HY birds (n=28) were classified as marine in origin, and only two showed influences from an agriculture source (Table 1.1, Appendix Ac).

Stable hydrogen analyses of first primary feathers of migrating HY lesser yellowlegs indicated they were born in highest numbers in the western portion of the

Northwestern Interior Forest BCR4, while smaller numbers show probable origins in the northeastern portion of Western Alaska BCR2, the southern portion of Arctic Plains and Mountains BCR3, and the northern portion of North Pacific Rainforest BCR5 (Figure 1.3, Appendix B). The probable natal origins of these birds encompass 11 different ecoregions of Alaska, with highest numbers in five ecoregions including Interior Forested Lowlands and Uplands, Highlands, and Bottomlands, Cook Inlet, and Alaska Range. Analyses of primary feathers of AHY birds (n=4) indicated that migrant lesser yellowlegs had various wintering origins ranging from southeastern North America through South America (Figure 1.4), including 44 different ecoregions. North American probable origins include the Florida peninsula, most of the Caribbean Islands, and coastal Texas and Louisiana. Locations in South America include: northeastern Venezuela, almost all of Guyana, Suriname and French Guiana, northeastern Brazil, western Peru into Bolivia around Lake Titicaca, along the border of Chile and Argentina, and the southern tips of Chile and Argentina.

Least sandpiper

All of the 13 individuals captured were AHY birds. Two birds (13%) captured during migration were classified as marine in origin ($\delta^{13}\text{C}$ values $>-20\text{‰}$) and were not assigned an origin using the δD_f isoscape. One of the birds showed agriculture values ($\delta^{15}\text{N}$ values $\geq 9\text{‰}$), and the other did not. Of the 13 birds used to assign origin, only 1 showed $\delta^{15}\text{N}$ value from an agriculture source (Table 1.1, Appendix Ad).

Stable hydrogen analyses of first primary feather of migrating least sandpipers examined on Chickaloon Flats during spring and fall migration indicated that migrant least sandpipers wintered throughout most of the range (Figure 1.5), including 129 different ecoregions. These sampled least sandpipers exhibit weak migratory connectivity due to origins spread throughout the wintering range. The highest numbers of birds show probable North American origins in southwestern Oregon, western California, and central Arizona and New Mexico. However moderate probability of origins occur in Central and South America including Belize, northern Guatemala, eastern Honduras and Nicaragua, Costa Rica, Panama, central Ecuador, and Colombia (Figure 1.5).

Pectoral sandpiper

Each of the 23 individuals captured were AHY birds. Three pectoral sandpipers (13%) captured from spring migration were classified as marine in origin ($\delta^{13}\text{C}$ values $> -20\text{‰}$) and were not assigned to origins using the δD_f isoscape. Ten individuals were not used in assigning origin due to deuterium values more enriched than any value existing in the δD_f to which they would have been assigned. Eight of the 11 birds showed agriculture values (Table 1.1, Appendix Ae).

Stable hydrogen analyses of first primary feather of spring migrating pectoral sandpipers indicated that they wintered in northern coastal South America (Figure 1.6) across 11 ecoregions. More specifically, birds originated in northeast Venezuela, northern Guyana and Suriname, most of French Guiana, north central interior Brazil, and an isolated area in southeast Peru (Figure 1.6).

Short-billed dowitcher

Of the 44 individuals captured, 18 were aged as AHY birds. All 18 AHY individuals (100%) captured during spring migration were classified as marine in origin ($\delta^{13}\text{C}$ values $>-20\text{‰}$) and were not assigned to origins using the δD_f isoscape. All of these birds exhibited $\delta^{15}\text{N}$ values indicating an agriculture source. None of the HY birds ($n=26$) were classified as marine in origin or had values showing an agriculture source (Table 1.1, Appendix Af).

Stable hydrogen analyses of first primary feathers of migrating HY birds examined on Chickaloon Flats indicated that migrant short-billed dowitchers were born in Northwestern Interior Forest (BCR4) and North Pacific Rainforest (BCR5) (Figure 1.7, Appendix M) across the Alaska Peninsula Mountains, Cook Inlet, Alaska Range, and Pacific Coastal Mountains ecoregions.

Long-billed dowitcher

Each of the 8 individuals captured were AHY birds. One bird (13%) captured during migration was classified as marine ($\delta^{13}\text{C}$ values $>-20\text{‰}$) and was not assigned an origin using the δD_f isoscape. This individual and the remaining 7 all showed $\delta^{15}\text{N}$ values indicating a non-agriculture source (Table 1.1, Appendix Ag).

Stable hydrogen analyses of first primary feather of migrating AHY long-billed dowitchers examined on Chickaloon Flats indicated that migrant long-billed dowitchers molted primaries at a variety of possible stopovers across western United States and

Canada (Figure 1.8a). Analyses of alternate tertial feathers indicate various wintering origins of the same individuals, from central California along the western portion of Lake Tahoe, southern Baja California, both coasts of Mexico, southern Texas east through southeastern North Carolina, and southern Guatemala and El Salvador (Figure 1.8b).

Discussion

Stable isotope results from 6 long-distant migrant shorebird species have helped to illustrate the importance of Chickaloon Flats as a stopover in south central Alaska. In addition to geographic origin (δD) of migrating shorebirds, stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) have provided information on migratory connectivity and broad habitat signatures within those probable origins.

Greater yellowlegs

The greater yellowlegs is one of the least-studied shorebirds in North America, and any information on migration is useful. Migration is across both interior and coastal regions, but more numerous along the coast, especially in the fall. Spring migration starts earlier than other shorebirds, between early February and March and through early June. Birds arrive at the breeding grounds in boreal-forest from south Alaska east to Newfoundland (O'Brien et al. 2006) mostly in late April. Fall migration is from late June to late November, and adult fall migration peaks during the third week of July in south-central Alaska. Additionally, Elphick and Tibbitts (1998) report (via R. Gill pers. comm.) that on the Alaska Peninsula, a peak, of mostly juveniles, occurs in mid-October. Winter

range is along the coast from southern British Columbia and Connecticut down throughout Central and South America and the West Indies (O'Brien et al. 2006). Definitive prebasic molt in adults is complete and starts immediately after breeding with some feathers on head, mantle, or chest, or scapulars. Primaries molt from P1 outward, often beginning before leaving breeding grounds, suspended during migration, and completed on wintering grounds between late November and early February (Morrison 1984, O'Brien et al. 2006).

The isotope results of my study show that during breeding season, greater yellowlegs are locally abundant in BCR 2 and 4, and these regions are of known importance to the species (Alaska Shorebird Group 2008). My analysis indicates a strong migratory connectivity between Chickaloon Flats and the breeding origins of greater yellowlegs. My data (n=66) provide a robust characterization of connectivity, and corroborate known large-scale Alaskan breeding areas (Elphick and Tibbitts 1998). Geographic origins implied by stable-isotope measurements suggest the importance of the ecoregions of southwestern Alaska for the production of Alaska breeding greater yellowlegs migrating through Chickaloon Flats. The origin results from this isotope analysis provide probable breeding locations for this shorebird species of moderate conservation concern (Alaska Shorebird Group 2008). With exception of a single bird with agriculture values, the overall habitat signature of breeding greater yellowlegs indicate similar habitat signatures (Appendix Aa).

Lesser yellowlegs

The lesser yellowlegs continental population has declined by an estimated 16.5% per year during the past 40 years (Sauer et al. 2007). Lesser yellowlegs are a priority shorebird species in BCR 4 for both breeding season and during migration (Alaska Shorebird Group 2008). The declining population size and nonbreeding area threats from hunting, loss and degradation of habitats and oil development are enough to consider lesser yellowlegs as a species of high concern (Alaska Shorebird Group 2008). The lesser yellowlegs migrates in high numbers during spring and fall migration in interior North America and is widespread elsewhere during migration, but in relatively low numbers. Primary spring migration routes are midcontinental, mostly west of the Mississippi River, and fall routes are midcontinental and along the Atlantic coast (Tibbitts and Moskoff 1999). Median first spring arrival date in Anchorage is 27 April. Birds start to move south late June-October, sometimes into November, starting with failed breeders in late June, successful breeders in mid July, and juveniles late July-early August (Tibbitts and Moskoff 1999). Molt out of juvenal plumage occurs on wintering grounds, and includes head-and-body feathers and inner rectrices. Primary flight feather molt takes place entirely on wintering grounds (O'Brien et al. 2006).

My isotope analyses have helped to identify Chickaloon as a migratory stopover area and to provide numerous wintering areas of lesser yellowlegs, which was one of many proposed research priorities of this species (Tibbitts and Moskoff 1999).

Additionally, the Lesser Yellowlegs Conservation Plan (Clay et al. 2012) illustrated the need for researching migratory connectivity (i.e. stable isotopes) as well as quantifying

the importance of the Guiana Coast and coastal wetlands of Chile as wintering habitat. My data have provided a bit more information in each of those gaps in knowledge. My limited winter data indicate a weak migratory connectivity for lesser yellowlegs, although the sample size (n=4) is small. Additional samples would provide a more robust data set of wintering origins to better determine degree of connectivity. However, my isotope analyses indicate several regions of importance for wintering lesser yellowlegs. The bay of Lake Titicaca showed probable origins for the highest number of wintering lesser yellowlegs. This area is an important aquatic ecosystem habitat for both resident and migratory avian species (Canales 1996), and indicates wintering importance of lesser yellowlegs that breed in western interior Alaska and migrate through south-central Alaska. This species also shows origins along the productive north coast of South America, where there are four WSHRN sites of hemispheric importance. These suitable nonbreeding habitats have potential threats from oil pollution and habitat conversion and degradation (Kushlan et al. 2002). Lesser yellowlegs caught on Chickaloon indicate the importance of the area as both a spring and fall migration stopover site to birds of wintering locations covering a wide diversity of ecoregions and latitudes.

Geographic origins suggest the importance of the ecoregions of western interior Alaska for the production of Alaska breeding lesser yellowlegs migrating through Chickaloon Flats. My data indicate a rather strong connectivity between breeding grounds and stopover site; although a larger sample size would provide a more robust characterization of connectivity. Lesser yellowlegs primarily breed in open boreal forest and forest/tundra transition habitats (O'Brien et al. 2006) and these wetland-breeding

habitats are drying as a result of recent climate change (Klein et al. 2005). The drying of these wetland habitats within BCR 4 is of most immediate concern regarding shorebirds (Alaska Shorebird Group 2008). Within the possible breeding origins, lesser yellowlegs may also show different habitat ranges, with two of the 28 having slightly higher $\delta^{15}\text{N}$ values in this terrestrial system.

Least sandpiper

The least sandpiper is widespread and has the broadest and southernmost breeding distribution of all the Nearctic *Calidris* sandpipers. Migration occurs between subarctic/boreal breeding areas and Central and northern South American wintering areas. Western populations migrate through interior North America to the Gulf Coast and Central America, or down the Pacific Coast to northwestern South America. Spring migrants start arriving in western Alaska by 10 May (Peterson et al. 1991), and numbers peak at Nelson Lagoon, central Alaska, in late June (Gill and Jorgenson 1979). There are two fall migration peaks with the adults migrating late June, females before males, and juveniles following early to mid-August (O'Brien et al. 2006). Definitive basic molt is complete, with primaries molted from P1 outward, and occurs on the wintering grounds. The timing of molt varies with length of migration. Short distance migrants wintering in California begin molt in July and complete flight feather molt by October and body molt by November (Page 1974). In contrast, birds wintering in northern South America begin their molt in August-September and finish by December-early January (Spaans 1976).

Definitive alternate plumage molt is incomplete, occurs January-June, and includes head, neck, mantle, most scapulars, and some upper wing and tail coverts.

Geographic origins implied by my analyses suggest the importance of southwestern Oregon, central New Mexico and Arizona, and California for the highest numbers of wintering least sandpipers. These origins confirm the known, widespread wintering range of least sandpipers (Nebel and Cooper 2008), and suggest weak migratory connectivity with probable origins spread across the entire range. A larger sample size would help to differentiate potential origins and better characterize connectivity. The Californian Central Valley is one of the most important shorebird migration and wintering regions in western North America (Shuford et al. 1998), and along with the California coast, hosts some of the highest numbers of wintering origins of least sandpipers from the present study. Threats to shorebirds wintering in the Central Valley include poor water quality, changing agriculture practices, and loss of habitat to urbanization (Shuford et al. 1998). Shorebird habitat has disappeared at a high rate, and Speth (1979) suggests that more than 70% of Californian intertidal wetlands were altered for human needs during the 100 years preceding his study. There are, however, five WHSRN sites to help protect these Californian habitats of regional, international, and hemispheric importance. Another high concentration of probable origins falls along Ecuador and Colombia, another site of high coastal productivity (Hötker et al. 1998, Butler et al. 2001). In the probable wintering locations, there are a variety of habitat signatures (Appendix Ad). Within these terrestrial birds, a single least sandpiper shows higher $\delta^{15}\text{N}$ values, indicating agriculture influences. The remaining twelve individuals

have similar $\delta^{13}\text{C}$ values, but represent a spectrum of $\delta^{15}\text{N}$ values, which may reflect foraging at various trophic levels.

Pectoral sandpiper

Pectoral sandpiper is the longest distance migrant of the North American shorebirds (O'Brien et al 2006) and is a species of low conservation concern in Alaska (Alaska Shorebird Group 2008). They breed in North American and Siberian wet tundra and winter primarily in southern South America. Spring migration takes place between late February and late June. In Alaska, pectoral sandpipers arrive nearly simultaneously on arctic breeding grounds in late May-early June (Pitelka 1959). Fall migration is between late June-early December. Males depart breeding territories by early to mid-July (Snyder 1957, Pitelka 1959). At this time, they disappear quickly from breeding areas, most moving south to subarctic wetland. Females leave breeding areas in northern Alaska early to mid-August (Pitelka 1959). Young will depart from breeding areas 4–6 weeks after hatching in mid-late August, at which point they have achieved adult body size (Pitelka 1959). Juveniles will go through a complete prejuvenile molt within several weeks of hatching and before fall migration (Holmes and Pitelka 1998). Definitive prebasic molt in adults is complete and begins late summer with feathers on head, back, mantle, or sides of breast, but arrested until after southward migration (Cramp and Simmons 1983, Higgins and Davies 1996). Molt occurs mainly on wintering grounds from late October - February and involves head, neck, mantle, scapulars, and underparts

first, followed by remainder of body, tail, and wings (Cramp and Simmons 1983, Higgins and Davies 1996).

Geographic origins from this study suggest the importance of the Guiana Coast (~2,000 km section between the Orinoco and Amazon Rivers) (Spaans 1978), to wintering pectoral sandpipers. The probable origins fall within the broad, known wintering range (Holmes and Pitelka 1998), and may provide more information about Alaskan breeding birds by highlighting northern South America. These results indicate strong migratory connectivity between Chickaloon and wintering origins, but this measure could be more powerful with an increased sample size. As previously stated, this coastal area is highly productive and has several established WSHRN sites to help with habitat conservation efforts of this long-distance migrant. Spaans (1978) reported pectoral sandpipers as scarce along the Surinam coast, preferring inland to coastal tidal flats. Looking at broad habitat signatures within the predicted origins, 8 of the 11 birds indicate agriculture influence, although the means of two groups overlap standard deviations, indicating more similar influences. I excluded ten individuals from geographic assignment due to their apparent use of ephemeral wetlands. Feathers from shorebirds using ephemeral sources may show more inter-annual δD_p variation due to assimilation of signatures reflecting a single precipitation event (Farmer et al. 2008).

Short-billed dowitcher

Short-billed dowitchers (*Limnodromus griseus*) are a common and noticeable intermediate coastal migrant, preferring mudflats and saline habitats (Jehl et al. 2001).

Although widespread, there is a lack of study of migratory biology on this species, particularly on the west coast (Jehl et al. 2001). There are three subspecies, *L.g. griseus*; *hendersoni*; *caurinus*, each with separate breeding grounds and migration routes. Short-billed dowitchers only breed in boreal and subarctic regions of North America, which extend nearly coast to coast across these regions of Canada and Alaska (Jehl et al. 2001). The *L. g. caurinus* subspecies has an estimated global breeding population size of 75,000 (Morrison et al. 2006) and breeds entirely within Alaska (Alaska Shorebird Group 2008). This subspecies is one of priority and high conservation concern due to its small population size, a relatively restricted breeding distribution, potential nonbreeding habitat threats, and declines in other populations (Alaska Shorebird Group 2008). This is a priority species for BCR 4 during breeding and migration periods and Cook Inlet (Gill and Tibbitts 1999), and Chickaloon Flats in particular, have been shown to be important areas during these periods. *L.g. caurinus* migrates mainly along the Pacific coast, with peak migration through west coast in mid-late April. Birds depart in early May, flying directly to the coast of southern Alaska, where numbers peak in early-mid May (5–10 May in Homer, Alaska; West 1996) before dispersing to breeding grounds. Adults leave breeding grounds first, and are present in the Pacific Northwest between late June-mid July, followed by juvenile peak numbers between August-early September (O'Brien et al. 2006).

Geographic origins implied by my stable-isotope measurements suggest the importance of the Cook Inlet ecoregion for breeding short-billed dowitchers. The *caurinus* subspecies is known to be a common breeder in the Prince William Sound

region (Isleib and Kessel 1973), which my results support. My data indicate a strong connectivity between Chickaloon and the probable breeding origins. Due to the relatively-small Alaskan breeding range and the clumped nature of probable origins within that range, my data provide a robust characterization of short-billed dowitcher migratory connectivity between Chickaloon and breeding sites. My results support the findings of Gill and Tibbitts (1999) that Cook Inlet unvegetated intertidal areas support breeding and migrating *Limnodromus griseus caurinus* subspecies.

Long-billed dowitcher

Long-billed dowitchers have rather distinct breeding and wintering grounds, and are a species of moderate conservation concern in Alaska (Alaska Shorebird Group 2008). Little is known about their migration in general, and almost nothing is known about where specific breeding populations winter. Spring migration takes place between early February and late May, with peak numbers through southern Alaska in early to mid-May (O'Brien et al. 2006). Long-billed dowitchers arrive at breeding grounds, primarily in coastal tundra, mid-late May. Fall migration takes place between early July-December. Adults migrate south 1–2 months earlier than juveniles (Takekawa and Warnock 2000), departing early-mid August moving to coastal areas (O'Brien et al. 2006). On Seward Peninsula, main migration of failed breeders and adult females occurs early to mid-July, while the remainder of adults migrate by the end of July and juveniles will migrate in early September; latest individuals 27 September (Kessel 1989). Juveniles will go through a complete prejuvenile molt within several weeks of hatching (Takekawa and

Warnock 2000). Definitive prebasic molt in adults is complete and begins late July-August away from the breeding grounds and is completed rapidly and finishes by September (Paulson 1993, Putnam 2005, O'Brien et al. 2006).

Geographic origins implied by stable-isotope measurements from my study suggest the importance of western North America and Canada for molt and stopover sites and southern North America and coastal Mexico for wintering areas of long-billeds that migrate through Chickaloon Flats. The results from probable primary molt locations agree with the known primary molt range (Putnam 2005), but may provide more insight into use of specific stable wetlands. My probable origins agree with established wintering areas across the entire range (Takekawa and Warnock 2000). Results indicate a weak connectivity for both molt and winter locations, but these characterizations would be more robust and informative if sample sizes were increased. Long-billed dowitchers are molt-migrants, meaning the primary feathers are molted between the breeding and wintering grounds, which is rare in shorebirds (Putnam 2005). Most flight feathers are molted at large, stable, inland wetlands alongside thousands of other long-billeds (Putnam 2005). These refueling and molting sites are important for long-term stopovers, especially if birds are estimated to complete molt in 66 days (Putnam 2005) and take another 10 days for refueling (found in short-billeds by Jehl 1963). Stable carbon and nitrogen values indicate these birds are feeding in similar habitats on these molting and refueling stopovers.

Long-distance shorebird migrants rely on stopover sites to take advantage of seasonally abundant food resources. There is not only importance in a network of

stopover sites (Skagen and Knopf 1994*a*, Skagen and Knopf 1994*b*, Farmer and Parent 1997) along a flyway, but also those ranging in sizes from small (Skagen and Knopf 1993) to large (Connors et al. 1979, Isleib 1979). Chickaloon is on the lower size-end, with an area of 10,684 ha, but this does not deem it an insignificant migration stopover. The importance of a stopover location within a migration flyway (Isleib 1979) can also be critical to migrating birds. Most of the Nearctic shorebirds that breed in western Alaska utilize a narrow migration corridor that follows the coast, which also presents topographic and climatic obstacles (Isleib 1979). Chickaloon is located in Upper Cook Inlet, nestled in Turnagain Arm against the western edge of the Kenai and Chugach mountains, and may be more difficult for avian species to access during northern migration because of these mountain barriers. Results from stable isotope analyses of six shorebird species with widespread breeding and wintering origins have shown that Chickaloon Flats plays an important role in providing a refueling area during critically important times during the annual cycle.

The widespread geographic breeding and wintering origins and diverse habitat use of six long-distant migrant species highlights the importance of Chickaloon Flats, Kenai NWR, as a distinct shorebird stopover within the Cook Inlet ecoregion and Northwestern Interior Forest BCR 4 during both spring and fall migration. Species breeding origins were from four of the five Bird Conservation Regions in Alaska: Western Alaska, Arctic Plains and Mountains, Northwestern Interior Forest, and North Pacific Rainforest. Connors et al. (1979) found that shorebirds changed habitat use toward the end of breeding season, and moved from upland tundra breeding sites to coastal littoral staging

areas. Chickaloon may provide this essential post-breeding coastal staging and foraging habitat before the long southern migration, as illustrated through probable breeding origins of both the greater and lesser yellowlegs (Figure 1.2 and 1.3). Wintering regions of shorebirds using Chickaloon Flats are widespread by encompassing 15 southern North American states, Mexico, Baja California, Caribbean Islands, all Central American countries, and 11 different South American countries. I found that the wintering origins of the shorebird species migrating through Chickaloon Flats generally mimic the coastal zones of high productivity, which hold major concentrations of shorebirds (Hötter et al. 1998, Butler et al. 2001). Most of these highly productive areas with major concentrations of birds are recognized as Western Hemisphere Shorebird Reserve Network (WHSRN) sites. WSHRN is a site-specific, hemispheric-scale shorebird conservation strategy developed in the mid-1980s to help address population declines in shorebirds. However, due to marine signatures that would enrich deuterium, some locations may be biased in the assignment of geographic origin. This possible bias may slightly alter the origin assignment, but will still provide valuable, previously unknown, information about the broad geographic origins of individuals.

I found one of the main areas of wintering origins to be along the north coast of South America, which is thought to be the most important wintering area for Nearctic shorebirds and supporting 85.6% of South American shorebirds (Morrison and Ross 1989). Within this coastal area, the importance of the Guiana Coast from Orinoco to Amazon Rivers is connected to mudflat habitats that are fed from the dynamic coastal system associated with the Amazon River (Reynaud 1992). The Guiana coast alone holds

42.1% of South American medium-sized shorebirds (Morrison and Ross 1989). The high concentration of shorebirds in this area is most likely related to the high coastal zone primary productivity of the region (Butler et al. 2001). The presence of suitable habitat and high biological productivity in adjacent coastal waters are major factors in the distribution and abundance of shorebirds on the wintering grounds (Butler et al. 2001).

Although coastal estuaries tend to support large concentrations of shorebirds, the importance of agricultural land to wintering shorebirds should not be overlooked (Evans-Ogden et al. 2008). The most common explanation of shorebirds feeding in agriculture fields is related to insufficient energy intake from intertidal feeding (Goss-Custard 1969, Heppleston 1971). Juveniles tend to feed more in riskier habitats than adults (Warnock 1990), as well as forage in agriculture areas (Evans-Ogden 2005), which emphasizes the importance of fields in supporting shorebird populations. Studies on oystercatchers in the United Kingdom (Stillman et al. 2001) and dunlin on the Fraser Delta (Evans-Ogden 2005) show the importance of intertidal areas with adjacent agriculture fields for wintering shorebird populations. Within the breeding and wintering isotopic signatures of the 6 shorebird species, I found a variety of habitat preferences associated with agricultural habitats. Because feathers are inert, all isotope signatures are associated with feather molt location and therefore agricultural signatures can be related to assigned geographic location.

Table 1.1: Stable isotope values (‰), with agriculture or non-agriculture influence, from summer and winter grown primary feathers of six shorebird species captured during spring and/or fall migrations 2009–2010 on Chickaloon Flats, Kenai National Wildlife Refuge, Alaska.

Species	Molt location		<i>n</i>	$\delta^{13}\text{C}$			$\delta^{15}\text{N}$		
				Mean	SE	Range	Mean	SE	Range
<i>Tringa melanoleuca</i>	Summer	non-agriculture	66	-25.8	0.2	-22.8	7.5	0.1	8.9
		agriculture	1	-27.2			9.2		
<i>Tringa flavipes</i>	Summer	non-agriculture	24	-26.0	0.3	-23.5	7.4	0.2	8.6
		agriculture	2	-27.7	1.6	-26.0	9.6	0.4	9.9
	Winter	non-agriculture	2	-25.5	1.7	-23.9	7.9	0.9	8.8
		agriculture	2	-22.6	0.4	-22.3	11.7	0.9	12.6
<i>Calidris minutilla</i>	Winter	non-agriculture	12	-23.5	0.1	-23.1	5.1	0.6	7.7
		agriculture	1	-20.5			11.0		
<i>Calidris melanotos</i>	Winter	non-agriculture	3	-25.1	1.7	-22.3	8.8	0.1	8.9
		agriculture	8	-23.1	0.7	-20.6	10.6	0.5	12.4
<i>Limnodromus griseus caurinus</i>	Summer	non-agriculture	26	-26.4	0.4	-22.8	5.9	1.3	7.8
<i>L. scolopaceus</i>	Winter	non-agriculture	8	-25.6	1.0	-22.1	6.2	1.1	7.2

Figure 1.1: Location of Chickaloon Flats, most northern portion of Kenai National Wildlife Refuge, Alaska.



Figure 1.2: Probable breeding origins of greater yellowlegs (*Tringa melanoleuca*) captured during migration on Chickaloon Flats, Kenai National Wildlife Refuge, Alaska. Individuals (n=66) were assigned geographic origins using a likelihood-based assignment based on deuterium (δD) values of feathers. Map represents the sum of origin assignments across all birds.

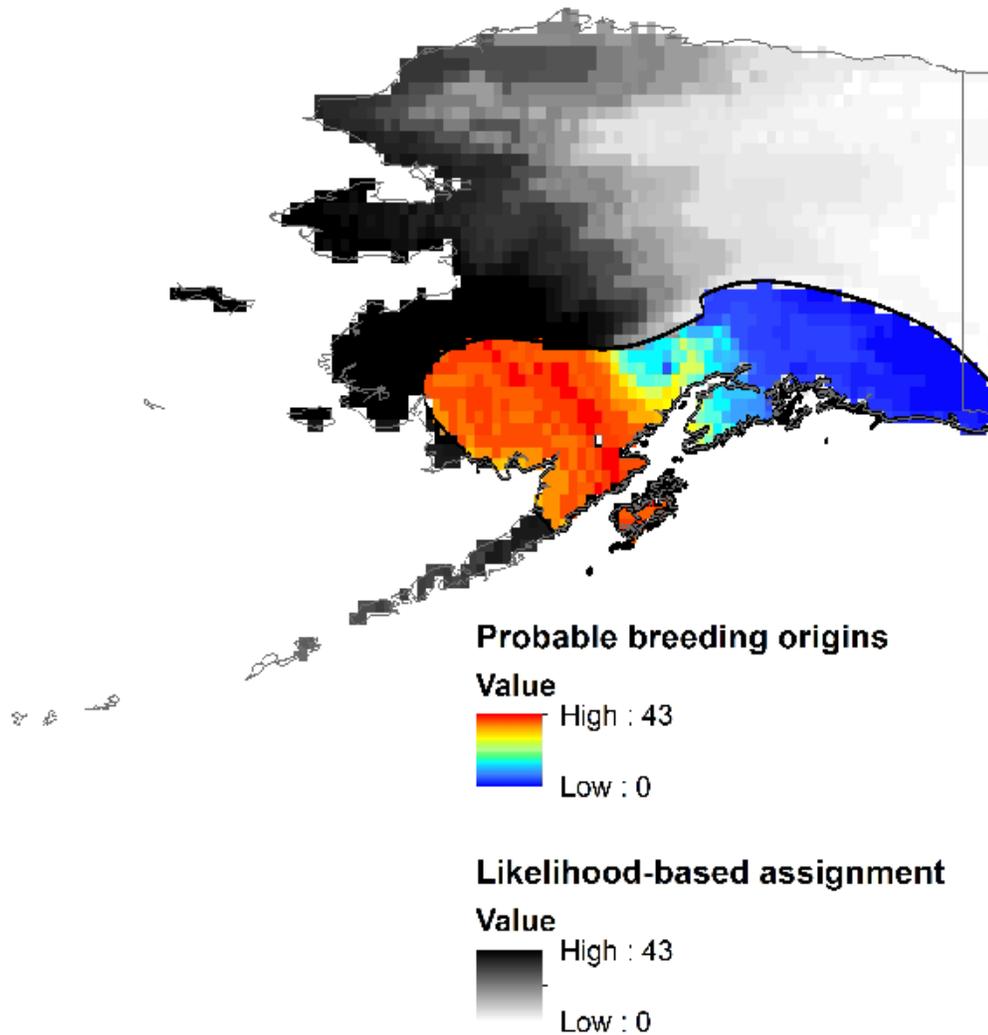


Figure 1.3: Probable breeding origins of lesser yellowlegs (*Tringa flavipes*) captured during migration on Chickaloon Flats, Kenai National Wildlife Refuge, Alaska. Individuals (n=26) were assigned geographic origins using a likelihood-based assignment based on deuterium (δD) values of feathers. Map represents the sum of origin assignments across all birds.

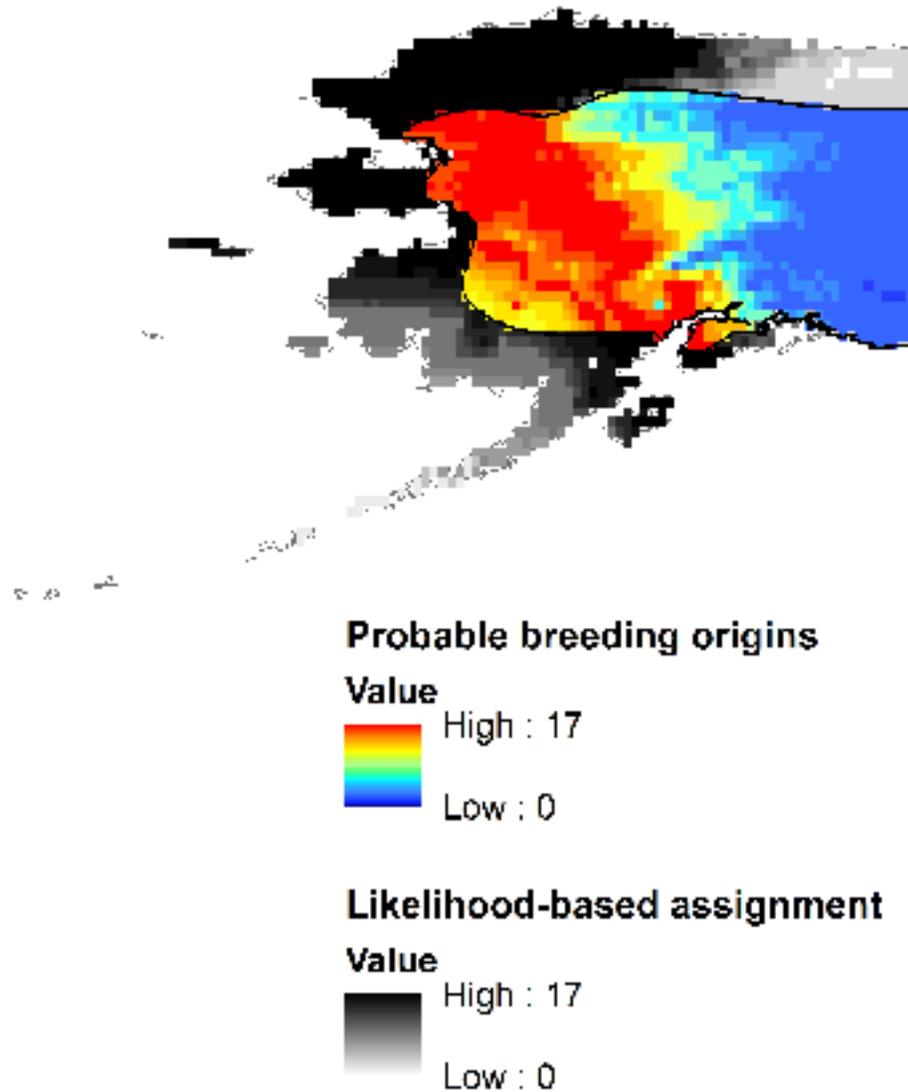


Figure 1.4: Probable wintering origins of lesser yellowlegs (*Tringa flavipes*) captured during migration on Chickaloon Flats, Kenai National Wildlife Refuge, Alaska. Individuals (n=4) were assigned geographic origins using a likelihood-based assignment based on deuterium (δD) values of feathers. Map represents the sum of origin assignments across all birds.

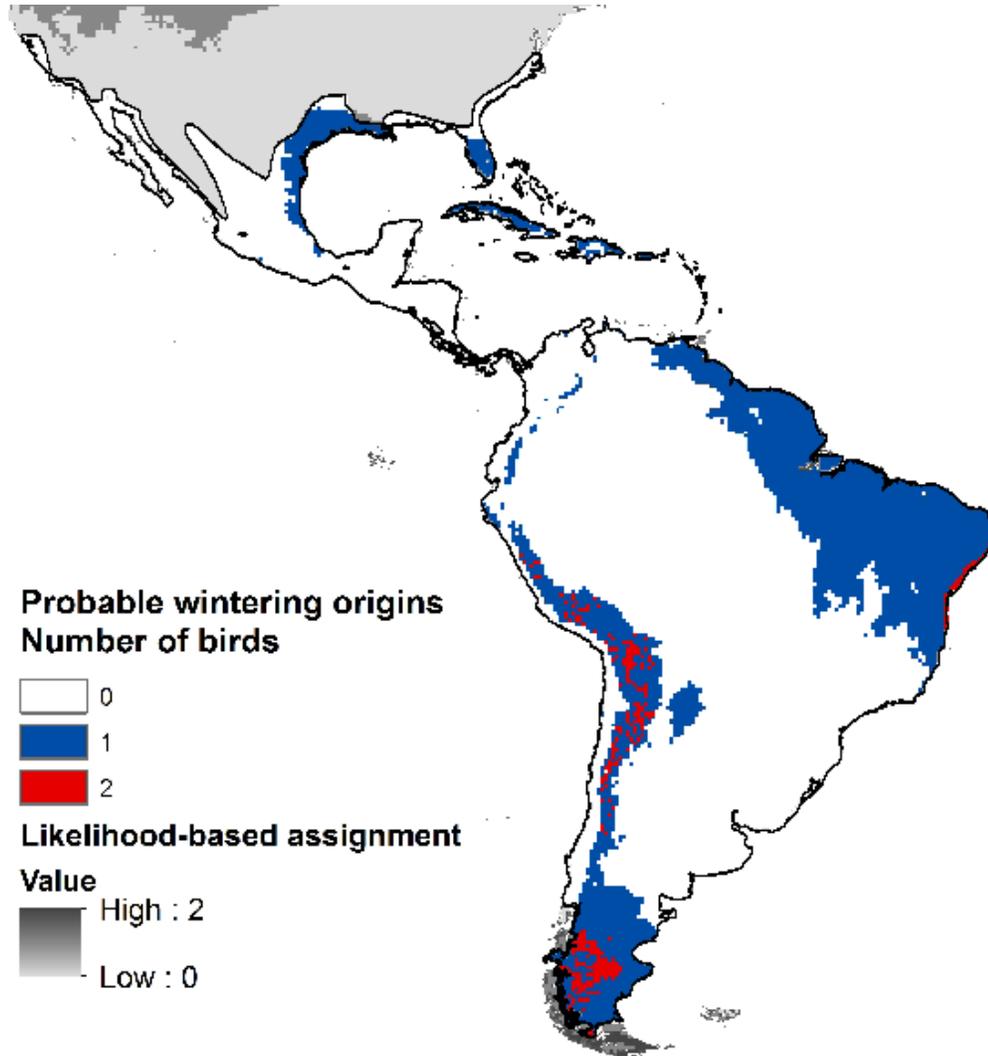


Figure 1.5: Probable wintering origins of least sandpiper (*Calidris minutilla*) captured during migration on Chickaloon Flats, Kenai National Wildlife Refuge, Alaska. Individuals (n=13) were assigned geographic origins using a likelihood-based assignment based on deuterium (δD) values of feathers. Map represents the sum of origin assignments across all birds.

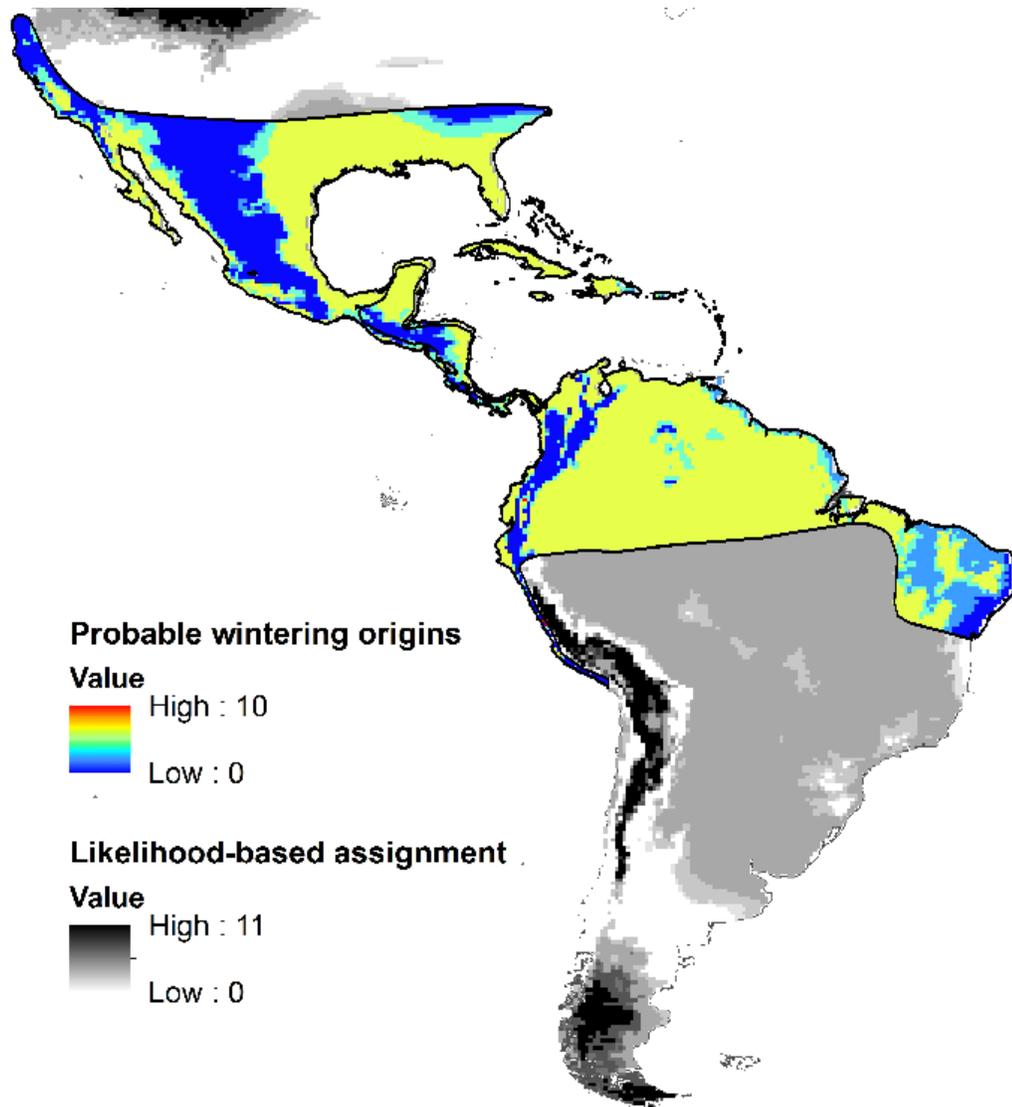


Figure 1.6: Probable wintering origins of pectoral sandpiper (*Calidris melanotos*) captured during migration on Chickaloon Flats, Kenai National Wildlife Refuge, Alaska. Individuals (n=11) were assigned geographic origins using a likelihood-based assignment based on deuterium (δD) values of feathers. Map represents the sum of origin assignments across all birds.

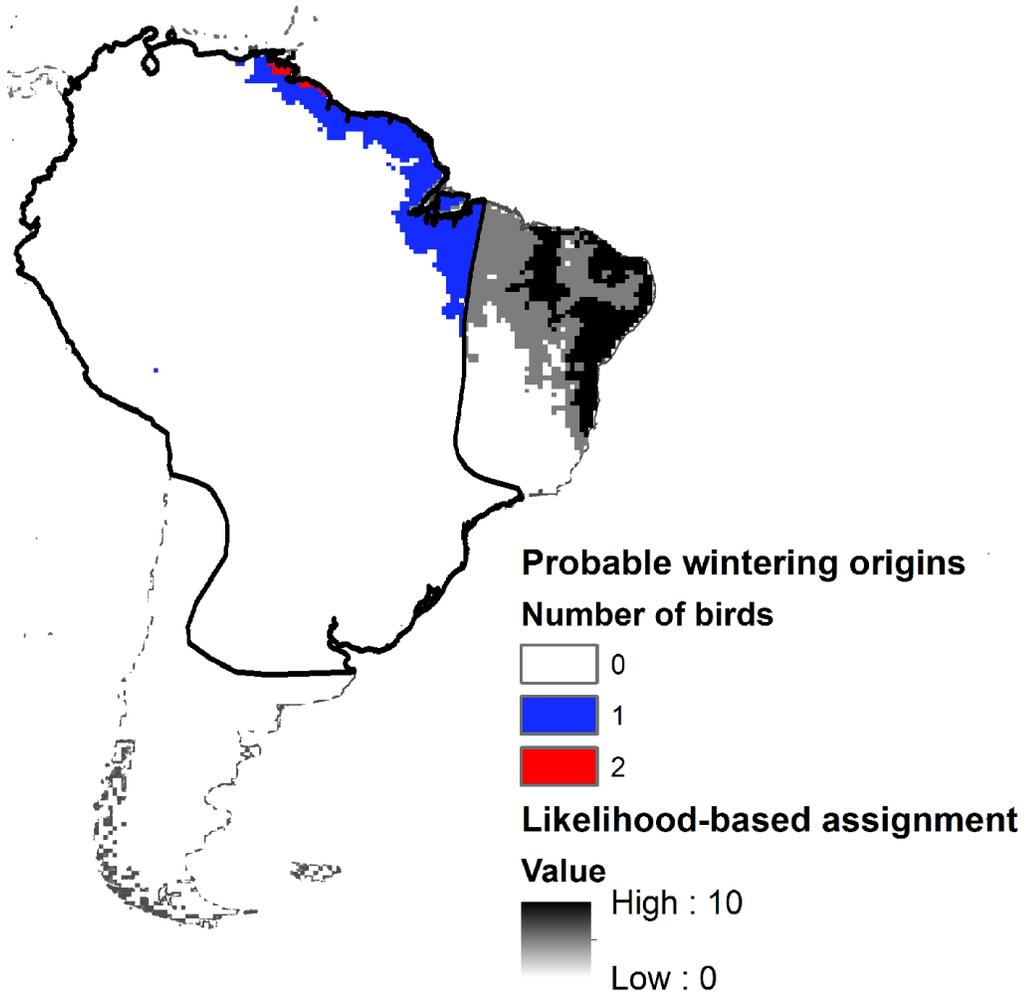


Figure 1.7: Probable breeding origins of short-billed dowitcher (*Limnodromus griseus caurinus*) captured during migration on Chickaloon Flats, Kenai National Wildlife Refuge, Alaska. Individuals (n=26) were assigned geographic origins using a likelihood-based assignment based on deuterium (δD) values of feathers. Map represents the sum of origin assignments across all birds.

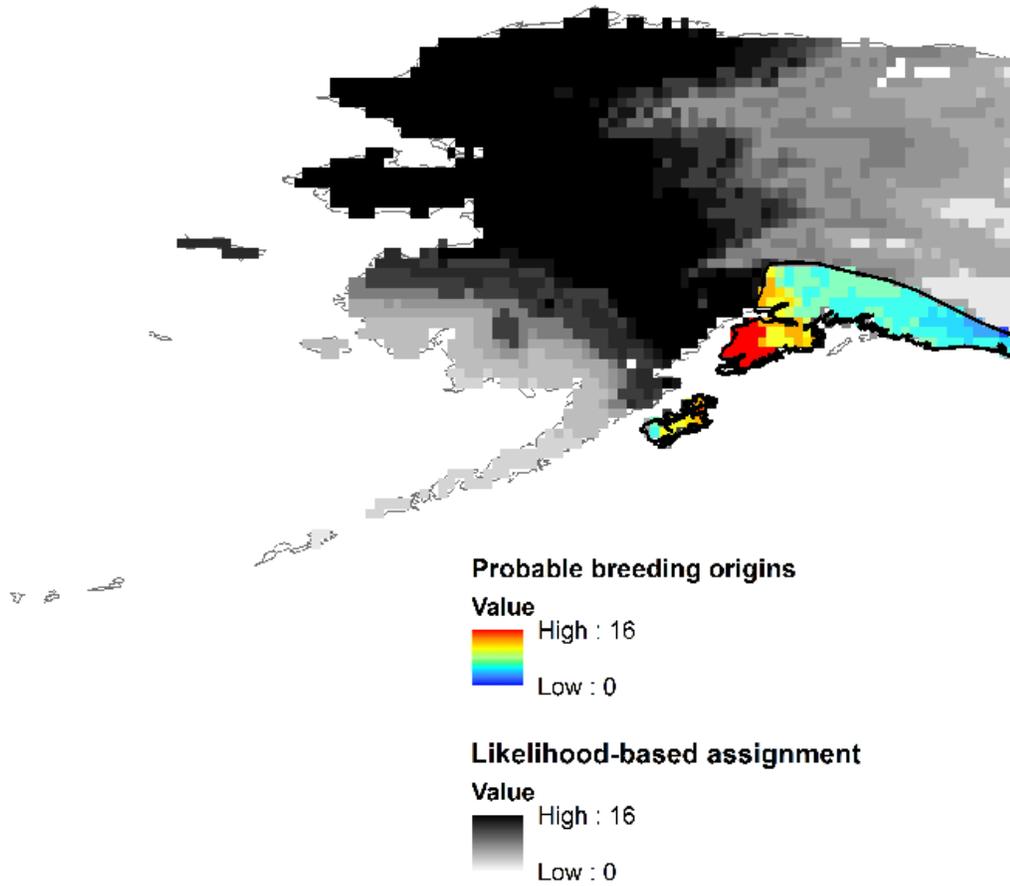
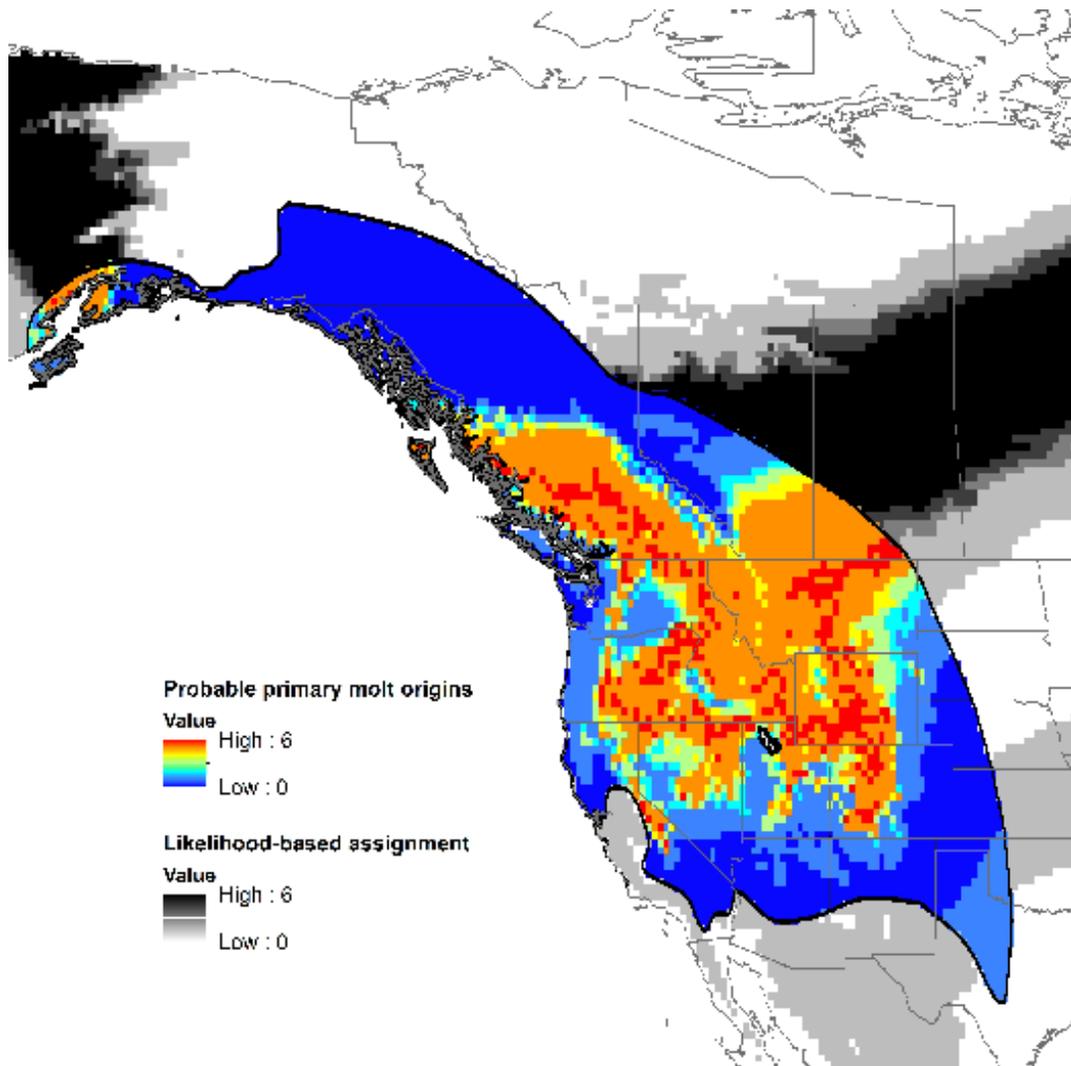
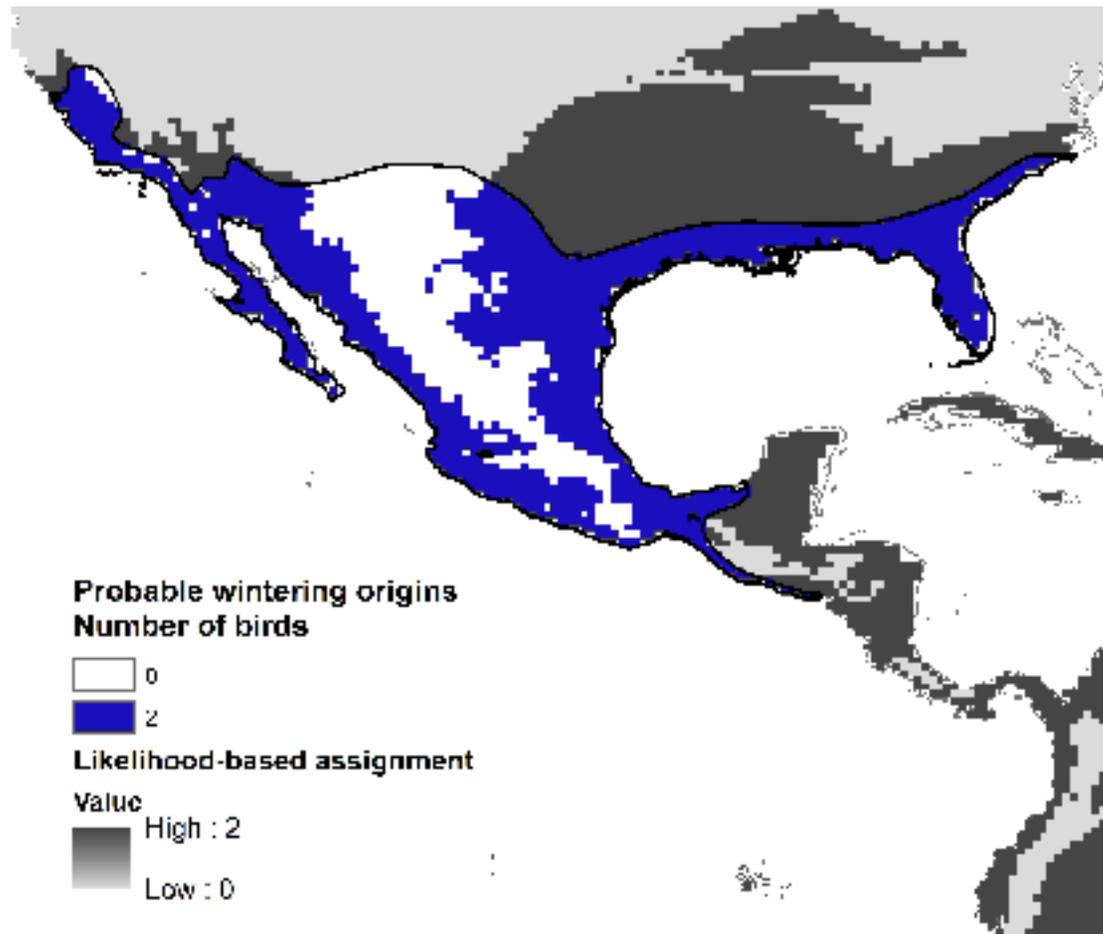


Figure 1.8: Probable *a*) primary molt and *b*) wintering origins of long-billed dowitcher (*Limnodromus scolopaceus*) captured during migration on Chickaloon Flats, Kenai National Wildlife Refuge, Alaska. Individuals (n=7 and 4) were assigned geographic origins using a likelihood-based assignment based on deuterium (δD) values of feathers. Maps represent the sum of origin assignments across all birds.

a.



b.



Chapter 2
AVIAN USE OF CHICKALOON FLATS
ON ALASKA'S SOUTH-CENTRAL COAST

Introduction

Stopover sites along migration routes are important for supporting and sustaining birds as they move between primary wintering, breeding, and staging grounds (Skagen and Knopf 1994*a*, Skagen and Knopf 1994*b*, Farmer and Parent 1997). Shorebird migration is of an opportunistic nature (Skagen and Knopf 1993), and conservation of a network of migration stopovers should contain protected wetlands dispersed widely over the landscape (Haig et al. 1998, Skagen et. al. 2008). Therefore, the importance of particular sites in a network of migration stopovers extends beyond counts of individuals (Bibby 2003). A location may be rarely used, but can be a critical connection to breeding areas (Skagen and Knopf 1994*b*) or buffer environmental stochasticity; e.g. during a cold or dry season or other unusual circumstances such as timing of spring weather near the breeding grounds (Klaassen 2003).

Of particular concern to spring migrating shorebirds is finding ice-free areas with open water and critical foraging habitat. Unlike waterfowl, spring shorebird migration through Alaska occurs in a shorter period of time beginning late April, peaking the first week of May, and finishing mid-May (Gill and Tibbitts 1999, Alaska Shorebird Working Group 2000). Therefore, environmental stochasticity and habitat ice-over have the potential to influence a large portion of spring migrants in Alaska.

Chickaloon Flats, an estuary on Alaska's south-central coast that consists primarily of unconsolidated mudflats and 10 other vegetated communities occurring along a salinity gradient, fits into the aforementioned conservation strategy as a protected coastal stopover site along the Pacific Flyway. As an estuary, this area can provide predictable tidal habitats and a reliable source (compared to interior wetlands) of abundant resources (Colwell 2010). During years of late ice-out, Chickaloon may provide more favorable, ice-free habitats for early spring migrants than other local or regional locations. Cook Inlet provides northern migrating birds with the last considerable area of ice-free littoral habitat before the breeding grounds (Gill and Tibbitts 1999). The availability of early spring ice-free habitat may provide critical foraging habitats for birds encountering iced-over habitats elsewhere in the area (Gill and Tibbitts 1999).

Historically, Chickaloon Flats was thought to be an important avian migratory stopover; however, confirmatory ground surveys of shorebirds have not been conducted since Quimby (1972). Quimby (1972) found avian use of vegetated communities to be variable, with most shorebird species utilizing unvegetated mud areas intensively, marsh vegetated communities moderately, and salt-tolerant vegetation/mud areas infrequently to moderately. However, the vegetation composition of Chickaloon Flats has changed over a 35-year period following the 1964 Earthquake, which registered 9.2 on the Richter scale and caused the land to drop as much as 4 m including decreases in emergent marsh communities and areas of exposed mud and increases in vegetated areas with a mix of mud and salt-tolerant species. I postulated that shorebird use of Chickaloon Flats may have changed to reflect the changing landscape over the past 35 years (see Chapter 3).

Due to a lack of information, my first objective was to observe current shorebird use of Chickaloon Flats during spring and fall migration, focusing on six species: (greater yellowlegs *Tringa melanoleuca*, lesser yellowlegs *Tringa flavipes*, least sandpiper *Calidris minutilla*, pectoral sandpiper *Calidris melanotos*, and short-billed and long-billed dowitcher *Limnodromus griseus caurinus* and *L. scolopaceus*). My second objective was to determine differential shorebird use among the various wetland landcover types within the Flats.

Study area

Chickaloon Flats, Alaska, is a mudflat complex located on the Kenai National Wildlife Refuge along Turnagain Arm in Cook Inlet (Figure 2.1). Tidal range within this area is 9.2 m, which is second greatest in the world behind Bay of Fundy (11.7 m) (Mulherin et al. 2001). Vegetated communities comprise 6,695 ha at high tide (9,533 ha including mud at low tide), and entails about 1% of the 773,759 ha Kenai National Wildlife Refuge. Chickaloon Flats has a high diversity of plant species due to the overlap of arctic and temperate species (Vince and Snow 1984), and the patterns of vegetation are largely due to saltwater and freshwater interactions, land subsistence from the 1964 earthquake, and tides (Neiland 1971, Quimby 1972, and Committee on the Alaska Earthquake 1973). Vegetation composition on Chickaloon Flats, initially described using 10 plant community types (Neiland 1971, Quimby 1972) shows spatial patchiness along a salinity gradient toward Cook Inlet. In addition to mud, the 6 landcover types prevalent enough to be surveyed in this study follow Quimby's (1972) names: Seaside arrow-grass,

Large alkali-grass, Creeping alkali-grass, Marsh, Floating marsh, and Type 3 Mud. For this study, 4 plots (2 km by 4 km) were established to sample all landcover types and avian abundance. Plots were spread across Chickaloon, and chosen by accessibility via the three current aircraft landing strips.

Methods

Landcover

Of the 10 landcover classifications described by Quimby (1972), Bog, Alder, Ramenski sedge, and Marsh fringe communities were not included in avian surveys due to narrow and sparse distribution. The remaining landcover classifications were grouped into four types; Creeping-Large alkali-grass, Floating marsh-Marsh community-Seaside arrow-grass, Mud, and Type 3 Mud. These types were used for analyses of avian survey data.

Avian surveys

To estimate avian diversity and abundance throughout the spring and fall, 2009–2010, I conducted surveys to quantify avian use of different landcover classes. Forty-five avian surveys (Gregory et al. 2004) were conducted throughout spring and fall of 2009 and 2010 every 5–10 days. A survey consisted of 5 to 7 independent transects, with 3 to 5 independent survey points (hereafter called visits) in each transect. Surveys were started between 0730–0830 and 1930–2030 because previous observations concluded that avian use of Chickaloon was linked more to a diurnal cycle rather than tidal stages. I and one other observer conducted a survey; each person completed 3 or 4 transects during a single

survey period, depending on landcover type and slough layout within a plot. Transect locations were randomly chosen every survey for each landcover type and were sampled without replacement to ensure maximum spatial coverage throughout survey periods. A robust spatial distribution of transects was a goal in order to incorporate variation of landcover quality present throughout the study area.

A survey point (visit) was a 100 m fixed-radius plot located entirely within a single landcover type. I assumed observations between points were independent. Each point along a transect was surveyed once. At each survey point, the observer stopped for 5 minutes and recorded every individual within the 100 m radius, ignoring fly-overs and ensuring birds were not double-counted. Infrequently, birds were disturbed when walking between points, and these birds were not recorded. When community types were narrow (~300 m), transects ran down the middle to allow for a sample plot to fall completely within a habitat. Depending on the length of habitat type, transects ran 400–800 m, with the longest transect being the goal.

Density estimates

To estimate densities and detection probabilities of shorebird species, I used negative binomial N-mixture models (Royle 2004a) to evaluate which survey covariate (habitat, season, time of day, and weekly time-period) influenced the detection probability in the pcount function of the ‘unmarked’ package (Fiske and Chandler 2011) for the software R V2.14.0 (R Development Core Team 2011). This approach allows density estimates using point count data, while incorporating the underlying detection process (Royle 2004b). In

all species, season most influenced detectability, and was used as the detection probability covariate in each model.

I estimated densities of 6 common shorebird species; lesser yellowlegs, greater yellowlegs, pectoral sandpiper, least sandpiper, and short- and long-billed dowitcher. I combined the two dowitcher species in the analysis to eliminate possible inaccuracies in estimates and to account for any observer bias and field identification errors. I also analyzed all 18 observed shorebird species pooled across the survey. To determine both spatial and temporal variation, the density (expressed as number detected per 100 m fixed-radius plot) of each species was determined for each combination of four landcover class types, spring and fall seasons, and weekly time-periods.

To generate an estimate of actual daily population size, in one-week increments, across all of Chickaloon Flats, I did a simple area expansion because derived density estimates were from a sample unit of known area (Royle 2004*b*). This produces a useful estimate of population size. I used the following area estimates for area expansion: creeping-large alkali-grass community (3,444 ha), floating marsh-marsh community-seaside arrow-grass (1,806 ha), mud (2,838 ha), and Type 3 mud (1,174 ha). Marsh community does not include area of permanent ponds. Mud includes a portion of coastal mudflats (at low tide) projected into Cook Inlet, as well as bare mud areas between vegetated communities and sloughs.

Results

I conducted 43 surveys, which consisted of 938 survey points across both spring and fall of 2009 and 2010 (Table 2.1). The average survey time per day was 2 h 47 min and

ranged from 1 h 47 min – 3 h 34 min. To improve analysis, survey dates were grouped into a single ‘weekly time-period’, broken into 7 weeks during spring migration and 9 weeks in the fall. Ideally there would have been a more balanced temporal and spatial distribution of surveys across study plots, but due to logistical constraints in plot accessibility, sampling effort varied across the 4 plots. Plots 1 and 2 were surveyed at 5–10 day intervals (Plot 1 N=17 surveys, Plot 2 N=16). Plot 3 was only visited during fall 2010, so only 2 surveys were conducted. I did not include those points in analysis because the plot was not fully represented across both years and season. Plot 4 was visited during spring and fall of both years, with 2–3 surveys per visit (N=10 surveys).

Of 95 bird species observed during the entire study (Appendix E), 42 were recorded during avian point-transect surveys in 2009 and 2010, including 18 shorebird species: black-bellied plover (*Pluvialis squatarola*, N= 37 detections), American-golden plover (*Pluvialis dominica*, N= 1), semipalmated plover (*Charadrius semipalmatus*, N= 36), greater yellowlegs (N= 273), lesser yellowlegs (N= 344), solitary sandpiper (*Tringa solitaria*, N= 6), whimbrel (*Numenius phaeopus*, N= 7), hudsonian godwit (*Limosa haemastica*, N= 32), black turnstone (*Arenaria melanocephala*, N= 9), red knot (*Calidris canutus*, N= 1), semipalmated sandpiper (*Calidris pusilla*, N= 6), western sandpiper (*Calidris mauri*, N= 3), least sandpiper (N= 411), pectoral sandpiper (N= 286), short-and long-billed dowitcher (N= 353), Wilson’s snipe (*Gallinago delicata*, N= 170), and red-necked phalarope (*Phalaropus lobatus*, N= 218).

The detection probability of individual species for spring ranged from 0.37 to 0.92, whereas the fall was much lower with a range of 0.02 to 0.40. The combined

shorebird species detectability was 0.37 in spring and 0.15 in the fall. Greater yellowlegs was 0.56 in spring and 0.11 in fall, and lesser yellowlegs 0.70 and 0.03. Least sandpiper had 0.70 spring detectability and the highest fall detectability with 0.40. Pectoral sandpiper had the highest in the spring at 0.92 and lowest in fall with 0.02. The spring detection for short- and long-billed dowitchers was 0.44 and fall was again the lowest with 0.02.

There were inter-annual and seasonal variations in estimated abundance of shorebirds (Figure 2.3). In both years, more shorebirds used Chickaloon Flats during the fall migration. Spring migration was concentrated, whereas fall was protracted with several migration pulses. Table 2 shows the weekly population estimates for all shorebird species (N=18), greater and lesser yellowlegs, least and pectoral sandpiper, and dowitcher species, recorded during ground surveys during spring and fall migration in 2009 and 2010. Pectoral sandpiper and dowitcher species were the only species more abundant during surveys in the spring than fall. Results from combined shorebird species show larger shorebird populations in the fall (Table 2.2a). The highest daily estimate for the spring occurred during the week of 10 May with an estimated 22,758 (\pm 3,519) birds across all of Chickaloon (Table 2.2a). There were several high estimates during the fall migration, with numerous pulses occurring the weeks of 5 July (85,203 \pm 22,373), 26 July (94,646 \pm 25, 315), and 9 August (97,465 \pm 30,122). The most abundant shorebird species in the spring was the dowitcher, but the least sandpiper and greater yellowlegs were the most abundant in the fall.

The timing of migration pulses and estimated number of birds that make up these pulses varied with species (Table 2.2). Greater yellowlegs abundance peaked in the spring ($3,891 \pm 1,723$) during the week of 10 May, with a prominent fall pulse occurring the week of 9 Aug ($48,435 \pm 11,321$) (Table 2.2b). Lesser yellowlegs exhibited a gradual increase to the spring maximum of $20,536 (\pm 12,200)$ individuals during the first week of June, with a slight increase in fall use of $24,117 (\pm 11,741)$ during the week of 19 July (Table 2.2c). Least sandpipers arrived earlier in the spring, with $5,125 (\pm 2,000)$ birds passing through during the first week of May and a much smaller pulse (606 ± 437) heading into first week of June. There were several pulses during fall migration (Table 2.2d), with the largest two occurring the first week of July ($48,920 \pm 8,606$) and last week of July ($32,615 \pm 7,119$). Pectoral sandpipers had obvious migration pulses in both migration periods (Table 2.2e). The two spring high pulses of $18,044 (\pm 4,902)$ and $17,484 (\pm 4,943)$ individuals were greater than the largest fall pulse ($15,167 \pm 6,437$). Dowitchers had multiple pulses throughout both spring and fall (Table 2.2f), with the largest spring pulse ($27,627 \pm 11,218$) in their first appearance on second week of May, and a similar fall pulse ($26,253 \pm 6,970$) in second week of July.

Shorebirds used landcover types differently (Table 2.2). The Creeping-Large alkali community type was most-densely used by greater yellowlegs, and second most-densely used for all other species. Population estimates for Floating marsh-Marsh community-Seaside arrow-grass landcover type were highest for lesser yellowlegs, pectoral sandpiper and dowitchers. The Mud community was not used by pectoral sandpipers and of minor importance for all other species. The Type 3 Mud was the most-

densely used landcover type for least sandpipers; in contrast, it was least used by all other shorebird species.

Discussion

Chickaloon Flats is an estuary that supports a diversity of avian species during spring and fall migration periods. I observed 39 species and 33 species, respectively, during spring and fall migration. With a peak daily population estimate of 22,758 (\pm 3,519) shorebirds in the spring and 94,646 (\pm 25,345) in the fall, this stopover site (Warnock 2010) has potential to host high numbers of birds for relatively short periods of time.

Vegetation types on Chickaloon Flats vary in area, distribution, and surface water presence. Vegetation composition on Chickaloon Flats changed over a 35-year period following the 1964 Earthquake based on Landsat imagery and point-to-point comparisons. Overall, both the emergent marsh communities and areas of exposed mud have decreased, while vegetated communities with a mix of mud and salt-tolerant species have increased in area. This changing vegetation composition has likely influenced the abundance and diversity of avian species using Chickaloon Flats.

Marsh community-Floating marsh-Seaside arrow-grass was the most used landcover type by shorebird species except the least sandpiper. This landcover type also decreased 7.0% in area from 1970 to 2005. The importance of this vegetation classification type is complicated by the dynamics of ephemeral pools within it. Ephemeral pools are significantly affected by extreme tidal events, which are variable

and sparse in occurrence. I observed the vast majority of shorebirds utilizing this area as roosting grounds rather than for foraging. On numerous accounts, I observed flocks of 40–200 shorebirds leave a marsh roosting area just before high tide and fly towards Cook Inlet, likely to forage on mudflats as high tide ebbed and exposed moist sediments.

Creeping-Large alkali-grass supported high numbers of shorebirds, and was the only landcover type that increased (16.8%) in area over the 35-year period. This landcover type occupied the most area, making up 36.1 % of the area of Chickaloon in 2005.

Mud is a relatively important habitat type for shorebirds in general, but was not highly used by the 6 focal species. Mud decreased 7.3% in area from 1970 to 2005, and could also alter the long-term use of some shorebird species. Chickaloon Flats has relatively hard mud, possibly due to long exposure between high tides. This may deter species which forage by probing because substrate penetrability varies with compaction, and may therefore affect foraging rates (Myers et al. 1980). Probing shorebirds prefer fine, soft sediments compared with the coarse, firm sediment preferred by species which eat off the surface (Colwell 2010). In addition to the mud itself, Mud type (as defined here) consists of sloughs of various sizes, ranging from small channels draining ephemeral pools to larger freshwater (but tidal) creeks such as Big Indian and Pincher Creeks. A variety of shorebird species were observed feeding along these sloughs and at all tidal stages. In contrast to hard-pan mudflats that are available for foraging around high tides, sloughs provide softer substrate throughout the day for foraging shorebirds.

Type 3 Mud, described as mud with sparse patches of alkali-grass, supported the lowest numbers of shorebirds, apart from the least sandpiper. This landcover type decreased slightly in area (2.5%) over the 35-year period, and probably has had minimal long-term impacts in numbers of birds using Chickaloon.

Short- and long-billed dowitchers used Chickaloon Flats in greater numbers in the spring than fall, while greater yellowlegs and least sandpipers were more abundant during the fall. Shorebird migration is more protracted in the fall, and I was unable to sample bird density throughout the entire fall migration period. Therefore, fall estimates may be lower for some species. For example, pectoral sandpipers are late fall migrants and I was only able to observe the first part of their southern migration, and most likely did not capture peak abundances. Detectability of each species was much higher in the spring. Low detection probability during the fall may be attributed to vegetation growth, and therefore lower visibility.

Long-distance shorebird migrants rely on stopover sites to take advantage of seasonally abundant food resources. There is not only importance in a network of stopover sites (Skagen and Knopf 1994*a*, Skagen and Knopf 1994*b*, Farmer and Parent 1997) along a flyway, but also those ranging in sizes from small (Skagen and Knopf 1993) to large (Connors et al. 1979, Isleib 1979). Unlike a major stopover like the Copper River Delta, which supports hundreds of thousands of migrating shorebirds on a daily basis in the spring (Bishop et al. 2000), Chickaloon supports an estimated maximum spring daily total of 17,304 (\pm 3,238) birds.

The importance of the location of a stopover within a migration flyway (Isleib 1979) can also be critical to migrating birds. Most of the Nearctic shorebirds that breed in western Alaska use a narrow migration corridor that follows the coast, which also presents topographic and climatic obstacles (Isleib 1979). Birds are funneled into coastal south-central Alaska and are offered two main areas, Copper River Delta and Lower Cook Inlet, with suitable shallow estuarine, tidal mudflats, and marsh areas to rest and refuel (Isleib 1979). The Copper River Delta area offers >100,000 ha of shorebird habitat, while the areas of Lower Cook Inlet, situated 300 km to the west, offer several estuaries an order of magnitude smaller (Isleib 1979, Gill and Tibbitts 1999). There are differences in relative community composition between these areas during spring migration. At least 20 shorebird species have been recorded on the Copper River Delta, of which the western sandpiper and dunlin have the greatest relative numbers (Christensen et al. 2000), while lesser yellowlegs and *Limnodromus* species have greatest relative numbers of the 24 shorebird species of Chickaloon Flats.

Isleib (1979) reported fall shorebird migrations in south-coastal Alaska are not as intense as spring migration. Aerial surveys conducted by Gill and Tibbitts (1999) support this conclusion, averaging 40,485 shorebirds per day during spring in contrast to only 730 per day during fall in the Lower Cook Inlet. However, I estimated 5 times more shorebird use of Turnagain Arm during the fall than spring. Chickaloon Flats is located in the Upper Cook Inlet, nestled in Turnagain Arm against the western edge of the Kenai and Chugach mountains. Relative to the Copper River Delta and Lower Cook Inlet,

Chickaloon Flats may be more difficult for avian species to access during northern migration because of these mountain barriers (Figure 2.2).

As shown through stable isotope analysis (see Chapter 1), Chickaloon provides a stopover site for numerous long-distance migrant shorebird species that breed in Alaska and winter from southern North America down through central South America. Connors et al. (1979) found that shorebirds changed habitat use toward the end of breeding season, and moved from upland tundra breeding sites to coastal littoral staging areas. Chickaloon may provide this essential post-breeding roosting and foraging habitat for shorebirds before beginning the long southern migration, as illustrated through probable breeding origins of both greater and lesser yellowlegs utilizing Chickaloon as a post-breeding site.

This study indicates that shorebird use of Chickaloon is much more extensive during the southern migration. There are fewer spring migration peaks, with fall migration showing a more protracted, variable migration. With an area of 9,533 ha, Chickaloon Flats is relatively-small, yet offers 7% of estuarine intertidal shorebird habitat in the south-central Alaskan region. Chickaloon supports Although Chickaloon Flats is not recognized as a major stopover for migrating shorebirds, it is an important area utilized by a diverse amount of avian species throughout the annual cycle.

Table 2.1 Number of transects and visits from 43 avian surveys conducted on Chickaloon Flats, Kenai National Wildlife Refuge, 2009–2010. Transects and visits are shown by season, year, vegetation classification type, and plot.

		Number of transects	Number of visits
Overall		270	938
Season	Spring	117	423
	Fall	153	515
Year	2009	105	405
	2010	165	533
Vegetation classification type	Creeping-Large alkali grass	89	311
	Floating marsh-Marsh community-Seaside arrow-grass	106	377
	Mud	38	128
	Type 3 mud	37	122
Plot	1	94	356
	2	118	374
	4	58	208

Table 2.2: Shorebird species population estimates (\pm SE) across total area of landcover types during 7 spring migration weeks and 9 fall migration weeks. Mean values account for species-specific detectability and were derived for (a) All combined 18 species, (b) greater yellowlegs, (c) lesser yellowlegs, (d) least sandpiper, (e) pectoral sandpiper, and (f) dowitcher species. Population estimates derived from density at 100 m fixed radius plot and extrapolated across landcover type area. Sample size of visits (N=) are indicated at each week and landcover class. Spring dates start on April 26 (week 1) and finish June 14 (end week 7). Fall dates start on June 28 (week 1) and finish August 30 (end week 9).

(a)

	Week	Total of all landcover types	N=	Creeping and Large alkali-grass		Floating marsh- Marsh community- Seaside arrow-grass		Mud		Type 3 Mud	
				N=	N=	N=	N=	N=	N=		
Spring	1	2,071 \pm 1,068	37	658 \pm 340	9	627 \pm 322	18	705 \pm 361	3	82 \pm 45	7
	2	15,793 \pm 4,871	23	5,010 \pm 1,524	8	4,777 \pm 1,454	7	5,375 \pm 1,680	5	632 \pm 213	3
	3	22,758 \pm 3,519	129	7,225 \pm 1,074	56	6,880 \pm 1,035	45	7,741 \pm 1,219	17	912 \pm 191	11
	4	14,546 \pm 2,601	94	4,615 \pm 811	29	4,397 \pm 764	37	4,950 \pm 894	14	583 \pm 131	14
	5	17,304 \pm 3,238	70	5,492 \pm 1,009	23	5,231 \pm 948	29	5,890 \pm 1,120	8	691 \pm 161	10
	6	11,845 \pm 2,825	41	3,760 \pm 888	14	3,581 \pm 839	15	4,029 \pm 967	6	475 \pm 131	6
	7	15,384 \pm 4,088	24	4,879 \pm 1,283	7	4,650 \pm 1,219	10	5,239 \pm 1,400	4	617 \pm 187	3
Fall	1	37,780 \pm 10,770	46	11,983 \pm 3,431	14	11,421 \pm 3,173	16	12,863 \pm 3,676	9	1,513 \pm 490	7
	2	85,203 \pm 22,373	64	27,035 \pm 7,126	19	25,757 \pm 6,507	31	28,996 \pm 7,705	5	3,416 \pm 1,035	9
	3	80,309 \pm 19,825	154	25,478 \pm 6,315	47	24,280 \pm 5,765	66	27,334 \pm 6,811	21	3,218 \pm 934	20
	4	47,269 \pm 12,762	67	14,997 \pm 4,067	21	14,290 \pm 3,736	27	16,088 \pm 4,372	10	1,895 \pm 587	9
	5	94,646 \pm 25,315	65	30,028 \pm 8,047	21	28,614 \pm 7,403	26	32,212 \pm 8,699	8	3,793 \pm 1,166	10
	6	31,609 \pm 10,130	36	10,031 \pm 3,223	12	9,553 \pm 2,995	14	10,758 \pm 3,460	6	1,267 \pm 452	4
	7	97,465 \pm 30,122	29	30,927 \pm 9,582	17	29,464 \pm 8,915	6	33,169 \pm 10,280	3	3,905 \pm 1,345	3
	8	33,370 \pm 10,231	29	10,590 \pm 3,245	3	10,088 \pm 3,018	17	11,354 \pm 3,505	6	1,338 \pm 463	3
	9	67,315 \pm 20,320	18	21,356 \pm 6,490	3	20,354 \pm 5,972	9	22,908 \pm 6,946	3	2,698 \pm 912	3

(b)

	Week	Total of all	N=	Creeping and	N=	Floating marsh-	N=	Mud	N=	Type 3 Mud	N=
		landcover types		Large alkali-grass		Marsh community- Seaside arrow-grass					
Greater yellowlegs <i>(Tringa melanoleuca)</i>	Spring										
	1	530 ± 576	37	186 ± 208	9	190 ± 201	18	135 ± 145	3	19 ± 22	7
	2	2,317 ± 1,876	23	822 ± 658	8	822 ± 655	7	587 ± 488	5	86 ± 75	3
	3	3,891 ± 1,723	129	1,381 ± 603	56	1,380 ± 586	45	985 ± 452	17	146 ± 82	11
	4	467 ± 378	94	164 ± 132	29	167 ± 132	37	117 ± 99	14	19 ± 15	14
	5	894 ± 626	70	318 ± 219	23	316 ± 218	29	226 ± 163	8	34 ± 26	10
	6	0 ± 0	41	0 ± 0	14	0 ± 0	15	0 ± 0	6	0 ± 0	6
7	0 ± 0	24	0 ± 0	7	0 ± 0	10	0 ± 0	4	0 ± 0	3	
Greater yellowlegs <i>(Tringa melanoleuca)</i>	Fall										
	1	7,087 ± 2,502	46	2,521 ± 877	14	2,512 ± 816	16	1,789 ± 677	9	265 ± 131	7
	2	4,110 ± 1,614	64	1,458 ± 570	19	1,460 ± 523	31	1,039 ± 443	5	153 ± 78	9
	3	7,206 ± 1,882	154	2,554 ± 658	47	2,558 ± 558	66	1,825 ± 551	21	269 ± 116	20
	4	4,931 ± 1,714	67	1,754 ± 603	21	1,747 ± 552	27	1,247 ± 470	10	183 ± 90	9
	5	8,110 ± 2,600	65	2,883 ± 899	21	2,874 ± 828	26	2,050 ± 732	8	303 ± 142	10
	6	2,718 ± 1,488	36	965 ± 526	12	966 ± 506	14	687 ± 388	6	101 ± 67	4
	7	48,435 ± 11,321	29	17,212 ± 3,936	17	17,175 ± 3,202	6	12,240 ± 3,433	3	1,809 ± 751	3
	8	12,771 ± 3,897	29	4,539 ± 1,337	3	4,529 ± 1,224	17	3,225 ± 1,111	6	478 ± 224	3
9	28,009 ± 8,630	18	9,954 ± 3,070	3	9,927 ± 2,661	9	7,082 ± 2,421	3	1,046 ± 478	3	

(c)

	Week	Total of all landcover types		Creeping and Large alkali-grass		Floating marsh- Marsh community- Seaside arrow-grass		Mud		Type 3 Mud		
			N=		N=		N=		N=		N=	
Lesser yellowlegs (<i>Tringa flavipes</i>)	Spring	1	630 ± 778	37	219 ± 252	9	397 ± 443	18	6 ± 72	3	7 ± 11	7
		2	7,214 ± 5,218	23	2,313 ± 1,644	8	4,139 ± 2,960	7	668 ± 524	5	93 ± 90	3
		3	7,125 ± 4,237	129	2,291 ± 1,327	56	4,081 ± 2,385	45	659 ± 443	17	93 ± 82	11
		4	6,512 ± 3,864	94	2,094 ± 1,217	29	3,736 ± 2,178	37	596 ± 397	14	86 ± 71	14
		5	12,542 ± 7,211	70	4,034 ± 2,258	23	7,191 ± 4,052	29	1,156 ± 759	8	161 ± 142	10
		6	14,423 ± 8,154	41	4,637 ± 2,554	14	8,271 ± 4,581	15	1,328 ± 858	6	187 ± 161	6
		7	20,536 ± 12,200	24	6,600 ± 3,837	7	11,783 ± 6,863	10	1,888 ± 1,265	4	265 ± 235	3
	Fall	1	5,520 ± 3,902	46	1,776 ± 1,250	14	3,167 ± 2,184	16	506 ± 397	9	71 ± 71	7
		2	13,645 ± 7,071	64	4,385 ± 2,269	19	7,829 ± 3,863	31	1,256 ± 786	5	176 ± 153	9
		3	23,224 ± 10,413	154	7,466 ± 3,355	47	13,318 ± 5,610	66	2,141 ± 1,201	21	299 ± 247	20
		4	24,117 ± 11,741	67	7,751 ± 3,771	21	13,830 ± 6,386	27	2,222 ± 1,319	10	314 ± 265	9
		5	23,970 ± 11,957	65	7,707 ± 3,837	21	13,749 ± 6,518	26	2,204 ± 1,337	8	310 ± 265	10
		6	3,412 ± 2,842	36	1,096 ± 910	12	1,954 ± 1,604	14	316 ± 280	6	45 ± 49	4
		7	0 ± 0	29	0 ± 0	17	0 ± 0	6	0 ± 0	3	0 ± 0	3
8	0 ± 0	29	0 ± 0	3	0 ± 0	17	0 ± 0	6	0 ± 0	3		
9	0 ± 0	18	0 ± 0	3	0 ± 0	9	0 ± 0	3	0 ± 0	3		

(d)

		Week	Total of all landcover types	N=	Creeping and Large alkali-grass	N=	Floating marsh- Marsh community- Seaside arrow-grass	N=	Mud	N=	Type 3 Mud	N=
Least sandpiper (<i>Calidris minutilla</i>)	Spring	1	422 ± 433	37	110 ± 121	9	115 ± 115	18	63 ± 63	3	135 ± 135	7
		2	5,125 ± 2,000	23	1,381 ± 647	8	1,374 ± 592	7	741 ± 36	5	1,629 ± 725	3
		3	3,815 ± 862	129	1,031 ± 274	56	1,023 ± 207	45	551 ± 126	17	1,211 ± 254	11
		4	296 ± 207	94	77 ± 55	29	80 ± 57	37	45 ± 27	14	93 ± 67	14
		5	0 ± 0	70	0 ± 0	23	0 ± 0	29	0 ± 0	8	0 ± 0	10
		6	606 ± 437	41	164 ± 121	14	161 ± 115	15	90 ± 63	6	191 ± 138	6
		7	0 ± 0	24	0 ± 0	7	0 ± 0	10	0 ± 0	4	0 ± 0	3
	Fall	1	7,369 ± 2,789	46	1,995 ± 811	14	1,977 ± 741	16	1,057 ± 406	9	2,339 ± 830	7
		2	48,920 ± 8,606	64	13,221 ± 3,059	19	13,111 ± 2,167	31	7,064 ± 1,310	5	15,523 ± 2,070	9
		3	24,297 ± 4,469	154	6,567 ± 1,557	47	6,512 ± 1,138	66	3,505 ± 687	21	7,713 ± 1,087	20
		4	8,217 ± 2,501	67	2,215 ± 756	21	2,207 ± 650	27	1,183 ± 370	10	2,612 ± 725	9
		5	32,615 ± 7,119	65	8,814 ± 2,335	21	8,743 ± 1,811	26	4,706 ± 1,075	8	10,351 ± 1,898	10
		6	17,451 ± 5,261	36	4,714 ± 1,601	12	4,679 ± 1,374	14	2,520 ± 777	6	5,538 ± 1,510	4
		7	7,428 ± 3,810	29	2,006 ± 1,074	17	1,989 ± 1,012	6	1,075 ± 551	3	2,358 ± 1,173	3
	8	5,516 ± 2,482	29	1,491 ± 702	3	1,477 ± 684	17	795 ± 352	6	1,753 ± 744	3	
	9	2,236 ± 2,273	18	603 ± 625	3	598 ± 609	9	325 ± 325	3	710 ± 714	3	

(e)

	Week	Total of all	N=	Creeping and	N=	Floating marsh-	N=	Mud	N=	Type 3 Mud	N=	
		landcover types		Large alkali-grass		Marsh community- Seaside arrow-grass						
Pectoral sandpiper (<i>Calidris melanotos</i>)	Spring	1	0 ± 0	37	0 ± 0	9	0 ± 0	18	0 ± 0	3	0 ± 0	7
		2	0 ± 0	23	0 ± 0	8	0 ± 0	7	0 ± 0	5	0 ± 0	3
		3	18,044 ± 4,902	129	3,582 ± 1,171	56	13,617 ± 3,215	45	0 ± 0	17	845 ± 517	11
		4	11,101 ± 3,449	94	2,204 ± 827	29	8,380 ± 2,294	37	0 ± 0	14	517 ± 329	14
		5	17,484 ± 4,943	70	3,478 ± 1,205	23	13,184 ± 3,233	29	0 ± 0	8	822 ± 505	10
		6	0 ± 0	41	0 ± 0	14	0 ± 0	15	0 ± 0	6	0 ± 0	6
		7	0 ± 0	24	0 ± 0	7	0 ± 0	10	0 ± 0	4	0 ± 0	3
	Fall	1	0 ± 0	46	0 ± 0	14	0 ± 0	16	0 ± 0	9	0 ± 0	7
		2	0 ± 0	64	0 ± 0	19	0 ± 0	31	0 ± 0	5	0 ± 0	9
		3	0 ± 0	154	0 ± 0	47	0 ± 0	66	0 ± 0	21	0 ± 0	20
		4	0 ± 0	67	0 ± 0	21	0 ± 0	27	0 ± 0	10	0 ± 0	9
		5	0 ± 0	65	0 ± 0	21	0 ± 0	26	0 ± 0	8	0 ± 0	10
		6	0 ± 0	36	0 ± 0	12	0 ± 0	14	0 ± 0	6	0 ± 0	4
		7	0 ± 0	29	0 ± 0	17	0 ± 0	6	0 ± 0	3	0 ± 0	3
8	6,860 ± 3,009	29	1,378 ± 654	3	5,165 ± 2,131	17	0 ± 0	6	317 ± 223	3		
9	15,167 ± 6,437	18	3,031 ± 1,446	3	11,432 ± 4,497	9	0 ± 0	3	704 ± 493	3		

(f)

	Week	Total of all landcover types		Creeping and Large alkali-grass		Floating marsh- Marsh community- Seaside arrow-grass		Mud		Type 3 Mud		
			N=		N=		N=		N=		N=	
Dowitcher (<i>Limnodromus</i>) species	Spring	1	0 ± 0	37	0 ± 0	9	0 ± 0	18	0 ± 0	3	0 ± 0	7
		2	0 ± 0	23	0 ± 0	8	0 ± 0	7	0 ± 0	5	0 ± 0	3
		3	27,627 ± 11,218	129	7,444 ± 3,201	56	18,181 ± 6,415	45	1,400 ± 1,120	17	602 ± 482	11
		4	21,937 ± 11,123	94	5,909 ± 3,081	29	14,439 ± 6,691	37	1,111 ± 948	14	478 ± 404	14
		5	6,027 ± 4,052	70	1,623 ± 1,107	23	3,966 ± 2,529	29	307 ± 289	8	131 ± 127	10
		6	8,467 ± 6,191	41	2,280 ± 1,677	14	5,570 ± 3,897	15	434 ± 434	6	183 ± 183	6
		7	13,259 ± 9,703	24	3,574 ± 2,642	7	8,720 ± 6,104	10	677 ± 668	4	288 ± 288	3
	Fall	1	2,114 ± 2,220	46	570 ± 603	14	1,391 ± 1,426	16	108 ± 135	9	45 ± 56	7
		2	18,637 ± 7,282	64	5,021 ± 2,061	19	12,260 ± 4,150	31	948 ± 750	5	407 ± 321	9
		3	26,253 ± 6,970	154	7,071 ± 2,138	47	17,273 ± 3,426	66	1,337 ± 985	21	572 ± 422	20
		4	2,563 ± 1,982	67	691 ± 537	21	1,690 ± 1,253	27	126 ± 135	10	56 ± 56	9
		5	18,517 ± 7,448	65	4,988 ± 2,083	21	12,186 ± 4,294	26	939 ± 750	8	404 ± 321	10
		6	2,429 ± 2,550	36	658 ± 691	12	1,592 ± 1,638	14	126 ± 154	6	52 ± 67	4
		7	0 ± 0	29	0 ± 0	17	0 ± 0	6	0 ± 0	3	0 ± 0	3
8	0 ± 0	29	0 ± 0	3	0 ± 0	17	0 ± 0	6	0 ± 0	3		
9	0 ± 0	18	0 ± 0	3	0 ± 0	9	0 ± 0	3	0 ± 0	3		

Figure 2.1: Location of Chickaloon Flats, Kenai National Wildlife Refuge, Alaska. Land-cover type classifications overlaid with four study plots (2 x 4 km).

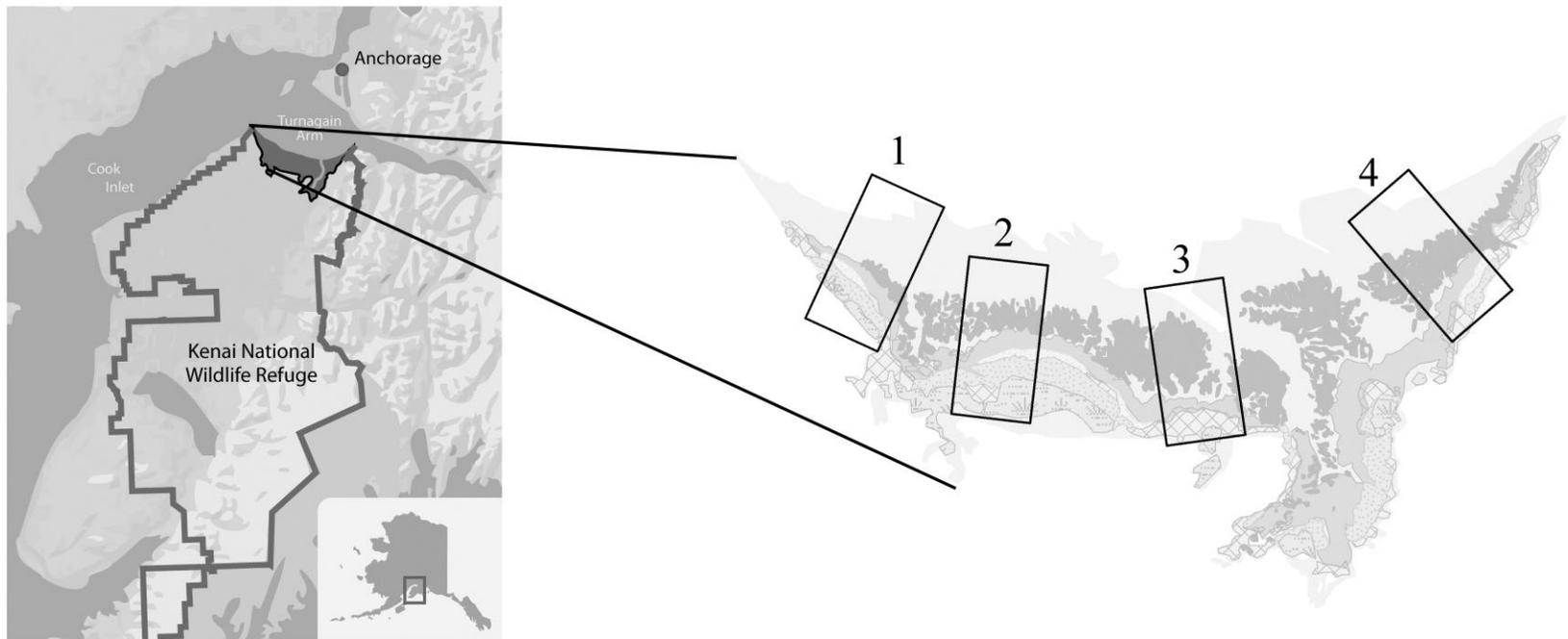
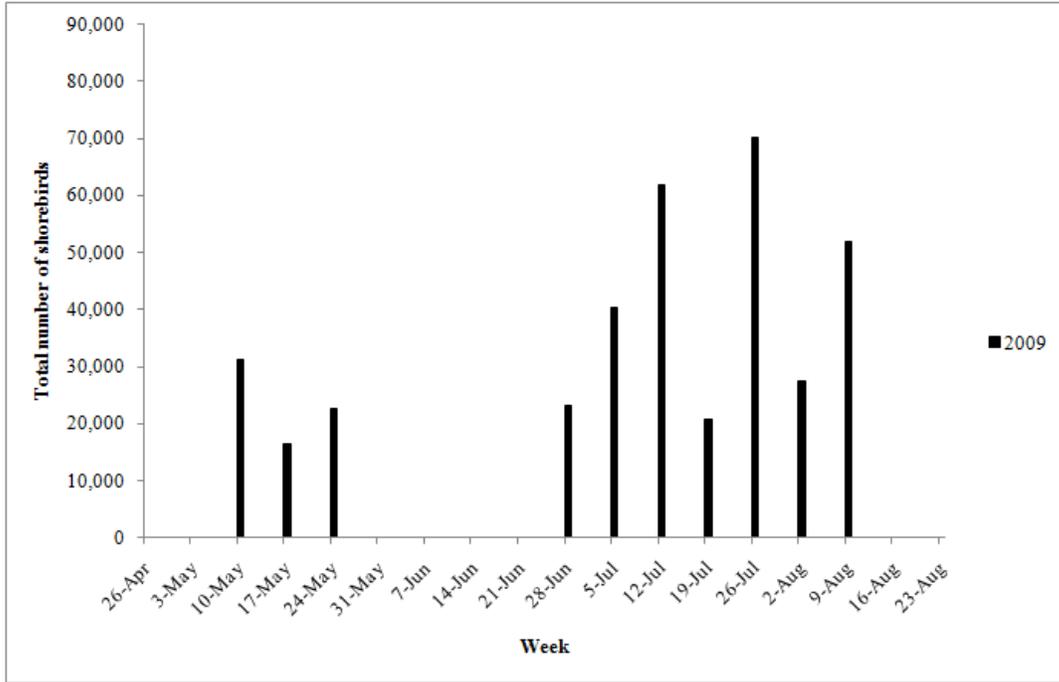


Figure 2.2: All survey points (visits) for avian surveys during spring and fall 2009 and 2010. Each point was a 100 m fixed-radius plot within a single landcover type.

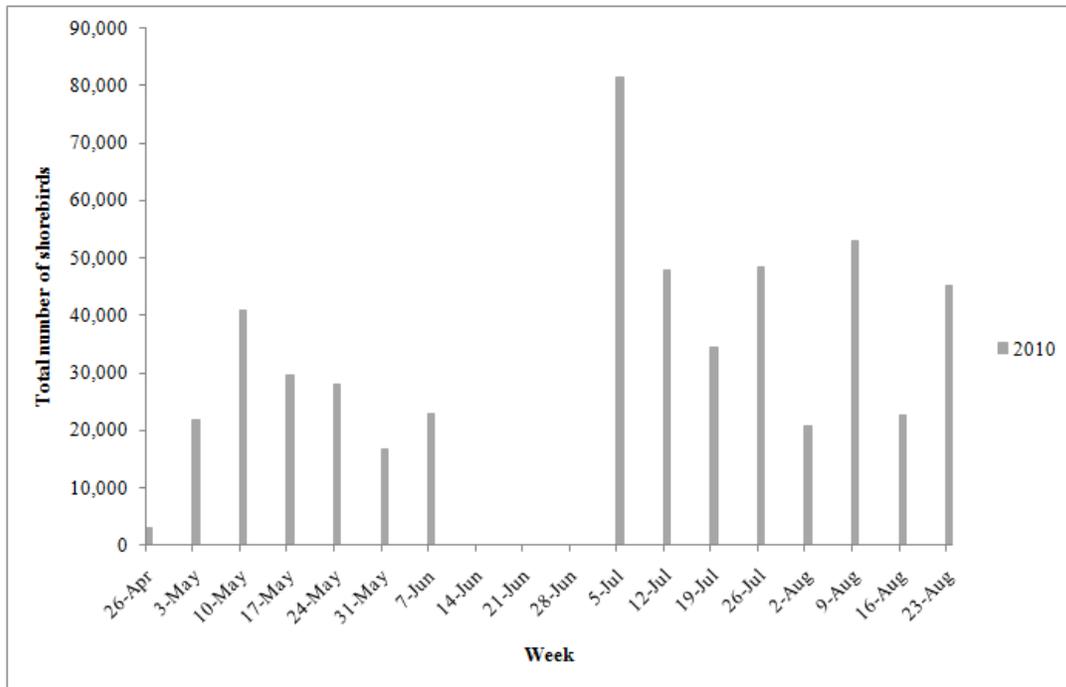


Figure 2.3: Weekly population estimates from ground survey data in a) 2009 and b) 2010 for 18 shorebird species across Chickaloon Flats, Alaska.

a.



b.



**SATELLITE IMAGE BASED VEGETATION CLASSIFICATION AND CHANGE
OVER 30 YEARS ON CHICKALOON FLATS**

Introduction

Alaska experiences postseismic vertical motions from the large megathrust earthquakes caused by its location on a convergent plate boundary (Larsen et al. 2005). The 1964 ‘Good Friday’ Earthquake was one of the strongest earthquakes in recent time; registering between 8.3–8.6 on the Richter scale with its epicenter about 125 km east of Anchorage in the Chugach Mountains, and significantly changed the landscape, and consequently the vegetation, of the surrounding areas. Thilenius (1990) showed the change in landscape greatly altered the tidal regime, and therefore the rate and pattern of vegetation succession on the Copper River Delta. Atwater et al. (2001) showed that following the subsidence caused by the 1964 earthquake, vegetated estuary areas in Turnagain Arm were turned to barren tidal flats (although these have aggraded rapidly and vegetation on the flats is maturing). Findings from those Turnagain Arm mudflats showed that sediment quickly filled in available areas following subsidence from the 1964 Earthquake (Atwater et al. 2001), and deposition slowed and sediment became finer into the 1980’s (Bartsch-Winkler 1988). Unlike most intertidal environments, Turnagain Arm has a clear lack of infauna (Bartsch-Winkler and Ovenshine 1984), which may be due to high amounts of suspended sediment from glacial rivers and erosion, as well as swift moving currents and tidal bore presence (Bartsch-Winkler and Ovenshine 1984). It

is unknown whether these changes have impacted the condition of the estuary and subsequently the use by avifauna.

Anecdotal field observations from 2009 showed vast mud areas spread within the Large alkali-grass and Creeping alkali-grass vegetated communities. These observations, paired with the knowledge that changes in elevation and vegetation (Thilenius 1990, Atwater et al. 1991) are produced by sea-level rise, postseismic vertical motions, and rapid uplift have prompted a discussion of the current health of the Chickaloon estuary. These vast mud areas could be a product of landscape change following the 1964 Earthquake, which could have altered the tidal regime (Thilenius 1990) and increased aggradations (Atwater et al. 1991) with sediment lacking infauna (Bartsch-Winkler and Ovenshine 1984). Alternatively, the vegetation succession could be occurring at a more rapid rate following the earthquake (much like the Copper River Delta, Thilenius 1990) and the current areas of mud pans are smaller than more recent post-earthquake mud areas. Due to the historical thought that Chickaloon Flats was an important avian migratory stopover, with relative regional importance in terms of estuarine intertidal area within Cook Inlet and Prince William Sound, there was a need to evaluate the current vegetation classification and determine if any changes have occurred since the last ground study in 1970 and 1971 (Quimby 1972). Therefore, the objectives of this study were to create an updated vegetation classification map of Chickaloon Flats, and quantify any changes in both non-vegetated and vegetation communities from 1975 to 2005.

Study Area

Cook Inlet is an important Alaskan water body with more than half (over 400,000) of the state's human population residing along its shores and watershed. It is a multi-use area used for commercial and recreational fishing, cargo transportation, and oil and gas exploration and production in northern areas since the 1960's (Mulherin et al. 2001). Chickaloon Flats is located along the northern part of the Kenai Peninsula (Figure 3.1), entailing about 10,000 ha of the 773,759 ha Kenai National Wildlife Refuge. Turnagain Arm, an extension of Cook Inlet, bounds the flats to the north, the Kenai Mountains to the east and southeast, and Kenai Lowlands to the south and west. Several riverine systems flow into this complex including the Chickaloon River, Big and Little Indian Creeks, and Pincher Creek. Chickaloon is an estuary of regional importance, representing 7% of all estuarine intertidal areas of the Cook Inlet and Prince William Sound area (Figure 3.2). Large alkali-grass (*Puccinellia grandis*), and creeping alkali-grass (*Puccinellia phryganodes*) are dominant in areas of higher salinity; lyngbye sedge (*Carex lyngbvaei*) and creeping spike-rush (*Scirpus paludosus*) are dominant in areas of lower salinity; however, much of the estuary is unconsolidated mudflats.

Similar to Susitna Flats on the northern side of Cook Inlet, Chickaloon has high plant diversity due to the overlap of arctic and temperate plant species (Vince and Snow 1984). This overlap gives rise to a complex of vegetation zones unique to south-central Alaska (Vince and Snow 1984). Vegetation patterns of Chickaloon were initially described in 1971–1972 using 10 plant communities (Neiland 1971, Quimby 1972). The

10 vegetated communities occur in salinity gradients toward Cook Inlet and in slightly different sequences and areas across Chickaloon (Figure 3.3).

Changes in elevation of a landscape can greatly alter vegetation structure and composition (Thilenius 1990, Atwater et al. 2001). The landscape of Chickaloon Flats has been altered due to subsidence, uplift, and siltation. Chickaloon is located in one of the major earthquake zones of the world and was significantly affected by the earthquake of March 27, 1964 (Committee on the Alaska Earthquake 1973). The region subsided in 1964 with the earthquake, causing considerable changes in land structure, and has been uplifting since (Jeff Freymueller pers. comm.). Freymueller et al. (2008) found large, very rapid uplifts on the Kenai Peninsula following this earthquake, which could have drastically altered the landscape. The 1964 tectonic uplift of tidal areas in the Copper River Delta resulted in a loss of tidal influence, which caused sudden changes in the composition and structure of vegetation (Thilenius 1990, Boggs and Shephard 1999). In addition to the tectonic uplift, the land elevation of Chickaloon Flats is changing from the rapid uplift in southern Alaska due to glacial unloading and melting ice fields (Larsen et al. 2005). Comparing data from 1964 to the late 1990's, the cumulative 30-year uplift reached 90 cm in the middle of the Kenai Peninsula and more than 1 m at Turnagain Arm (Freymueller et al. 2008). Chickaloon Flats has experienced uplift from ~30 cm in west to 75–80 cm in east (Jeff Freymueller pers. comm.) since originally subsiding 61 cm to 137 cm west to east (Quimby 1972) following the 1964 Earthquake. Since 1990, uplift rates have continued by ~9 mm per year raising the flats by an additional 10 cm by the year

2000. Considering subsidence and uplift after earthquake, the net change in land elevation results in a drop of 21 cm in west to about 47-52 cm in the east.

In addition to uplift, the elevation is increasing annually due to sediment accretion. Vince and Snow (1984) showed a positive correlation with siltation rates and flooding frequency on Susitna Flats, and recorded a range of annual siltation of 4.0-10.3 mm in 1978 and 9.7-14.3 mm in 1979 for the outer mudflats. If I was to assume minimum and maximum annual siltation rates from that study and apply those to Chickaloon, there may have been an additional 13.6 cm to 48.62 cm from sediment accretion across the outer mudflats since the 1964 Earthquake. The net effects of subsidence, tectonic and rapid uplift, and siltation accretion could almost equal (Boggs 2000), or increase the overall elevation across the flats.

The changes in elevation following the 1964 Earthquake have been shown to influence vegetation on mudflats in Turnagain Arm (Atwater et al. 2001) and Copper River Delta (Thilenius 1990), and I predict similar changes may have occurred on Chickaloon Flats. I hope to depict some of those vegetation landscape changes through this study.

Methods

I utilized information from Quimby's (1972) land cover classification, my current land cover classification of ground-truthed points, and Landsat imagery from 1975 and 2005. Quimby created a land cover map by delineating communities from ground survey information and using both black and white aerial photographs taken in June 1970 by the

Bureau of Land Management for the base map, and 35mm colored transparencies of July 1970 to identify plant communities. I then digitized the delineated land cover communities.

The plant communities typically occurred from Turnagain arm to the forest in the following sequence; Large alkali-grass, Ramenski sedge, Type 3 Mud, Creeping alkali-grass, Marsh, Seaside arrow-grass, Floating marsh, Bog, Alder, and Marsh Fringe.

Descriptions are derived from Quimby (1972), scientific names from Hultén (1968), and a list of all plant species within each community is in Appendix F. Large alkali-grass is the most abundant community, comprising primarily of large alkali-grass, seaside arrow-grass (*Triglochin maritimum*), goose-tongue (*Plantago maritima juncoides*) and large mud pans throughout. Ramenski sedge is a rare inland community primarily made of clumped ramenski sedge (*Carex Raménskii*) surrounding drainage sloughs. Type 3 Mud is primarily unvegetated except for creeping spike-rush (*Scirpus paludosus*), and was formed by siltation of previously vegetated areas. The Creeping alkali-grass community is primarily made of creeping alkali-grass, seaside arrow-grass, shallow ponds, and mud. Marsh consists primarily of Lyngbye sedge (*Carex Lyngbyaéi*) and various other sedge species that bordered numerous permanent ponds of varying depths. Although seaside arrow-grass community is principally made of seaside arrow-grass, it has complex vegetation patterns and dead black spruce (*Picea mariana*) trees throughout, both possibly resulting from revegetation following the 1964 Earthquake. Floating marsh is dominated by sedges, and contains floating mats of diverse vegetation, few permanent ponds, and dead black spruce. Bog community is nearest the forest edge and consists of

sedges, dwarf birch (*Betula nana*), and dwarf willows (*Salix* sp.). The Alder community is an uncommon, mainly inland community, containing alders (*Alnus* sp.) as well as species found in Floating marsh. Marsh-fringe was another uncommon community type, and much like Alder, contained a mix of inland and wetland species.

For logistical reasons and to ensure spatial coverage of this almost 10,000 ha study area, I assigned 4 sampling plots (2 km x 4 km) across Chickaloon Flats (Figure 3.3) based on location of airplane landing strips. Per plot, I used the GIS Hawth's Tools' 'generation of random points' to randomly select 20 points within mud and 10 points within each of the 10 land cover types (to total 330 points, 80 points for mud and 250 points across vegetated types). However, not all land cover types were found in each of the plots, so some types have smaller sample sizes. Ground truthed data from corresponding time periods were used to determine the true land cover represented by each pixel grouping in each year. The vegetation type classifications of points for the 1975 imagery were assigned directly from types derived from digitized vegetation community maps from Quimby (1972). I assumed these vegetated community boundaries to be accurately drawn from ground survey information. For the 2005 imagery, I used current land cover data from my field observations in 2009 and 2010 to assign vegetation classes for training data used for classification (Table 3.1). I collected vegetation data (Figure 3.3) from Plots 1, 2, and 4 between 28 June 2009–18 July 2009 and from Plot 3, between 20–23 July 2010. At each of the vegetation points, I visually estimated percent cover of each plant species at two spatial scales. The small scale was a 1-m square divided into four quadrants, and the larger was a 20-m radius circle. The use of two

spatial scales helped me to best classify each point into the correct current vegetation type. I used Quimby's (1972) descriptions to correctly classify my vegetation point data to the current land cover type.

To quantify change in land cover types over a 35-year period, I used two different approaches. One was a comparison of classifications of Landsat imagery and the other investigated changes of Quimby's (1972) classification with my updated classification.

Landsat imagery classifications

Landsat imagery came from United States Geological Survey, Path 69 Row 17. I wanted low-tide images with similar Julian dates and no cloud cover, and was very limited on available dates of Landsat imagery for the study area. I chose the closest available imagery dates to correspond with dates of ground-truth data (1970-1971 and 2009-2010), a single Landsat-1 Multispectral Scanner (MSS) image (11 July 1975) and a Landsat-5 Thematic Mapper (TM) image (28 June 2005). Landsat MSS is at a coarser resolution (60m), so I did a resampling of this image to the same 30m-pixel size of the TM imagery using ENVI's Resize Data tool. This data fusion then allows comparison of imagery from different satellite sensors. Because some spectral bands present similar signatures, I ran correlation matrix statistics for each year to determine the best bands to include. Based on the statistics and visual representation of the bands, I used bands 2, 3, and 4 from Landsat MSS and bands 3, 4, 5, and 7 from Landsat TM imagery.

Imagery from 1975 and 2005 was classified using ISODATA unsupervised classification techniques followed by a supervised maximum likelihood classification in

Environment for Visualizing Images (ENVI) 4.8 software. From the ISODATA classification, pure classes were identified and initially assigned one of twelve land cover classifications: Mud, Type 3 Mud, Creeping alkali-grass, Large alkali-grass, Marsh community, Floating marsh, Seaside arrow-grass, Bog, Alder, Marsh fringe, and Ramenksi sedge and Water (permanent ponds). Many classes were mixed, and required further rounds of ISODATA clustering to obtain pure classes of each type. In order to avoid inaccurate representation of classes with overlapping spectral signatures and smaller areas, I did not include Bog, Alder, Marsh fringe, and Ramenksi sedge communities in the final classifications. Due to the similar species composition (Appendix F) of some land cover classes, and therefore similar spectral signatures, I lumped together Creeping alkali-grass and Large alkali-grass, as well as Marsh community, Floating marsh, and Seaside arrow-grass for a more accurate analysis. The elimination of some classes and the combination of others resulted in five final land cover classes for analysis of Landsat imagery. I used the five-class data derived from the ISODATA method as training data for the supervised classification.

To ensure that I chose the most accurate supervised classification, I performed both a maximum likelihood and minimum distance supervised classification of the imagery using ENVI 4.8. A maximum likelihood calculates the probability that a given pixel belongs to a particular class. I applied a probability threshold of 0.1, which resulted in a more accurate classification than a threshold of zero. The minimum distance uses the mean vectors of each training data point and calculates the Euclidean distance from each unknown pixel to the mean vector for each class, and each pixel is assigned to the closest

class. Overall accuracies of the classified images are based on an average of each the class accuracies, and were used to determine preferred classification method.

1970 to 2005 land cover change

Within this comparison, I used two approaches to look at general change in land cover type. First, I took the areas for each land cover class delineated by Quimby in 1970, and compared overall change (in hectares) to those land classes in the current 2005 classification. Because the final land cover classes between years are not directly comparable, the same class combinations were used as in the Landsat imagery classification for 2005, and a few more classes were lumped for 1970 classification. For the 1970 classification, I added Ramenski sedge, Bog, Alder, and Marsh fringe to the Marsh community, Floating marsh, and seaside arrow-grass land cover class. There was no Water category in 1970 classification, so Water was combined with the marsh-like class in 2005. The final groupings resulted in four land cover classes for area comparisons between 1970 and 2005.

The second approach provided more precise information on changes within each individual land cover class. For this method I took a point to point approach, and compared the 2005 land cover classification of each visited vegetation point to the 1970 land cover classification of each point; determining the percentage of points that remained the same during the time period.

Results

Landsat imagery classifications

I ran an initial maximum likelihood supervised classification including all 11 classes, resulting in an overall classification accuracy of 41.79%. Because of this low accuracy, I ultimately grouped similar land cover types together according to species composition. Consequently, I ended up using Mud, Type 3 Mud, Water, and 2 classes of mixed vegetated community types (Table 3.1). Both the current vegetation type map of Chickaloon Flats and estimated land cover class areas were derived from the 2005 maximum likelihood classification (86.31% overall accuracy; Figure 3.4). The 2005 classification provided updated information on the current land cover classes of Chickaloon. Of the 9,533 ha used in this classification (Table 3.1), 5,250 ha (55.0%) are classified as vegetated, 4,012 ha (42.1%) as Mud, and 271 ha (2.9%) as Water.

The 278 vegetated points were used to create a training data set for each class via ISODATA clustering. The total area covered by all vegetation points was 867.1 ha, which encompassed 33.0% of the area of Chickaloon, and ranged from 4.4 to 13.0% coverage of a land cover class (Table 3.1). The points used for the Water class (15.0% of class) were not ground-truthed, but assigned to areas of known permanent water (Table 3.1). Training data used for supervised classifications covered a range of 11.9 to 99.1% of area of each of the land cover classes (Table 3.1).

Both overall accuracy and the Kappa coefficient are used in determining the best classification method. The Kappa coefficient, scaled between 0 and 1, is used to test if the classification map is significantly better than a randomly generated classification and

represents the proportion of agreement acquired after the chance agreement is removed (Foody 1992). The maximum likelihood method resulted in the most accurate classification for the current land cover of Chickaloon, with an overall accuracy of 86.31% and a Kappa coefficient of 0.8056 for the 2005 classification (Table 3.2). The minimum distance was less accurate, with a 71.43% overall and 0.6151 Kappa. The 1975 classifications were extremely inaccurate (11.2% and 11.8%) for both supervised methods (Table 3.2). Due to the poor accuracy of the 1975 imagery, I did not compute change statistics using 1975 and 2005 Landsat imagery.

The class confusion matrix of each year and supervised classification method demonstrate where the errors in classification lie. The matrices for 1975 (Table 3.3) indicate that most of the inaccuracies are associated with the misidentification of points to the AG-LG class. This class represented the vast majority of the total area of Chickaloon in the 1975 Landsat classifications, so most points were classified as such, even though ground-truth data characterized the points in a different land cover type. Due to better accuracy of the 2005 classifications, the 2005 matrices provide more useful information for each land cover class (Table 3.3). The 2005 maximum likelihood classification shows that the Marsh community-Floating marsh-Seaside arrow-grass, Mud, and Water land cover types had high accuracies (Table 3.3), while the two remaining class types, Type 3 Mud and Creeping alkali-grass-Large alkali-grass, had moderate accuracies. The misidentifications of points amongst these two classes (Table 3.3) are mainly from AG-LG points misclassified as MC-FM-SG land cover type, and 3M points misclassified as AG-LG type.

Quimby to Ulman comparison

The comparison of land cover class areas from 1970 (ground-truthed aerial photos) to 2005 (supervised classification) indicated a loss of total area in 3 of the 4 land cover classes, while the Creeping alkali-grass and Large alkali-grass type increased in area (Table 3.4). This land cover type increased by 16.8%, while the others decreased from 2.5 to 7.3% (Table 3.4).

I collected species composition and coverage information at 278 vegetation points, and reclassified many of the points from the 1970–1971 characterization derived from digitized aerial photos (Table 3.5). For example, across all 4 plots, I visited 40 randomly selected points within the 1970–1971 characterized Type 3 Mud land cover class. Of these 40 points, I classified only 11 points (27.5%) as Type 3 Mud in 2009–2010, and reclassified the other 29 (72.5%) to different vegetation land cover types (Appendix G). For these point to point comparisons I looked at change among 8 individual vegetation land classes, which ranged from 19.4% to 91.8% (Table 3.5). Large alkali-grass had the least amount of change from 1970–1971 to 2009–2010, with 19.4%. Most of the change (13.2%) was to unvegetated mud classes, with the remaining to the closely associated Creeping alkali-grass type. Floating marsh had 21.4% change to the more landward land class types of either Bog or Alder. Less than half of Mud changed; 42.1% to the vegetated classes of Large alkali-grass (31.6%) and Creeping alkali-grass (10.5%), and only 1.8% to unvegetated Type 3 Mud. About half of Creeping alkali-grass type changed, mainly to Large alkali-grass (29.6%). Seaside arrow-grass changed to both landward (43.3%) and seaward (16.7%) land cover types. Most of the

change for Marsh community was to Floating marsh (39.4%), with the others spread across vegetated (18.2%) and unvegetated (3%) land cover types. Type 3 Mud had a significant amount (65%) of points that changed to Large alkali-grass type and 7.5% across Mud or Ramenski sedge. The class with the most change was Ramenski sedge, with only 8.2% of points unchanged. The majority (81.6%) of Ramenski sedge changed to other vegetated land cover types, with 10.2% to unvegetated mud classes.

Discussion

My inability to discriminate unique spectral signatures between all original land cover classes and the extreme inaccuracies of the 1975 supervised classification did not allow for a detailed and robust land cover type change analysis. The types described by Quimby (1972) included many with similar species and mud composition, which resulted in overlapping spectral signatures. Unlike upland plant communities, the effective quantification of wetlands through remote sensing is challenging due to the spatial distribution and diverse species composition (Ozesmi and Bauer 2002). The land cover types with overlapping signatures had to be grouped together to ensure a more accurate classification (Jensen 1996), which resulted in a coarser classification.

I chose to lump several classes together based on mud and vegetation cover characteristics. Joining classes of similar structure helped alleviate the troubles of spectral signature overlap and improve classification accuracy. The final classification using Landsat imagery resulted in five combined land cover types, which is not directly comparable to that of Quimby's, but is the most accurate current land cover classification

I could derive with available imagery and class divisions. Although a classification with only five land cover types may not be ideal, it more accurately portrays that of Chickaloon Flats. Accuracy and reliability in classification are priorities to ensure proper management actions and decisions.

Due to the poor accuracy of the 1975 classification, I did not assess change in land cover using Landsat imagery. Therefore I was not able to map exact locations of land cover change across the entire study area. Instead, I am limited to discussing general trends of change using the point to point comparison.

Changes in elevation following the 1964 Earthquake have influenced vegetation on mudflats in Turnagain Arm (Atwater et al. 2001) and Copper River Delta (Thilenius 1990), and my results show that change in vegetation structure and composition has occurred on Chickaloon Flats as well. Overall, areas of mud closest to the water decreased in area. More than half of mud sampling points were revegetated; primarily to Large alkali-grass. This is consistent with the findings of Atwater et al. (2001) at mudflats near Portage, where rapid sediment deposition followed the 1964 Earthquake, but slowed by 1973, and vegetation started maturing. After the earthquake, the areas of Type 3 Mud on Chickaloon were created by siltation of previously vegetated areas (Quimby 1972). If Chickaloon followed a similar timeline to Portage mudflats, then rapid deposition of sediments may have slowed in early 1970's, allowing vegetation to return to the Type 3 Mud areas by 2005. The first stage of primary succession of tidal marshes is to establish pioneer species on newly exposed mudflats (Boggs 2000), and this may be occurring on Chickaloon.

More inland vegetated classes increased in area over the 35-year period. Of these two types, Large alkali-grass occupied the largest area (Quimby 1972) and changed the least, while Creeping alkali-grass changed to both inland and seaward land classes. The most inland land cover types representing the more stable marsh-like communities decreased in area as a whole. The overall direction of vegetation change within this land cover class was toward the less established, early successional (Neiland 1971, Quimby 1972) seaward communities. Quimby (1972) demonstrated that Creeping alkali grass established in marsh areas that had been silted over following subsidence from the earthquake, and that the Marsh community was more extensive prior to the earthquake, and may be continuing to decrease due to drainage of permanent and semi-permanent ponds. Quimby (1972) indicated that the overall effect of the earthquake on vegetation was to promote early successional plant communities (Creeping alkali-grass) while decreasing more stable plant communities (Marsh community), and my results support this observation.

In addition to the post-earthquake subsidence and uplift, sediment accretion may also change elevation, and thereby influence vegetation structure on Chickaloon. Rates of sediment accretion are higher in vegetated areas, because plants slow the water and trap sediments (Boggs 2000), and siltation will continue to increase land elevation relative to mean high tide (Thilenius 1990, Boggs 2000). Although the rapid deposition has ceased, annual siltation of the mudflats continues, and is positively correlated with frequency of flooding events (Vince and Snow 1984). Quimby (1972) measured silt deposition of several locations within Type 3 Mud during the peak flooding months of August and

September 1970, and found silt deposits ranged from 6.4mm to 25.4 mm. This considerable amount of siltation could still be within the rapid deposition time frame following the earthquake, but indicates that silt accretion can play a dynamic role in vegetation structure of Chickaloon. As land elevation increases from siltation, this alters the frequency and locations of tidal inundations (Boggs 2000), which in turn can change vegetation structure and composition (Neiland 1971).

In addition to changes elevation may cause, the patterns of vegetation on Chickaloon are largely due to tides, and salt water and fresh water interactions (Neiland 1971, Quimby 1972). Neiland (1971) presented five physical factors that affect vegetation: 1) duration and number of times of inundation; 2) amount and duration of water retained; 3) location and rate of cutting by drainage ditches; 4) amounts of salt and fresh water received and retained; and 5) erosion and deposition rates of sediments. I found a temporal and spatial variation in tidal inundation from extreme tide events (Appendix H), which may have partially affected the patterns of vegetation currently on Chickaloon. Tidal inundations of vegetated areas are infrequent, which may be compounded by an increase in elevation due to sediment accretion. Because duration of tidal flooding is a dominant factor in salt marsh salinity (Mahall and Park 1976), vegetation types with more salt-tolerant species may not be receiving enough tidal inundation, and may be converting to areas containing no plants or less salt-tolerant plant species. If infrequency of tidal inundations causes a decrease in alkali-tolerant species, I should see an overall decrease in alkali-dominated land cover types. My results actually show the opposite, with an overall increase (16.8%) in land cover classes with salt-

tolerant plant species. Although this indicates an overall increase in these classes across Chickaloon, 13.2% of Large alkali-grass points changed to mud. All of these changes were in the western part of Chickaloon, which is a surprise because the eastern side has the larger amount of uplift and less tidal inundations, and is where I would have suspected to see loss of salt-tolerant species and vegetated land cover. Although this study has provided evidence of broad vegetation change over a 35-year time frame, the mechanisms for this change are not fully answered.

Elevation changes such as subsidence and uplift following the 1964 Earthquake and annual sediment accretion are probable factors affecting the vegetation composition and structure change. Another factor that may be driving the conversion of vegetation types on Chickaloon may be the overall drying of wetlands, as shown by the wetland drying and succession of the Kenai Lowlands (Klein et al. 2005).

I effectively created a current land cover classification of Chickaloon Flats and examined vegetation changes over a 35-year time span. My final classification of 2005 Landsat imagery was accurate, with strong Kappa coefficients (Congalton 1996). However, the current vegetative health of this Alaskan estuary remains uncertain. My results indicate vegetation may be reestablishing on areas silted over following the earthquake subsidence, and that more inland land cover classes with permanent and ephemeral ponds are losing area. With this loss of more stable vegetation to early successional species, the 1964 Earthquake may have initiated a new ecosystem balance (Boggs 2000) and/or changed the rate or stage of succession (Thilenius 1990). The value of Chickaloon as a long-term productive estuary may be at risk due to these changes and

loss of marsh, or there may be no risk at all if Chickaloon has been reset on the rate and stage of succession. Chickaloon Flats is currently and has been historically used by a diversity of avian species for both a migratory stopover and breeding site, and the change in vegetation over a 35-year timeframe may not alter the overall importance and value of this area to avian species.

Table 3.1: Area data for each of the five land cover classes used in the maximum likelihood supervised classification of 2005 imagery. Area is represented in hectares.

Land cover classes	Area of land cover class	Area of surveyed points	% Class surveyed	Area used for training data	% Class used for training data
Creeping alkali-grass- Large alkali-grass	3444.0	446.1	13.0	410.8	11.9
Type 3 Mud	1173.9	53.4	4.5	354.6	30.2
Marsh community- Floating marsh- Seaside arrow-grass	1805.7	201.1	11.1	455.8	25.2
Mud	2837.8	125.7	4.4	2811.0	99.1
Water	271.4	40.8	15.0	11.6	4.3
Total	9532.8	867.1		4043.8	

Table 3.2: Overall accuracy, reported in percentage, and Kappa coefficient for each supervised classification method, maximum likelihood and minimum distance, for 1975 and 2005 classifications using Landsat imagery of Chickaloon Flats.

	Maximum likelihood		Minimum distance	
	1975	2005	1975	2005
Overall accuracy	11.2094	86.31	11.7994	71.43
Kappa coefficient	-0.024	0.8056	-0.0064	0.6151

Table 3.3: Class confusion matrix of 5 land cover classes used in maximum likelihood and minimum distance supervised classifications of 1975 Landsat MSS and 2005 Landsat TM imagery. Classes are: Creeping and Large alkali-grass (AG-LG), Type 3 Mud (3M), Marsh community, Floating marsh, and Seaside arrow-grass (MC-FM-SG), Mud, and Water. Class cover types produced from training data are in columns and reference test ground points in rows. Producer accuracy is assessment of how accurately the analyst classified the image data by land cover types. User accuracy is assessment of how well the classification performed with ground truth data by land cover types. All numbers are percentages.

		Maximum likelihood						Producer Accuracy	User Accuracy
		AG-LG	3M	MC-FM-SG	Mud	Water	Total		
1975	Unclassified	0	0	0	0	0	0		
	AG-LG	98.28	90	73.81	95.12	66.38	79.94	1.72	2.04
	3M	1.72	5	25	4.88	19.83	14.45	90	13.28
	MC-FM-SG	0	5	1.19	0	13.79	5.6	1.19	5.26
	Mud	0	0	0	0	0	0	0	0
	Water	0	0	0	0	0	0	0	0
	Total	100	100	100	100	100	100		

		Minimum distance						Producer Accuracy	User Accuracy
		AG-LG	3M	MC-FM-SG	Mud	Water	Total		
1975	Unclassified	0	0	0	0	0	0		
	AG-LG	100	100	100	100	85.34	94.99	0	0
	3M	0	0	0	0	3.45	1.18	100	12.42
	MC-FM-SG	0	0	0	0	11.21	3.83	0	0
	Mud	0	0	0	0	0	0	0	0
	Water	0	0	0	0	0	0	0	0
	Total	100	100	100	100	100	100		

Maximum likelihood							Producer Accuracy	User Accuracy	
	AG-LG	3M	MC-FM-SG	Mud	Water	Total			
2005	Unclassified	0	0	0	0	0			
	AG-LG	68.18	36.36	1.39	8	14.29	68.18	62.5	
	3M	4.55	54.55	1.39	0	7.69	54.55	66.67	
	MC-FM-SG	22.73	0	91.67	0	0	91.67	92.96	
	Mud	4.55	9.09	0	92	0	28.57	92	95.83
	Water	0	0	5.56	0	92.31	9.52	92.31	75
	Total	100	100	100	100	100	100		

Minimum distance							Producer Accuracy	User Accuracy	
	AG-LG	3M	MC-FM-SG	Mud	Water	Total			
2005	Unclassified	0	0	0	0	0			
	AG-LG	59.09	18.18	30.56	12	7.69	59.09	29.55	
	3M	0	72.73	1.39	0	0	72.73	88.89	
	MC-FM-SG	18.18	0	65.28	0	0	65.28	92.16	
	Mud	0	0	0	86	23.08	27.38	86	93.48
	Water	22.83	9.09	2.78	2	69.23	10.71	69.23	50
	Total	100	100	100	100	100	100		

Table 3.4: Area of land cover classes and % of total Chickaloon area in 1970 and 2005 and difference in area between those time periods. Area is in hectares. *Water was not a separate class in 1970, so 2005 area of water is added into this class.

Land cover classes	1970		2005		Difference from 1970 to 2005	
	Area	% Chickaloon	Area	% Chickaloon	Area	% Chickaloon
Mud	3957.1	37.0	2837.8	29.8	-1119.3	-7.3
Type 3 Mud	1587.1	14.9	1173.9	12.3	-413.2	-2.5
Creeping alkali-grass and Large alkali-grass	2059.8	19.3	3444.0	36.1	1384.2	16.8
Marsh community, Floating marsh, Seaside arrow-grass, and Water*.	3080.0	28.8	2077.1	21.8	-1002.9	-7.0

Table 3.5: Point to point comparison of land cover classifications from 1970–1971 to 2009–2010. The eight land cover types in point to point comparison and number of ground truthed points are: LG (Large alkali-grass, N=38), FM (Floating marsh, N=14), MUD (Mud, N=57), AG (Creeping alkali-grass, N=27), SG (Seaside arrow-grass, N=30), MC (Marsh community, N=33), 3M (Type 3 Mud, N=40), and RS (Ramenski sedge, N=39). Bog and Alder are additional land cover types used only in Reclassification due to small area of types. Percentage of points classified as the same land cover type in both time periods represented as % same. Percentage of points reclassified as different land cover type in 2009–2010 than 1970–1971 represented as % reclassify.

1970–1971 classification	2009–2010 reclassification	% Same	% Reclassify
LG	LG	81.6	
	MUD		7.9
	AG		5.3
	3M		5.3
FM	FM	78.6	
	BOG		14.3
	ALDER		7.1
MUD	MUD	56.1	
	LG		31.6
	AG		10.5
	3M		1.8
AG	AG	51.9	
	LG		29.6
	MC		3.7
	RS		11.1
	SG		3.7
SG	SG	40	
	FM		26.7
	BOG		13.3
	AG		10
	LG		6.7
	MC		3.3

1970–1971 classification	2009–2010 reclassification	% Same	% Reclassify
MC	MC	39.4	
	FM		39.4
	SG		12.1
	AG		6.1
	3M		3
3M	3M	27.5	
	LG		65.0
	MUD		5
	RS		2.5
RS	RS	8.2	
	LG		59.2
	MUD		6.1
	3M		4.1
	AG		22.4

Figure 3.1: Location of Chickaloon Flats, Kenai National Wildlife Refuge, Alaska.



Figure 3.2: Intertidal estuarine areas of Cook Inlet and Prince William Sound, Alaska derived from National Wetlands Inventory data from the U. S. Fish and Wildlife Service. The estuarine area of Chickaloon Flats makes up 15,214 ha (7%) of the total 218, 376 ha shown on the map.

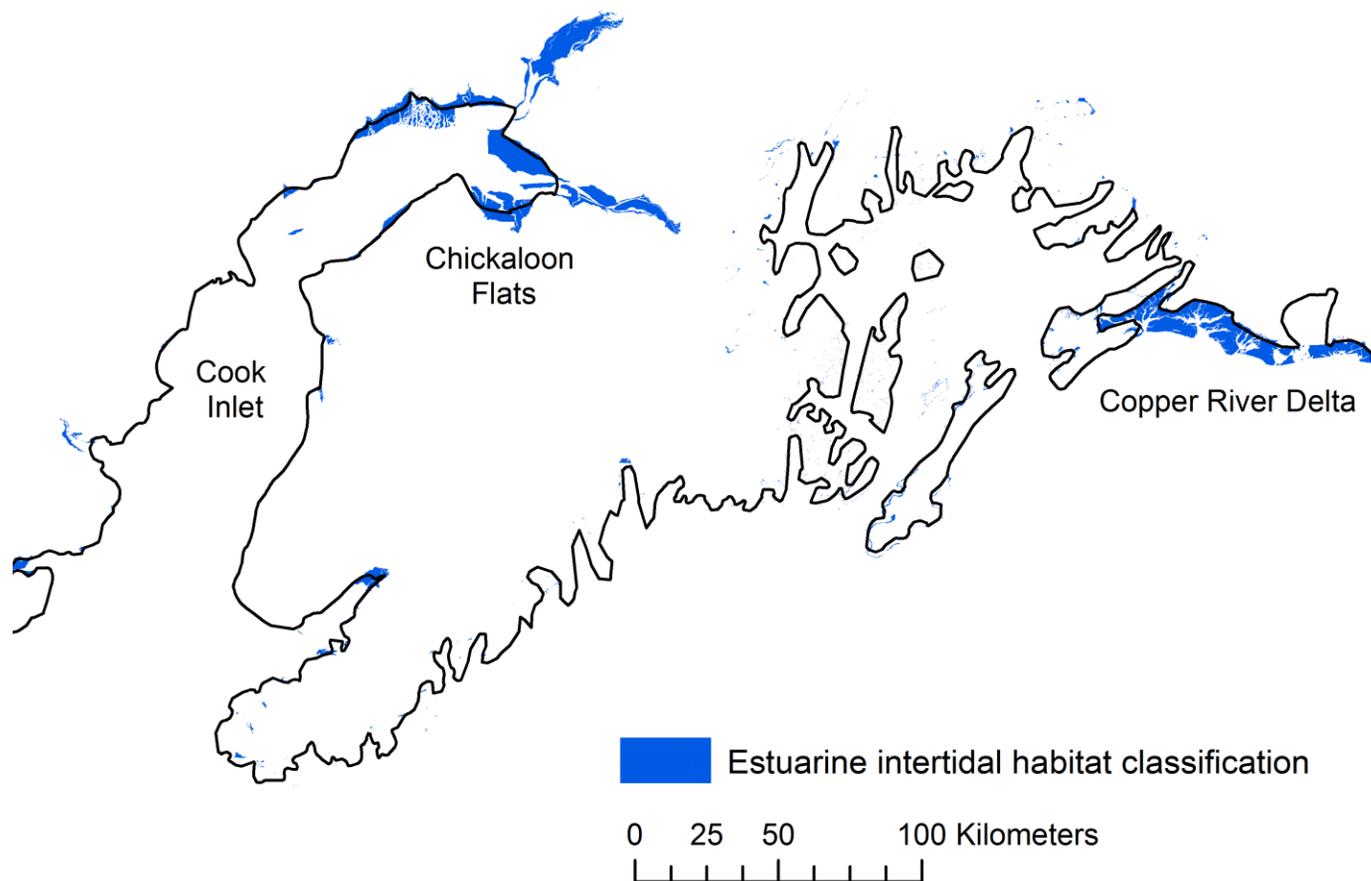


Figure 3.3: The community types of Chickaloon Flats digitized from cover maps from Quimby (1972). Four study plots (2 x 4 km) with 287 randomly assigned vegetation data points across Mud and each of the ten vegetated community types. Plots are from west (Plot 1) to east (Plot 4).

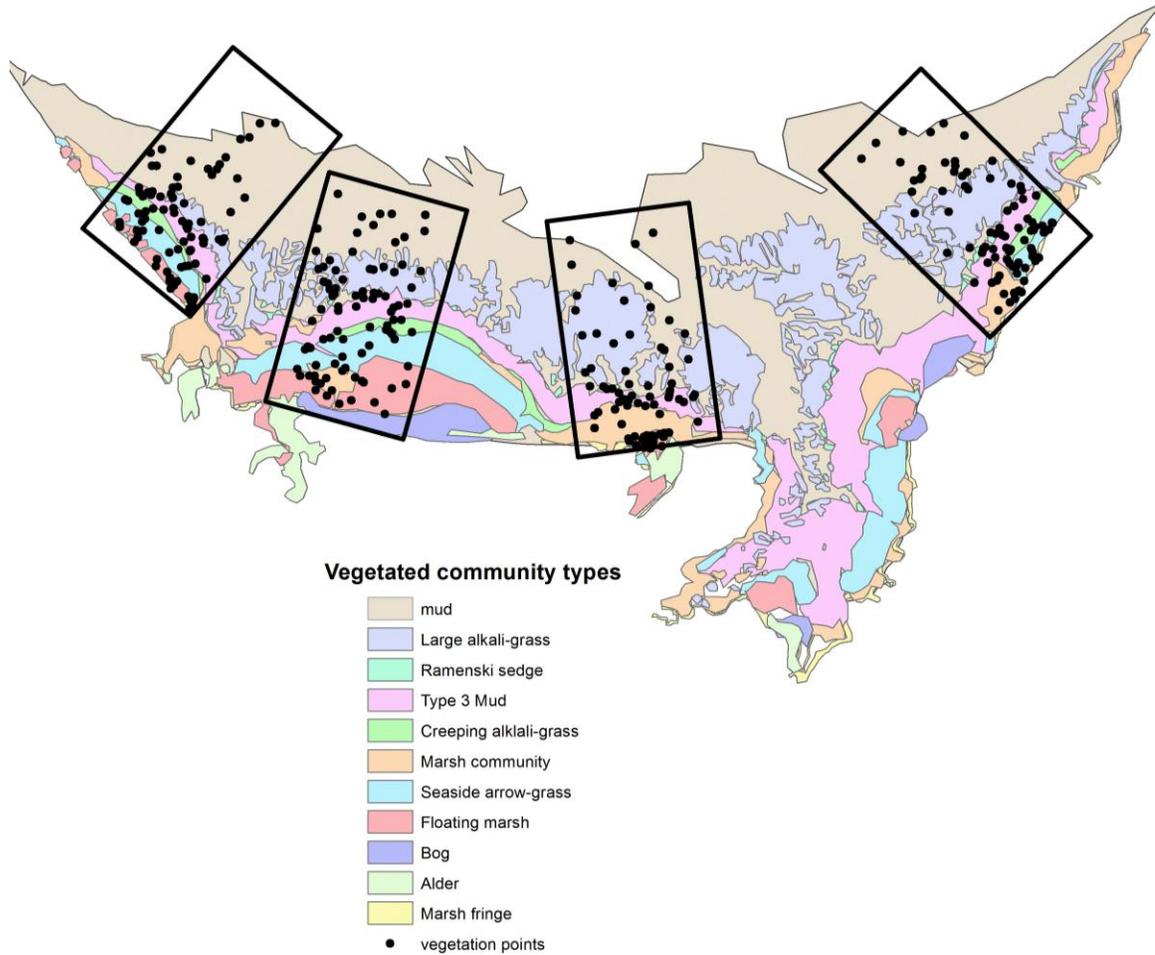
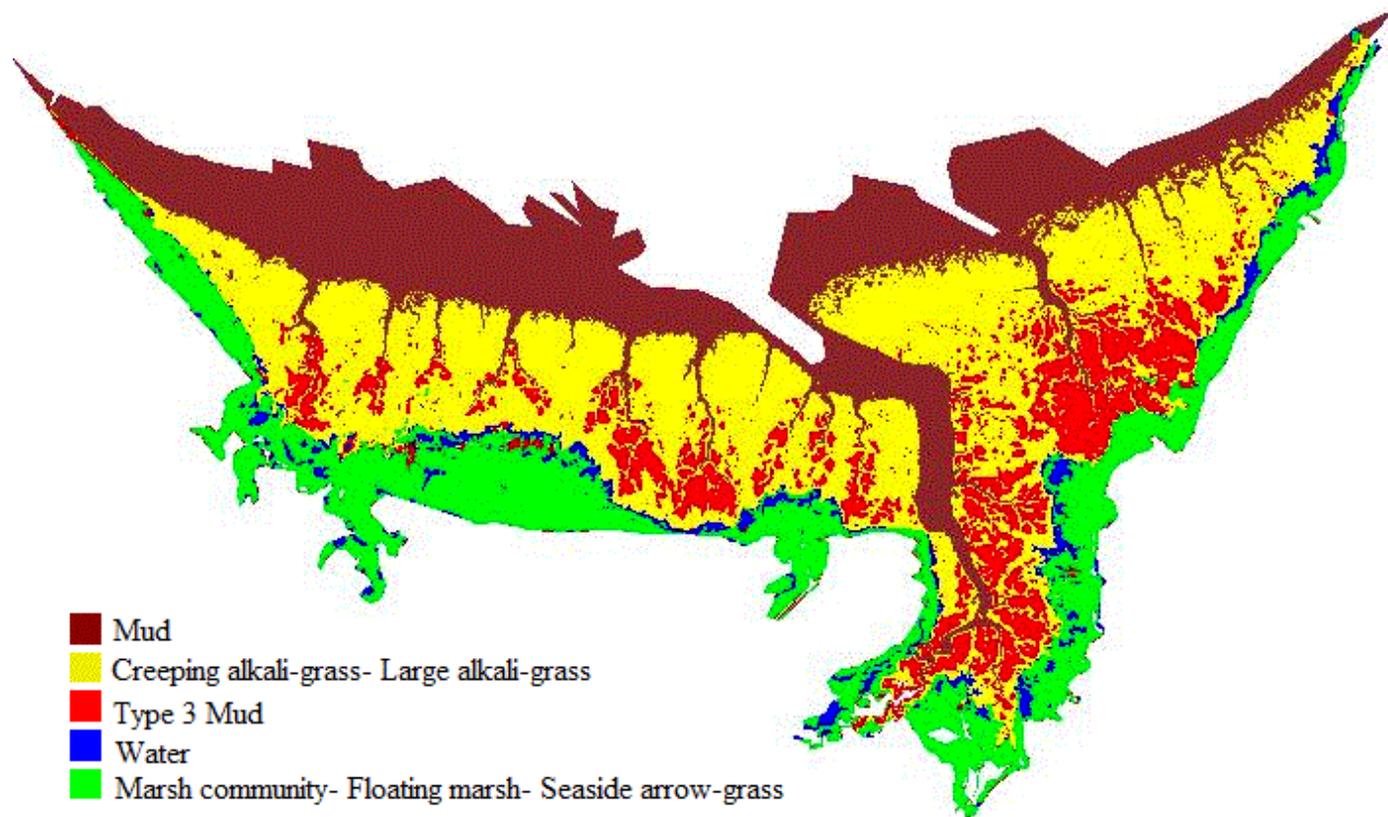


Figure 3.4: The 2005 maximum likelihood supervised classification of Chickaloon Flats with five land class covers.



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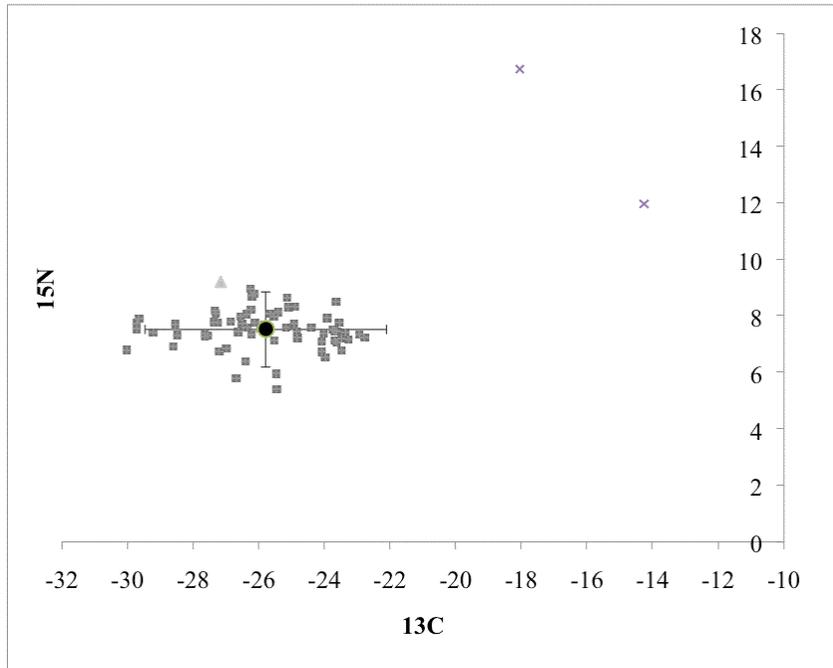
Yerkes, T., K. A. Hobson, L. I. Wasserman, R. Macleod, and J. M. Coluccy. 2008. Stable
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725.

Appendix A

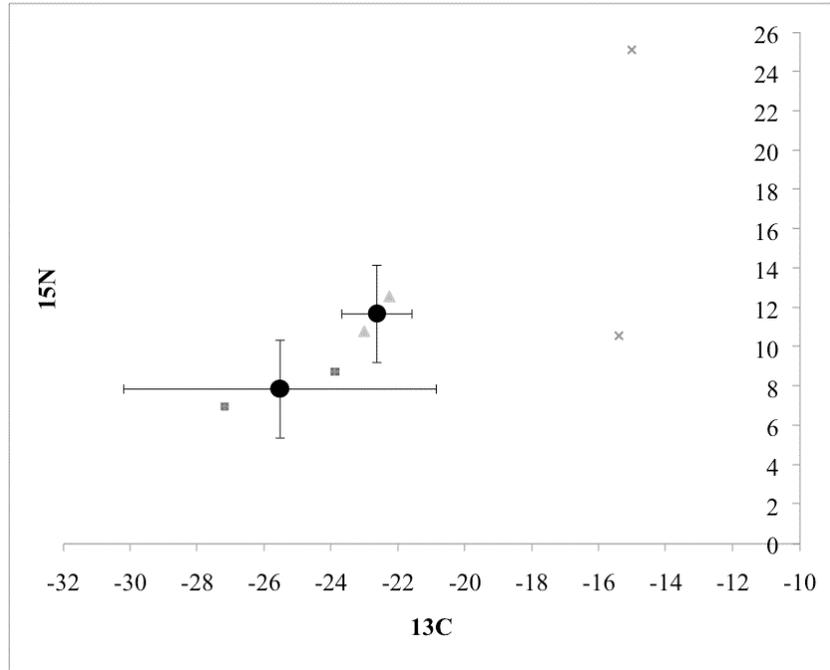
PLOTS OF $\delta^{13}\text{C}$ AND $\delta^{15}\text{N}$ FOR 6 MIGRATORY SHOREBIRD SPECIES

Birds captured on Chickaloon Flats, Alaska during 2009-2010 spring and/or fall migrations. Means only represent individuals used in assigning geographic origins. Birds indicating marine source ($\delta^{13}\text{C}$ values $> -20\text{‰}$), therefore not used in assignment, are symbolized by an X. Birds with $\delta^{15}\text{N}$ values $\geq 9\text{‰}$ are classified as agriculture, which are denoted by a triangle, and non-agriculture values denoted by square. Large dots represent the means and error bars 2 standard deviations of the groups. Some scale bars differ among graphs. Plots represent the a) breeding range greater yellowlegs, b) wintering range lesser yellowlegs, c) breeding range lesser yellowlegs, d) wintering range least sandpiper, e) wintering range pectoral sandpiper, f) breeding range short-billed dowitcher, and g) wintering range long-billed dowitcher.

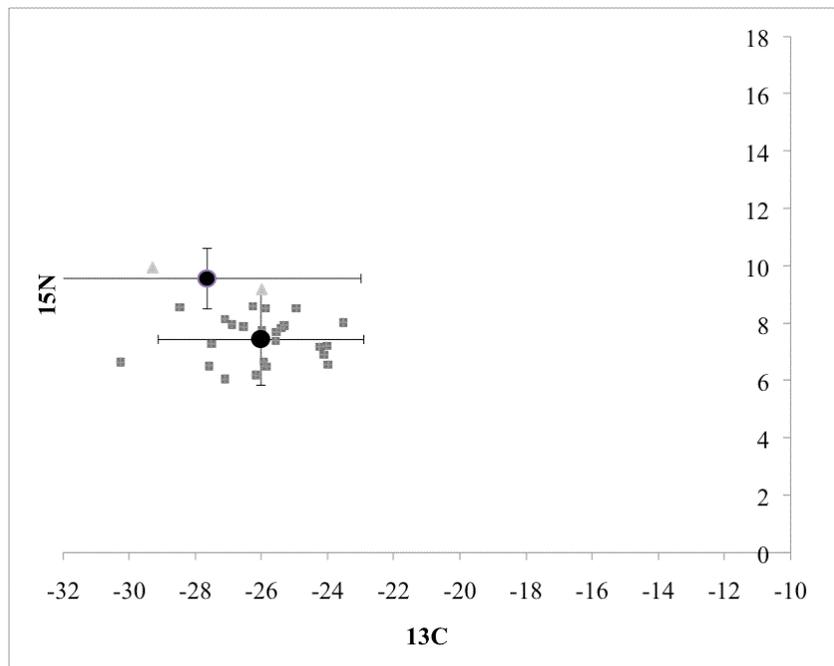
a)



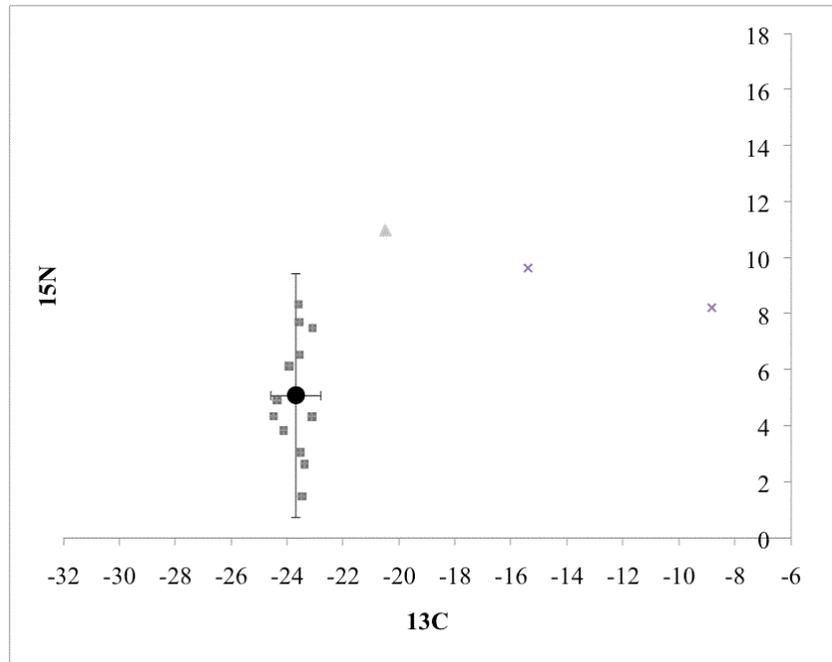
b)



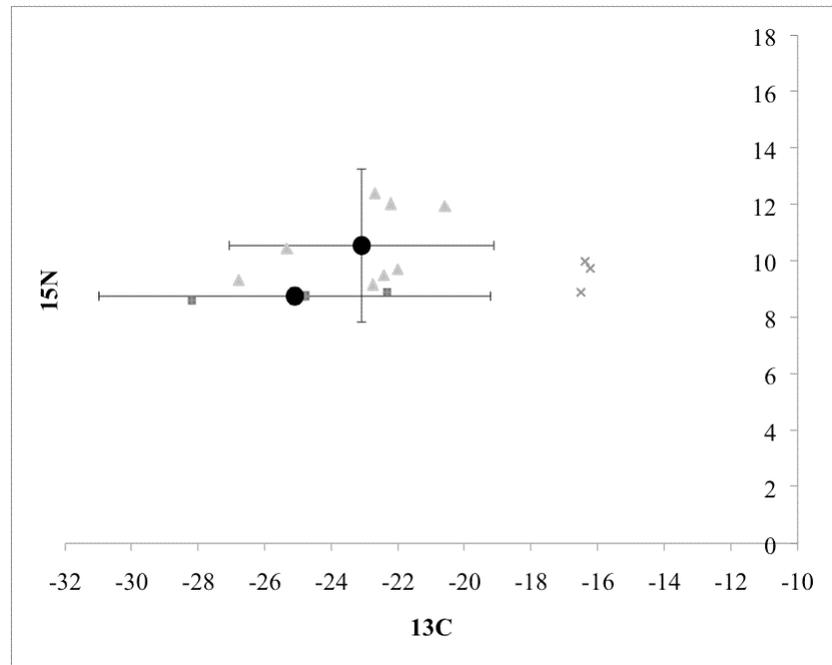
c)



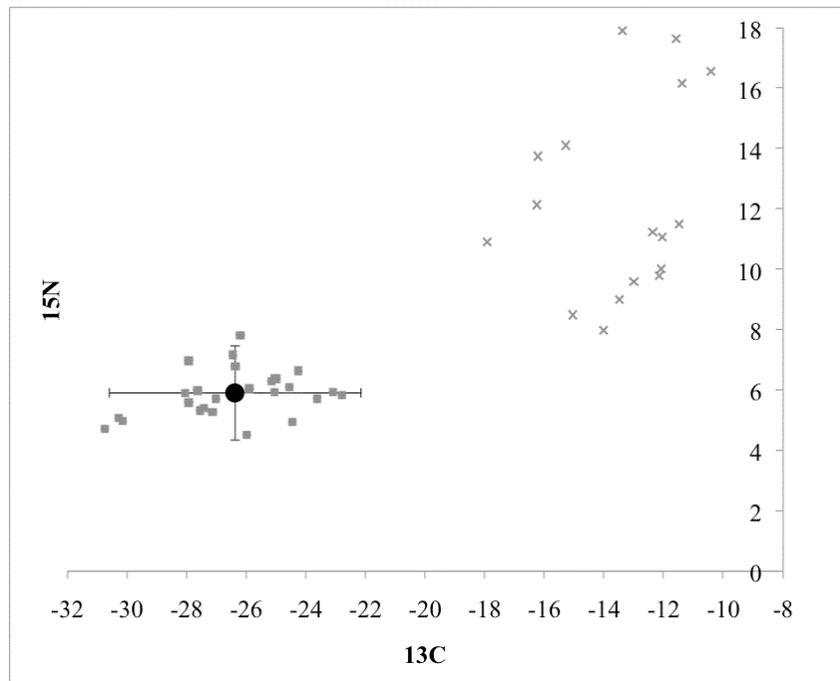
d)



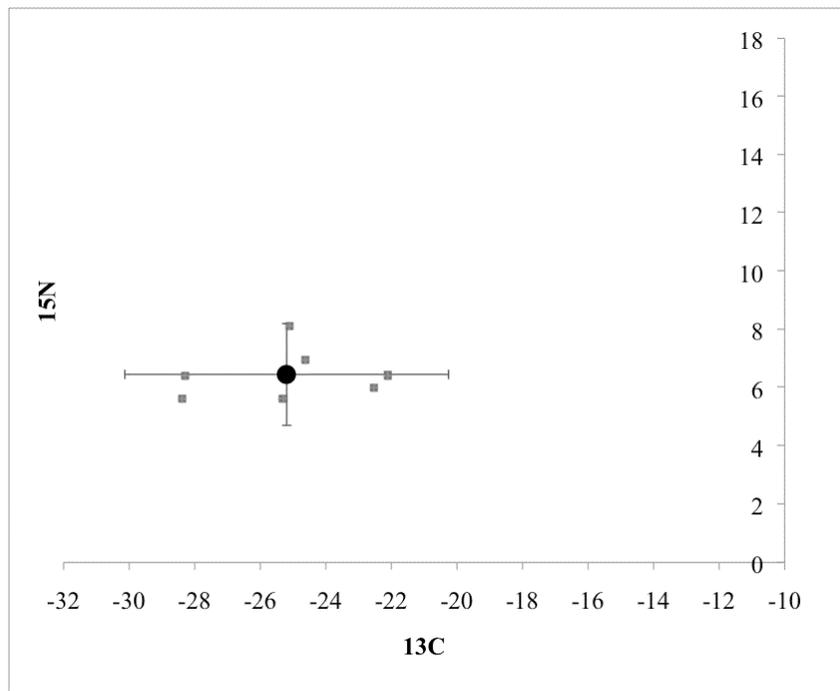
e)



f)



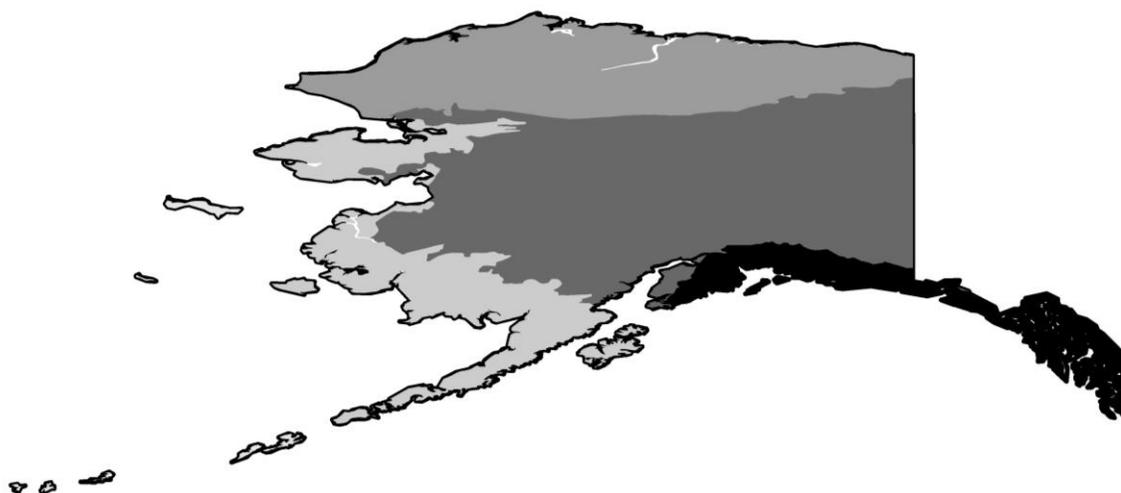
g)



Appendix B

FIVE BIRD CONSERVATION REGIONS

Bird Conservation Regions (BCRs; United States North American Bird Conservation Initiative 2000*a,b*) are named as followed; BCR 1: Aleutian/Bering Sea Islands, BCR 2: Western Alaska, BCR 3: Arctic Plains and Mountains, BCR 4: Northwestern Interior Forest, and BCR 5: North Pacific Rainforest.



Alaska Bird Conservation Regions (BCR)

-  BCR 1: Aleutian/Bering Sea Islands
-  BCR 2: Western Alaska
-  BCR 3: Arctic Plains and Mountains
-  BCR 4: Northwestern Interior Forest
-  BCR 5: North Pacific Rainforest

Appendix C

DAILY OBSERVATIONS OF AVIAN SPECIES OF CHICKALOON FLATS IN 2009 AND 2010

An additional avian survey method was to maintain a daily log of bird species and estimated abundance of each species. This was not a structured survey, rather a record of birds encountered each day while conducting related fieldwork. Although there were not set transects followed daily, there was a certain degree of repetition for area coverage, with walking routes to, from, and within plots. The daily species log information utilizes every daily count and does not take into consideration weather variables, which may reduce detection of some forest species (Bibby and Burgess 2000).

To look at seasonal and yearly avian diversity, I compared mean number of avian species at the study area level between seasons within years and within season between years using a Student's t-test ($P \leq 0.05$). I also compared total avian abundance at the study area level between seasons within years and within season between years using a Student's t-test ($P \leq 0.05$). Finally, I compared total shorebird abundance at the study area level between seasons within years and within season between years using a Student's t-test ($P \leq 0.05$).

Results

To capture an overall idea of species diversity and abundance throughout the spring and fall migration periods, the daily observation was a valuable resource. The daily species richness fluctuated from 4–43 during spring seasons (5–26 May 2009 and

20 April – 14 June 2010) and 5–28 species during fall (27 June – 6 August 2009, 15–18 August 2009 and 8 July – 25 August 2010). Fall shorebird migration is protracted late June through mid-September (Gill and Tibbitts 1999), and therefore this study did not quite capture the entire fall migration period.

Daily observation data from 2009 and 2010 indicate Chickaloon was utilized by more species during fall migration than spring in 2009 ($t_{65} = -12.00$, $P < 0.01$) and more in spring than fall for 2010 ($t_{101} = 2.89$, $P < 0.01$). Comparing between years, there was also a lower diversity during spring 2009 than in 2010 ($t_{75} = -7.14$, $P < 0.01$), but no difference between fall 2009 and 2010 ($t_{91} = -1.82$, $P = 0.07$). In addition to species diversity, there was also a higher sum of all species abundance during spring than fall of both years (2009: $t_{65} = 8.96$, $P < 0.01$; 2010: $t_{101} = 2.89$, $P < 0.01$). Although there was no difference in abundance in fall between 2009 and 2010 ($t_{91} = 1.80$, $P = 0.08$), there were higher total abundances during spring 2009 than in 2010 ($t_{75} = 7.14$, $P < 0.01$), but that may have been biased by a difference in number and timing of spring sampling days between years.

Focusing on 14 shorebird species, There was no difference in abundance of the sum of 14 shorebird species between spring and fall for 2009 ($t_{65} = 1,773$, $P = 0.08$), but a significantly higher abundance for 2010 ($t_{101} = 9.343$, $P < 0.01$). Although there was no difference in shorebird abundance in spring between 2009 and 2010 ($t_{75} = 1.807$, $P = 0.07$), fall 2009 had significantly higher abundance than fall 2010 ($t_{91} = 10.67$, $P < 0.01$).

Appendix D

AVIAN BREEDING SPECIES OF CHICKALOON FLATS, 2009-2010

I recorded nests to document the breeding species of Chickaloon Flats. There was no formal survey established for nest searching, but I recorded nests while conducting other fieldwork. Additionally, I initiated nest searches when individuals performed nest defense behaviors. Other confirmed breeders were determined by observations of fledglings.

Results

There were 24 species of confirmed breeders during 2009 and 2010 (Appendix E). Of those, 10 species were confirmed through observations of fledglings, while nests substantiated 14 breeding species. Fledglings included; red-necked grebe, American green-winged teal, merlin, greater yellowlegs, least sandpiper, Wilson's snipe, Bonaparte's gull, gray jay, black-billed magpie, and American robin. Through opportunistic nest searches, I found 56 nests (Figure D.1) representing 11 different species; mew gull (N=28), arctic tern (N=9), northern pintail (N=5), herring gull (N=4), lesser yellowlegs (N=2), semipalmated plover (N=2), violet-green swallow (N=2), short-billed dowitcher (N=1), red-necked phalarope (N=1), northern shoveler (N=1), and mallard (N=1). Additionally, along the forest edge there was one active nest each of red-tailed hawk, common raven, and bald eagle. Species utilized a variety of breeding

habitats of Chickaloon. The majority of the waterfowl (N= 7) and gull (32) nests were located around the large permanent ponds in Plot 2 in Floating marsh, Marsh community, and Seaside-arrow grass land cover types. The arctic tern nests were in Type 3 Mud community, typically found in dry clumps of large alkali-grass in the middle of mud pans. Semipalmated plover nests were also in Type 3 Mud community, in bigger patches of large alkali-grass. Although similar time was spent on Plot 1 and Plot 2, no nests were found on Plot 1, potentially attributed to the smaller, narrower area of possible nesting habitats and lack of permanent ponds. Extreme tide events do not usually occur during nesting season, so areas usually exposed to tidal waters during spring and fall are protected from flooding events during nesting season.

Discussion

Of the 24 breeding species, 5 are species of conservation concern. On the Kenai Peninsula, the red-necked phalarope has declined by 40% over the last ten years (pers. comm. T. Eskelin). A single nest was found during 2009 in the Marsh community. Short-billed dowitcher is a species of high conservation concern with long-term declines (NABCI 2009). Short-billed dowitcher is a confirmed breeder, with a single nest found on Plot 4 and two chicks observed foraging on Plot 2 in 2010. Lesser yellowlegs and least sandpiper are both experiencing long-term declines as well (NABCI 2009). Two lesser yellowlegs nests were found in 2010 and least sandpiper is a suspected breeder. Another species with declining numbers suspected to breed on Chickaloon is the rusty blackbird, which has declined by 75% in the past 40 years (NABCI 2009). Rusty blackbirds often

nest on margins of beaver ponds (Avery 1995), and one pair was seen throughout spring/summer seasons during 2009 and 2010 near the beaver pond on Pincher Creek.

In addition, a pair of Wilson's phalaropes (*Phalaropus tricolor*) was observed and documented on June 7, 2010 on the east-central part of Plot 2. Although there were attempts to relocate birds in the following days, they were not seen again. Wilson's phalarope is listed as rare (annual or possibly annual in small numbers; most such species occur at the perimeter of Alaska) according to the Checklist of Alaska Birds (Gibson et al. 2012), however this pair was the first documented sighting of the species on the Kenai National Wildlife Refuge.

Although the numbers of breeding individuals is low for all species, especially those of concern, Chickaloon provides productive breeding habitat for a variety of migratory species.

Figure D.1: Locations of 56 nests of 11 species opportunistically found within and between four study plots during 2010 on Chickaloon Flats.



Appendix E

ALL 95 AVIAN SPECIES RECORDED ON CHICKALOON FLATS DURING SPRING AND FALL OF 2009-2010

a) Spring survey dates 4–26 May 2009 and 21 April – 12 June 2010 and b) fall dates were 27 June – 6 August 2009, 15–18 August 2009 and 8 July – 25 August 2010. All survey dates are indicated by grey, daily presence of each species is indicated by black, and non-survey days are indicated by white. Confirmed breeding status indicated by *. No assumptions on observing all breeding species.

a)

Common name	Scientific name	Year	21-Apr	28-Apr	5-May	12-May	19-May	26-May	2-Jun	9-Jun
common loon	<i>Gavia immer</i>	2009								
		2010								
red-necked grebe*	<i>Podiceps grisegena</i>	2009								
		2010								
trumpeter swan	<i>Cygnus buccinator</i>	2009								
		2010								
greater white-fronted goose	<i>Anser albifrons</i>	2009								
		2010								
snow goose	<i>Chen caerulescens</i>	2009								
		2010								
cackling goose	<i>Branta hutchinsii</i>	2009								
		2010								
canada goose	<i>Branta canadensis</i>	2009								
		2010								
american green-winged teal*	<i>Anas c. carolinensis</i>	2009								
		2010								
mallard*	<i>Anas platyrhynchos</i>	2009								
		2010								

Common name	Scientific name	21-Apr	28-Apr	5-May	12-May	19-May	26-May	2-Jun	9-Jun
northern pintail*	<i>Anas acuta</i>	2009							
		2010							
northern shoveler*	<i>Anas clypeata</i>	2009							
		2010							
gadwall	<i>Anas strepera</i>	2009							
		2010							
american wigeon	<i>Anas americana</i>	2009							
		2010							
eurasian wigeon	<i>Anas penelope</i>	2009							
		2010							
scaup spp.	<i>Aythya</i> spp.	2009							
		2010							
blue-winged teal	<i>Anas discors</i>	2009							
		2010							
canvasback	<i>Aythya valisineria</i>	2009							
		2010							
ring-necked duck	<i>Aythya collaris</i>	2009							
		2010							
Barrow's goldeneye	<i>Bucephala islandica</i>	2009							
		2010							
common merganser	<i>Mergus merganser</i>	2009							
		2010							
bufflehead	<i>Bucephala albeola</i>	2009							
		2010							
white-winged scoter	<i>Melanitta fusca</i>	2009							
		2010							
brant	<i>Branta bernicla</i>	2009							
		2010							
surf scoter	<i>Melanitta perspicillata</i>	2009							
		2010							

Common name	Scientific name	Year	21-Apr	28-Apr	5-May	12-May	19-May	26-May	2-Jun	9-Jun
osprey	<i>Pandion haliaetus</i>	2009								
		2010								
bald eagle*	<i>Haliaeetus leucocephalus</i>	2009								
		2010								
northern harrier	<i>Circus cyaneus</i>	2009								
		2010								
northern goshawk	<i>Accipiter gentilis</i>	2009								
		2010								
red-tailed hawk*	<i>Buteo jamaicensis</i>	2009								
		2010								
merlin*	<i>Falco columbarius</i>	2009								
		2010								
peregrine falcon	<i>Falco peregrinus</i>	2009								
		2010								
sandhill crane*	<i>Grus canadensis</i>	2009								
		2010								
black-bellied plover	<i>Pluvialis squatarola</i>	2009								
		2010								
pacific golden-plover	<i>Pluvialis fulva</i>	2009								
		2010								
american golden-plover	<i>Pluvialis dominica</i>	2009								
		2010								
semipalmated plover*	<i>Charadrius semipalmatus</i>	2009								
		2010								
ruddy turnstone	<i>Arenaria interpres</i>	2009								
		2010								
black turnstone	<i>Arenaria melanocephala</i>	2009								
		2010								
greater yellowlegs*	<i>Tringa melanoleuca</i>	2009								
		2010								
lesser yellowlegs*	<i>Tringa flavipes</i>	2009								
		2010								

Common name	Scientific name	Year	21-Apr	28-Apr	5-May	12-May	19-May	26-May	2-Jun	9-Jun
solitary sandpiper	<i>Tringa solitaria</i>	2009								
		2010								
whimbrel	<i>Numenius phaeopus</i>	2009								
		2010								
hudsonian godwit	<i>Limosa haemastica</i>	2009								
		2010								
semipalmated sandpiper	<i>Calidris pusilla</i>	2009								
		2010								
western sandpiper	<i>Calidris mauri</i>	2009								
		2010								
least sandpiper*	<i>Calidris minutilla</i>	2009								
		2010								
red knot	<i>Calidris canutus</i>	2009								
		2010								
pectoral sandpiper	<i>Calidris melanotos</i>	2009								
		2010								
dunlin	<i>Calidris alpina</i>	2009								
		2010								
surfbird	<i>Aphriza virgata</i>	2009								
		2010								
short-billed dowitcher*	<i>L. griseus caurinus</i>	2009								
		2010								
long-billed dowitcher	<i>Limnodromus scolopaceus</i>	2009								
		2010								
stilt sandpiper	<i>Calidris himantopus</i>	2009								
		2010								
Wilson's snipe*	<i>Gallinago delicata</i>	2009								
		2010								
Wilson's phalarope	<i>Phalaropus tricolor</i>	2009								
		2010								
red-necked phalarope*	<i>Phalaropus lobatus</i>	2009								
		2010								

Common name	Scientific name	2009	2010	21-Apr	28-Apr	5-May	12-May	19-May	26-May	2-Jun	9-Jun
bonaparte's gull*	<i>Chroicocephalus philadelphia</i>										
mew gull*	<i>Larus canus</i>										
herring gull *	<i>Larus argentatus</i>										
glaucous-winged gull	<i>Larus glaucescens</i>										
arctic tern*	<i>Sterna paradisaea</i>										
great horned owl	<i>Bubo virginianus</i>										
short-eared owl	<i>Asio flammeus</i>										
northern saw-whet owl	<i>Aegolius acadicus</i>										
downy woodpecker	<i>Picoides pubescens</i>										
hairy woodpecker	<i>Picoides villosus</i>										
american three-toed woodpecker	<i>Picoides dorsalis</i>										
olive-sided flycatcher	<i>Contopus cooperi</i>										
western wood-pewee	<i>Contopus sordidulus</i>										
alder flycatcher	<i>Epidonax alnorum</i>										

Common name	Scientific name	Year	21-Apr	28-Apr	5-May	12-May	19-May	26-May	2-Jun	9-Jun
tree swallow	<i>Tachycineta bicolor</i>	2009								
		2010								
violet-green swallow*	<i>Tachycineta thalassina</i>	2009								
		2010								
bank swallow	<i>Riparia riparia</i>	2009								
		2010								
gray jay*	<i>Perisoreus canadensis</i>	2009								
		2010								
black-billed magpie*	<i>Pica hudsonia</i>	2009								
		2010								
common raven*	<i>Corvus cora</i>	2009								
		2010								
northern shrike	<i>Lanius excubitor</i>	2009								
		2010								
black-capped chickadee	<i>Poecile atricapillus</i>	2009								
		2010								
boreal chickadee	<i>Poecile hudsonicus</i>	2009								
		2010								
red-breasted nuthatch	<i>Sitta canadensis</i>	2009								
		2010								
ruby-crowned kinglet	<i>Regulus calendula</i>	2009								
		2010								
swainson's thrush	<i>Catharus ustulatus</i>	2009								
		2010								
hermit thrush	<i>Catharus guttatus</i>	2009								
		2010								
american robin*	<i>Turdus migratorius</i>	2009								
		2010								
varied thrush	<i>Icterus naevius</i>	2009								
		2010								

Common name	Scientific name	Year	21-Apr	28-Apr	5-May	12-May	19-May	26-May	2-Jun	9-Jun
american pipit	<i>Anthus rubescens</i>	2009			■					
		2010								
orange-crowned warbler	<i>Vermivora celata</i>	2009				■		■		
		2010							■	
yellow-rumped warbler	<i>Dendroica coronata</i>	2009			■	■	■	■		
		2010			■	■	■	■	■	■
savannah sparrow*	<i>Passerculus sandwichensis</i>	2009			■	■	■	■		
		2010			■	■	■	■	■	■
dark-eyed junco	<i>Junco hyemalis</i>	2009			■	■	■	■		
		2010			■	■	■	■	■	■
lapland longspur	<i>Calcarius lapponicus</i>	2009			■	■	■	■		
		2010			■	■	■	■	■	■
rusty blackbird	<i>Euphagus carolinus</i>	2009			■	■	■	■		
		2010			■	■	■	■	■	■
spruce grouse	<i>Falcipecten canadensis</i>	2009								
		2010								
common redpoll	<i>Acanthus flammea</i>	2009			■					
		2010								
white-winged crossbill	<i>Loxia leucoptera</i>	2009				■				
		2010								

b)

Common name	Scientific name	27-Jun	4-Jul	11-Jul	18-Jul	25-Jul	1-Aug	8-Aug	15-Aug	22-Aug
common loon	<i>Gavia immer</i>	2009								
		2010								
red-necked grebe*	<i>Podiceps grisegena</i>	2009								
		2010								
trumpeter swan	<i>Cygnus buccinator</i>	2009								
		2010								
greater white-fronted goose	<i>Anser albifrons</i>	2009								
		2010								
snow goose	<i>Chen caerulescens</i>	2009								
		2010								
cackling goose	<i>Branta hutchinsii</i>	2009								
		2010								
canada goose	<i>Branta canadensis</i>	2009								
		2010								
american green-winged teal*	<i>Anas c. carolinensis</i>	2009								
		2010								
mallard*	<i>Anas platyrhynchos</i>	2009								
		2010								
northern pintail*	<i>Anas acuta</i>	2009								
		2010								
northern shoveler*	<i>Anas clypeata</i>	2009								
		2010								
gadwall	<i>Anas strepera</i>	2009								
		2010								
american wigeon	<i>Anas americana</i>	2009								
		2010								
eurasian wigeon	<i>Anas penelope</i>	2009								
		2010								
scaup spp.	<i>Aythya spp.</i>	2009								
		2010								
blue-winged teal	<i>Anas discors</i>	2009								
		2010								

Common name	Scientific name	27-Jun	4-Jul	11-Jul	18-Jul	25-Jul	1-Aug	8-Aug	15-Aug	22-Aug
canvasback	<i>Aythya valisineria</i>	2009								
		2010								
ring-necked duck	<i>Aythya collaris</i>	2009								
		2010								
Barrow's goldeneye	<i>Bucephala islandica</i>	2009								
		2010								
common merganser	<i>Mergus merganser</i>	2009								
		2010								
bufflehead	<i>Bucephala albeola</i>	2009								
		2010								
white-winged scoter	<i>Melanitta fusca</i>	2009								
		2010								
brant	<i>Branta bernicla</i>	2009								
		2010								
surf scoter	<i>Melanitta perspicillata</i>	2009								
		2010								
osprey	<i>Pandion haliaetus</i>	2009								
		2010								
bald eagle*	<i>Haliaeetus leucocephalus</i>	2009								
		2010								
northern harrier	<i>Circus cyaneus</i>	2009								
		2010								
northern goshawk	<i>Accipiter gentilis</i>	2009								
		2010								
red-tailed hawk*	<i>Buteo jamaicensis</i>	2009								
		2010								
merlin*	<i>Falco columbarius</i>	2009								
		2010								
peregrine falcon	<i>Falco peregrinus</i>	2009								
		2010								
sandhill crane*	<i>Grus canadensis</i>	2009								
		2010								

Common name	Scientific name		27-Jun		4-Jul		11-Jul		18-Jul		25-Jul		1-Aug		8-Aug		15-Aug		22-Aug
black-bellied plover	<i>Pluvialis squatarola</i>	2009																	
		2010																	
pacific golden-plover	<i>Pluvialis fulva</i>	2009																	
		2010																	
american golden-plover	<i>Pluvialis dominica</i>	2009																	
		2010																	
semipalmated plover*	<i>Charadrius semipalmatus</i>	2009																	
		2010																	
ruddy turnstone	<i>Arenaria interpres</i>	2009																	
		2010																	
black turnstone	<i>Arenaria melanocephala</i>	2009																	
		2010																	
greater yellowlegs*	<i>Tringa melanoleuca</i>	2009																	
		2010																	
lesser yellowlegs*	<i>Tringa flavipes</i>	2009																	
		2010																	
solitary sandpiper	<i>Tringa solitaria</i>	2009																	
		2010																	
whimbrel	<i>Numenius phaeopus</i>	2009																	
		2010																	
hudsonian godwit	<i>Limosa haemastica</i>	2009																	
		2010																	
semipalmated sandpiper	<i>Calidris pusilla</i>	2009																	
		2010																	
western sandpiper	<i>Calidris mauri</i>	2009																	
		2010																	
least sandpiper*	<i>Calidris minutilla</i>	2009																	
		2010																	
red knot	<i>Calidris canutus</i>	2009																	
		2010																	
pectoral sandpiper	<i>Calidris melanotos</i>	2009																	
		2010																	

Common name	Scientific name	27-Jun	4-Jul	11-Jul	18-Jul	25-Jul	1-Aug	8-Aug	15-Aug	22-Aug
dunlin	<i>Calidris alpina</i>	2009								
		2010								
surfbird	<i>Aphriza virgata</i>	2009								
		2010								
short-billed dowitcher*	<i>L. griseus caurinus</i>	2009								
		2010								
long-billed dowitcher	<i>Limnodromus scolopaceus</i>	2009								
		2010								
stilt sandpiper	<i>Calidris himantopus</i>	2009								
		2010								
Wilson's snipe*	<i>Gallinago delicata</i>	2009								
		2010								
Wilson's phalarope	<i>Phalaropus tricolor</i>	2009								
		2010								
red-necked phalarope*	<i>Phalaropus lobatus</i>	2009								
		2010								
bonaparte's gull*	<i>Chroicocephalus philadelphia</i>	2009								
		2010								
mew gull*	<i>Larus canus</i>	2009								
		2010								
herring gull *	<i>Larus argentatus</i>	2009								
		2010								
glaucous-winged gull	<i>Larus glaucescens</i>	2009								
		2010								
arctic tern*	<i>Sterna paradisaea</i>	2009								
		2010								
great horned owl	<i>Bubo virginianus</i>	2009								
		2010								
short-eared owl	<i>Asio flammeus</i>	2009								
		2010								
northern saw-whet owl	<i>Aegolius acadicus</i>	2009								
		2010								

Common name	Scientific name	Year	27-Jun	4-Jul	11-Jul	18-Jul	25-Jul	1-Aug	8-Aug	15-Aug	22-Aug
downy woodpecker	<i>Picoides pubescens</i>	2009									
		2010									
hairy woodpecker	<i>Picoides villosus</i>	2009	■	■				■		■	■
		2010									
american three-toed woodpecker	<i>Picoides dorsalis</i>	2009									
		2010			■	■					
olive-sided flycatcher	<i>Contopus cooperi</i>	2009	■	■	■	■	■	■			
		2010				■	■	■		■	
western wood-pewee	<i>Contopus sordidulus</i>	2009									
		2010				■	■				
alder flycatcher	<i>Empidonax alnorum</i>	2009									
		2010					■				
tree swallow	<i>Tachycineta bicolor</i>	2009					■	■			
		2010				■					
violet-green swallow*	<i>Tachycineta thalassina</i>	2009		■	■	■	■				
		2010			■	■	■	■			
bank swallow	<i>Riparia riparia</i>	2009						■			
		2010									
gray jay*	<i>Perisoreus canadensis</i>	2009		■		■		■			■
		2010									
black-billed magpie*	<i>Pica hudsonia</i>	2009	■	■							
		2010			■	■					
common raven*	<i>Corvus cora</i>	2009	■	■	■	■	■	■	■	■	■
		2010			■	■	■	■	■	■	■
northern shrike	<i>Lanius excubitor</i>	2009									
		2010					■				
black-capped chickadee	<i>Poecile atricapillus</i>	2009									
		2010						■			
boreal chickadee	<i>Poecile hudsonicus</i>	2009				■	■			■	■
		2010				■	■	■	■	■	■
red-breasted nuthatch	<i>Sitta canadensis</i>	2009									
		2010									

Common name	Scientific name	27-Jun	4-Jul	11-Jul	18-Jul	25-Jul	1-Aug	8-Aug	15-Aug	22-Aug
ruby-crowned kinglet	<i>Regulus calendula</i>	2009								
		2010								
swainson's thrush	<i>Catharus ustulatus</i>	2009								
		2010								
hermit thrush	<i>Catharus guttatus</i>	2009	■	■						
		2010								
american robin*	<i>Turdus migratorius</i>	2009	■	■	■	■				
		2010								
varied thrush	<i>Ixoreus naevius</i>	2009	■	■						
		2010								
american pipit	<i>Anthus rubescens</i>	2009								
		2010								
orange-crowned warbler	<i>Vermivora celata</i>	2009	■							
		2010								
yellow-rumped warbler	<i>Dendroica coronata</i>	2009								
		2010								
savannah sparrow*	<i>Passerculus sandwichensis</i>	2009	■	■	■	■	■	■	■	■
		2010								
dark-eyed junco	<i>Junco hyemalis</i>	2009	■	■						
		2010								
lapland longspur	<i>Calcarius lapponicus</i>	2009								
		2010								
rusty blackbird	<i>Euphagus carolinus</i>	2009	■							
		2010								
spruce grouse	<i>Falcipectnis canadensis</i>	2009								
		2010								
common redpoll	<i>Acanthus flammea</i>	2009								
		2010								
white-winged crossbill	<i>Loxia leucoptera</i>	2009								
		2010								

Appendix F

PLANT SPECIES OF VEGETATED CLASSIFICATION TYPES OF CHICKALOON FLATS USED FOR SUPERVISED CLASSIFICATION

Plant species and classification follows Quimby (1972).

Common species name by vegetation type	Scientific name	Species classification
Mud		
Mud		primary
Algae		primary
Large Alkali-grass		
Large Alkali-grass	<i>Puccinellia grandis</i>	primary
Seaside Arrow-grass	<i>Triglochin maritimum</i>	primary
Goose-tongue	<i>Plantago maritima juncooides</i>	secondary
Slender Glasswort	<i>Salicornia europaea</i>	secondary
Creeping Alkali-grass	<i>Puccinellia phryganodes</i>	secondary
Beach Rye-grass	<i>Elymus arenarius mollis</i>	secondary
Pacific silverweed	<i>Potentilla egedii grandis</i>	secondary
Mud		secondary
Ramenski Sedge		
Ramenski Sedge	<i>Carex ramenski</i>	primary
Seaside Arrow-grass	<i>Triglochin maritimum</i>	secondary
Type 3 Mud		
Mud		primary
Creeping Alkali-grass	<i>Puccinellia phryganodes</i>	secondary
Creeping Alkali-grass		
Seaside Arrow-grass	<i>Triglochin maritimum</i>	primary
Creeping Alkali-grass	<i>Puccinellia phryganodes</i>	primary
Large Alkali-grass	<i>Puccinellia grandis</i>	secondary
Marsh Arrow-grass	<i>Triglochin palustris</i>	secondary

Short-stalk sedge	<i>Carex podocarpa</i>	secondary
Creeping Alkali-grass	<i>Puccinellia phryganodes</i>	secondary
Marsh		
Lyngbye sedge	<i>Carex lyngbyei</i>	primary
Creeping Spike-rush	<i>Scirpus paludosus</i>	primary
Sitka sedge	<i>Carex sitchensis</i>	primary
Pondweed	<i>Potamogeton</i> sp.	secondary
Four-leaved Mare's tail	<i>Hippuris tetraphylla</i>	secondary
Great Bulrush	<i>Scirpus validus</i>	secondary
Water sedge	<i>Carex aquatilis</i>	secondary
Short-stalk sedge	<i>Carex podocarpa</i>	secondary
Sedge	<i>Carex loliaceae</i>	secondary
Horned Pondweed	<i>Zannichellia palustris</i>	secondary
Seaside Arrow-grass		
Seaside Arrow-grass	<i>Triglochin maritimum</i>	primary
Lyngbye sedge	<i>Carex lyngbyei</i>	secondary
Marsh Arrow-grass	<i>Triglochin palustris</i>	secondary
Large Alkali-grass	<i>Puccinellia grandis</i>	secondary
Short-stalk sedge	<i>Carex podocarpa</i>	secondary
Four-leaved Mare's tail	<i>Hippuris tetraphylla</i>	secondary
Horned Pondweed	<i>Zannichellia palustris</i>	secondary
Floating Marsh		
Lyngbye sedge	<i>Carex lyngbyei</i>	primary
Creeping Spike-rush	<i>Scirpus paludosus</i>	primary
Sitka sedge	<i>Carex sitchensis</i>	primary
Lesser Panicked Sedge	<i>Carex diandra</i>	primary
Silvery Sedge	<i>Carex canescens</i>	primary
Buckbean	<i>Menyanthes trifoliata</i>	secondary
Western Water Hemlock	<i>Cicuta douglasii</i>	secondary
Seaside Crowfoot	<i>Ranunculus cymbalaria</i>	secondary
Red Fescue	<i>Pestuca rubra</i>	secondary
Sedge	<i>Carex pluriflora</i>	secondary
Ryegrass sedge	<i>Carex loliacea</i>	secondary
Water sedge	<i>Carex aquatilis</i>	secondary
Loose-flowered Alpine Sedge	<i>Carex rariflora</i>	secondary
Northern Reed-grass	<i>Calamagrostis inexpansa</i>	secondary
Great Bulrush	<i>Scirpus validus</i>	secondary

Three-flowered Rush	<i>Juncus triglumis</i>	secondary
Yellow Marsh Marigold	<i>Caltha palustris</i>	secondary
Arctic Dock	<i>Rumex arcticus</i>	secondary
Wild Iris	<i>Iris setosa</i>	secondary
Fireweed	<i>Epolobium</i> sp.	secondary

Bog

Sweet gale	<i>Myrica gala</i>	primary
Arctic Dock	<i>Rumex arcticus</i>	primary
Sweet gale	<i>Myrica gala</i>	primary
Dwarf Alpine Birch	<i>Betula nana</i>	primary
Willow	<i>Salix myrtillifolia</i>	primary
Willow	<i>Salix</i> sp.	primary
Bluejoint	<i>Calamagrostis canadensis canadensis</i>	primary
Wild Iris	<i>Iris setosa</i>	primary
Loose-flowered Alpine Sedge	<i>Carex rariflora</i>	secondary
Lyngbye sedge	<i>Carex lyngbvaei</i>	secondary
Western Water Hemlock	<i>Cicuta douglasii</i>	secondary
Red Fescue	<i>Pestuca rubra</i>	secondary
Sedge	<i>Carex pluriflora</i>	secondary
Sitka sedge	<i>Carex sitchensis</i>	secondary
Water sedge	<i>Carex aquatilis</i>	secondary
Three-flowered Rush	<i>Juncus triglumis</i>	secondary

Alder

Alder	<i>Alnus</i> sp.	primary
Northern Reed-grass	<i>Calamagrostis inexpansa</i>	secondary
Bluejoint	<i>Calamagrostis canadensis canadensis</i>	secondary
Lyngbye sedge	<i>Carex lyngbyei</i>	secondary
Red Fescue	<i>Pestuca rubra</i>	secondary
Arctic Dock	<i>Rumex arcticus</i>	secondary
Western Water Hemlock	<i>Cicuta douglasii</i>	secondary

Marsh Fringe

Large-flowered spear-grass	<i>Poa eminens</i>	primary
Beach rye-grass	<i>Elymus arenarius mollis</i>	primary
Bluejoint	<i>Calamagrostis canadensis canadensis</i>	primary
Large Alkali-grass	<i>Puccinellia grandis</i>	primary
Seaside Arrow-grass	<i>Triglochin maritimum</i>	secondary
Marsh Arrow-grass	<i>Triglochin palustris</i>	secondary

Lyngbye sedge	<i>Carex lyngbyei</i>	secondary
Goose-tongue	<i>Plantago maritima juncoides</i>	secondary
Pacific silverweed	<i>Potentilla egedii grandis</i>	secondary
Arctic daisy	<i>Chrysanthemum arcticum</i>	secondary
Creeping Alkali-grass	<i>Puccinellia phryganodes</i>	secondary
Squirrel-tail barley	<i>Hordeum jubatum</i>	secondary
Star flower	<i>Trientalis europaea</i>	secondary
Red top	<i>Agrostis</i> sp.	secondary
Dogwood	<i>Cornus</i> sp.	secondary

Appendix G

287 VEGETATION POINTS VISITED DURING 2009-2010

Points with associated NAD83 ((North American Datum of 83); Alaska Albers Equal Area projection) coordinates and Plot number. Vegetation type classification of each point from Quimby derived from digitized aerial photos from 1970-1971. Ulman classification is from ground truth points of 2009-2010. Type abbreviations are as follows: Type 3 Mud (3M), Creeping alkali-grass (AG), Floating marsh (FM), Marsh community (MC), Ramenski sedge (RS), Seaside arrow-grass (SG), Fringe community (FC), and Large alkali-grass (LG). Ulman classification reflects if there was a change in vegetation type classification from Quimby.

Latitude	Longitude	Plot	Quimby classification	Ulman classification
651261	6757274	1	3M	MUD
651471	6757252	1	3M	
650559	6758097	1	3M	LG
651255	6757038	1	3M	
651535	6756517	1	3M	
651099	6757559	1	3M	LG
650536	6758035	1	3M	LG
650957	6757706	1	3M	LG
650704	6757999	1	3M	LG
650703	6757999	1	3M	LG
650767	6757766	1	3M	MUD
654546	6756261	2	3M	LG
653644	6755424	2	3M	
654367	6756162	2	3M	LG
654858	6755920	2	3M	
654970	6756075	2	3M	LG
654897	6755771	2	3M	
655054	6756069	2	3M	LG
653986	6755106	2	3M	RS
654905	6755995	2	3M	LG
654233	6756011	2	3M	LG

660050	6754338	3	3M	LG
659032	6754342	3	3M	LG
659198	6754398	3	3M	LG
658968	6754284	3	3M	
659116	6754220	3	3M	LG
659597	6754242	3	3M	LG
659122	6754331	3	3M	LG
660129	6754287	3	3M	LG
659136	6754310	3	3M	LG
665817	6757430	3	3M	LG
666157	6757435	3	3M	
654234	6756011	3	3M	
665739	6756908	3	3M	LG
665703	6757053	3	3M	LG
330458	6757050	4	3M	
330709	6757438	4	3M	LG
340180	6756726	4	3M	LG
330702	6756738	4	3M	
340197	6757036	4	3M	LG
650389	6758008	1	AG	
651151	6756741	1	AG	RS
650680	6757396	1	AG	
651029	6757046	1	AG	
651213	6756747	1	AG	
650318	6757695	1	AG	
650425	6757599	1	AG	RS
650444	6757733	1	AG	RS
650073	6757951	1	AG	
655229	6755547	2	AG	LG
654775	6755594	2	AG	LG
654836	6755562	2	AG	LG
654927	6755423	2	AG	LG
653763	6755448	2	AG	
655048	6755766	2	AG	LG
654482	6755643	2	AG	
653894	6755570	2	AG	
653993	6755426	2	AG	
341130	6757196	4	AG	LG
341172	6757106	4	AG	
330775	6756293	4	AG	MC

330659	6756482	4	AG	
330800	6756398	4	AG	SG
340958	7656884	4	AG	LG
330623	6756562	4	AG	
341049	6757264	4	AG	
330668	6756703	4	AG	LG
653488	6754500	3	FM	
659485	6753501	3	FM	ALDER
659706	6753708	3	FM	
659781	6753725	3	FM	
659561	6753679	3	FM	
659612	6753672	3	FM	
659412	6753462	3	FM	BOG
659762	6753657	3	FM	
659391	6753608	3	FM	
659737	6753489	3	FM	BOG
653904	6754252	3	FM	
650676	6756723	3	FM	
650829	6756642	3	FM	
650958	6756425	3	FM	
651304	6756146	1	MC	
651279	6756111	1	MC	FM
651308	6756185	1	MC	FM
651375	6755995	1	MC	FM
651386	6755929	1	MC	FM
651310	6756033	1	MC	FM
651159	6756095	1	MC	FM
651274	6756139	1	MC	
651247	6756136	1	MC	FM
653504	6754666	2	MC	AG
653479	6754763	2	MC	AG
653790	6754502	2	MC	
653786	6754504	2	MC	
653589	6754619	2	MC	FM
653689	6754724	2	MC	FM
653971	6754849	2	MC	
653853	6754977	2	MC	
653704	6754404	2	MC	FM
654034	6754899	2	MC	
659437	6754219	3	MC	SG

659135	6753625	3	MC	
659865	6753733	3	MC	
659246	6753665	3	MC	
658892	6754152	3	MC	SG
330458	6756285	4	MC	3M
330789	6756128	4	MC	FM
330928	6756382	4	MC	
330767	6755971	4	MC	
330310	6756171	4	MC	SG
330375	6755664	4	MC	
330404	6756199	4	MC	SG
330691	6755952	4	MC	FM
330600	6755782	4	MC	FM
651252	6758650	1	MUD	
651018	6758176	1	MUD	
650637	6758557	1	MUD	
651010	6758356	1	MUD	
652090	6758331	1	MUD	
651866	6758608	1	MUD	
651723	6758498	1	MUD	
650557	6758558	1	MUD	
651969	6757725	1	MUD	
651777	6758588	1	MUD	
651634	6758393	1	MUD	
650927	6758167	1	MUD	
652227	6757983	1	MUD	
650530	6758793	1	MUD	
653647	6756462	2	MUD	LG
654728	6756728	2	MUD	LG
654154	6756998	2	MUD	
654877	6757694	2	MUD	
655100	6757275	2	MUD	
653605	6755964	2	MUD	
653640	6756732	2	MUD	LG
654259	6757342	2	MUD	
654630	6757634	2	MUD	
655231	6756735	2	MUD	
655161	6757717	2	MUD	
654709	6757701	2	MUD	
654226	6756206	2	MUD	LG

654936	6757175	2	MUD	
654534	6757490	2	MUD	
659150	6754612	3	MUD	LG
659533	6755998	3	MUD	LG
660150	6755524	3	MUD	
658357	6754823	3	MUD	LG
659870	6755767	3	MUD	
658205	6756208	3	MUD	LG
658848	6756439	3	MUD	LG
659520	6754380	3	MUD	LG
659781	6755225	3	MUD	LG
658443	6754575	3	MUD	LG
659871	6754924	3	MUD	LG
659491	6754581	3	MUD	LG
659915	6754621	3	MUD	LG
659724	6755274	3	MUD	LG
339664	6758409	4	MUD	3M
339815	6758231	4	MUD	AG
339187	6758156	4	MUD	AG
338867	6758490	4	MUD	
339246	6758331	4	MUD	AG
339028	6757939	4	MUD	LG
399085	6758135	4	MUD	AG
338178	6758621	4	MUD	
338459	6758877	4	MUD	
338902	6758966	4	MUD	
339461	6758985	4	MUD	
339849	6758419	4	MUD	AG
339229	6758196	4	MUD	LG
339843	6758337	4	MUD	AG
650481	6758080	1	RS	
651341	6756786	1	RS	3M
651128	6757189	1	RS	LG
651176	6757461	1	RS	LG
651193	6757414	1	RS	LG
650943	6757790	1	RS	LG
650331	6758073	1	RS	AG
651237	6757016	1	RS	MUD
650507	6758061	1	RS	
650317	6758163	1	RS	

653810	6756203	1	RS	LG
654353	6756290	2	RS	LG
654529	6756153	2	RS	LG
653909	6758934	2	RS	LG
653435	6755755	2	RS	LG
654635	6756251	2	RS	LG
653835	6756245	2	RS	LG
654754	6756198	2	RS	LG
653855	6756343	2	RS	LG
659304	6754265	3	RS	LG
658683	6754566	3	RS	LG
658961	6754449	3	RS	LG
660385	6753934	3	RS	3M
659862	6754367	3	RS	
658840	6754525	3	RS	LG
660303	6754372	3	RS	LG
658745	6754520	3	RS	MUD
659883	6754490	3	RS	LG
659873	6754406	3	RS	LG
330831	6757511	4	RS	LG
330622	6756978	4	RS	LG
330575	6757017	4	RS	LG
340245	6756828	4	RS	LG
340268	6756536	4	RS	LG
330368	6757077	4	RS	LG
339991	6756203	4	RS	MUD
341000	6757622	4	RS	LG
340213	6756797	4	RS	LG
341243	6757664	4	RS	LG
659972	6757645	1	SG	FM
650056	6757630	1	SG	FM
650128	6757923	1	SG	MC
651081	6756726	1	SG	
650374	6757556	1	SG	FM
653220	6754763	2	SG	
653388	6754759	2	SG	AG
654877	6755512	2	SG	LG
654465	6755307	2	SG	LG
653167	6754884	2	SG	AG
654330	6755165	2	SG	AG

659585	6753560	3	SG	FM
659534	6753604	3	SG	FM
659495	6753466	3	SG	BOG
659530	6753446	3	SG	BOG
659556	6753585	3	SG	FM
659526	6753487	3	SG	BOG
659433	6753613	3	SG	FM
659507	6753574	3	SG	FM
659483	6753490	3	SG	BOG
331114	6756558	4	SG	
341307	6757113	4	SG	
331114	6756638	4	SG	
331082	6756576	4	SG	
331087	6756659	4	SG	
330719	6756429	4	SG	
341484	6757152	4	SG	
331072	6756728	4	SG	
330817	6756789	4	SG	
341322	6756995	4	SG	
651274	6756062	1	FC	FM
330694	6755845	4	FC	FM
341417	6757032	4	FC	FM
341420	6757066	4	FC	
330863	6756137	4	FC	FM
331113	6756489	4	FC	
341497	6757143	4	FC	MC
330776	6755979	4	FC	FM
330805	6755960	4	FC	FM
650898	6758049	1	LG	MUD
651484	6757222	1	LG	
651580	6757244	1	LG	MUD
651819	6757187	1	LG	
651761	6757229	1	LG	3M
650928	6757987	1	LG	3M
651216	6757514	1	LG	
651134	6757883	1	LG	MUD
651480	6757156	1	LG	
654478	6756694	2	LG	
653754	6756329	2	LG	
653720	6756431	2	LG	

654545	6756678	2	LG	
653548	6756689	2	LG	
653990	6756501	2	LG	
653864	6756673	2	LG	
655128	6756378	2	LG	
655065	6756772	2	LG	AG
659162	6755505	3	LG	
660328	6754419	3	LG	
658303	6755492	3	LG	
658870	6755349	3	LG	
659084	6754848	3	LG	
660214	6755060	3	LG	
658184	6755942	3	LG	
658460	6754895	3	LG	
659061	6756121	3	LG	
658566	6755526	3	LG	
340825	6757920	4	LG	
340982	6757869	4	LG	
339560	6756778	4	LG	
340995	6757783	4	LG	
339578	6757900	4	LG	AG
339650	6757524	4	LG	
339955	6758140	4	LG	
339985	6757953	4	LG	
339042	6757546	4	LG	
340034	6757891	4	LG	

Appendix H

EXTREME TIDAL EVENTS SUSTAIN FORAGING HABITAT FOR MIGRATING SHOREBIRDS ON AN ALASKAN ESTUARY

Introduction

Ephemeral pools in tidal estuaries are temporary sources of water represented by a variety of shapes and sizes, and are usually lacking in fish, but abundant in invertebrates (Scheffers et al. 2006). Ephemeral pools can provide key foraging areas for both resident and migratory waterfowl and shorebirds (Haig et al. 1998, Silveira 1998). Most pools are initially filled by snow and ice melt, with varying periods of recharging water via tidal flow and precipitation. Some are consistently recharged with daily flooding tides, which provide reliable foraging habitat.

Other areas do not experience consistent flooding, and pools dry up as spring progresses, being sustained only by precipitation (Schalles and Shure 1989). These ephemeral pools dry up, leaving deeper permanent ponds as the only reliable water source in some areas. While the edges of permanent ponds provide roosting sites for birds, they do not provide optimal foraging depths like ephemeral pools (Silveira 1998). Therefore, the availability of ephemeral pools as foraging habitat for migrating waterfowl and shorebirds is critical in some areas, and knowing the factors that drive these ephemeral pools is important for habitat management and species conservation.

During a study of shorebird use on a coastal estuary in south-central Alaska, we gradually realized that the hydrology of ephemeral pools we were studying was atypical of most tidal systems. The goal of this research was to determine what environmental factors (maximum weekly high tide, extreme tide event presence in that week, maximum weekly temperature, and cumulative weekly precipitation) are most important in determining presence and surface area of ephemeral pools on Chickaloon.

Study Area

Chickaloon Flats is a 10,000 ha tidal estuary located along Turnagain Arm in upper Cook Inlet, on the Kenai National Wildlife Refuge, Alaska. Several riverine systems flow into this complex including the Chickaloon River, Big and Little Indian Creeks, and Pincher Creek. Seaside arrow-grass (*Triglochin maritimum*), Large alkali-grass (*Puccinellia grandis*), and Creeping alkali-grass (*Puccinellia phryganodes*) are dominant in areas of higher salinity; Lyngbye sedge (*Carex lyngbvaei*) and Creeping spike-rush (*Scirpus paludosus*) are dominant in areas of lower salinity; however, much of the estuary is unconsolidated mudflats.

Tides are an important ecological factor in Cook Inlet and on Chickaloon Flats. The shape and depth of Cook Inlet generates very large tidal amplitude. Cook Inlet tides are semi-diurnal with a mean tidal range of 9.2 m, which is second greatest in the world behind Bay of Fundy (11.7 m) (Mulherin et al. 2001).

Despite this high tidal variation, sheet flow of saltwater over Chickaloon Flats is a relatively rare event. Unlike most estuaries that experience saltwater inundation twice

daily, saltwater only overflows the banks of tidal sloughs during extreme tide events. An extreme tide event is when tide levels exceed 8.84 m (Quimby 1972, pers. obs.) and water overflows the sloughs and spreads across the flats (pers. obs.). Extreme tide events occur cyclically on Chickaloon Flats, usually during February, March, August, and September (Quimby 1972).

This unusual flooding regime is made even more so by the peculiar topography due to tectonic subsidence in the aftermath of an earthquake in 1964. Extreme tides inundate Chickaloon at varying levels depending on west-east location (Figure H.1, pers. obs.). On the western side, extreme tides completely submerge most vegetated communities almost to the forest edge. Approximately 4 km to the east of that area, extreme tides do not inundate in a wave, but rather flooding occurs from sloughs being breached and water overflowing onto vegetated communities. Extreme tides on the far eastern side (Figure H.1) near Big Indian Creek do not completely submerge vegetated areas, and only partially submerge the plant community closest to Cook Inlet. This west-east inundation gradient prevents some habitats from receiving the recharging waters from predictable extreme tides.

Methods

I monitored surface areas of pools beginning 24 April 2010, when initial water came from melting ice. I measured the width and length as surface area of each pool to the nearest 0.25 m, once a week for 18 weeks, with the exception of weeks 8–11 because I was not in the field. Due to the absence of measurements for weeks 8–11, only dried up

pools (areas of zero) for both weeks 7 and 12 were used in analysis. This excluded 7 pools that were recharged with water during the weeks of no measurements. Sample size for analysis was 14 ephemeral pools. An auto-regressive lag-1 model ($p \leq 0.10$) was run on each of the 14 pools to determine what main effects (maximum weekly high tide, extreme tide event presence in that week, maximum weekly temperature, and cumulative weekly precipitation) influenced the auto correlated surface area of ephemeral pools over time. This model identified the primary factors in determining surface area while accounting for temporal correlation in pool size.

Results

The occurrence of an extreme tide event was a significant factor in determining surface area in 12 of 14 pools (Table H.1). Weekly maximum tide was also a significant factor for 2 of the 14 ephemeral pools. No single factor significantly determined surface area for two of the pools. Temperature and weekly cumulative precipitation did not significantly influence pool surface area.

Extreme tides (>8.84 m) were the most important dynamic in determining size of ephemeral pools. Extreme tides are temporally variable across seasons and years, and typically occur only 4–5 times from April through August in a given year. Over the 7-year span of 2004–2010 there were only 17 total extreme tide events during spring migration and 15 during fall (Figure H.2), with a range of only 1-3 extreme events during both spring and fall of those years. Not only are these extreme tide events variable in seasonal occurrence, but also in duration. Over those 7 years, the average duration of an

extreme tide event was 3.76 days (range 2-7 days) during spring, and 3.27 days (range 2-6 days) for fall. The variation in seasonal occurrence and duration may substantially change the amount and extent to which reliable shorebird foraging habitat is available.

Though temporally variable, tides are periodic and predictable because of the gravitational effect of the sun and moon (Hicks 2006). From 2004–2010 the first extreme tide event of spring occurred from 1–16 April 2004–2010, with the second spring tide occurring during 26 April – 24 May (Figure H.2). Extreme tide events are also variable in their height, ranging from 8.9–9.7 m across 32 tide events from 2004–2010. This seasonal variation in extreme tides affects when pools are recharged, and can therefore significantly influence the distribution of, and available water in ephemeral pools available during shorebird and waterfowl migrations.

Although I did not find precipitation to be a significant predictor of pool surface area, it is possible this result was biased by higher precipitation in 2010 (NOAA 2010). While conducting other research on the study area during 2009, I anecdotally noted and photographed that the longevity and availability of ephemeral pools was lower. Comparing the available ephemeral pools between 2009 and 2010, 2009 was much drier with less available surface water, most likely linked to precipitation (Figure H.3). Evaluating photos from the second week in July of 2009 and 2010, the 2009 season was less green and much drier (with no ground water present) including noticeable salt pans in east. This comparison represents precipitation only, as extreme tides occurred 19 and 71 days, respectively, before photos were taken. Taking into account observations and photos, precipitation may help to sustain ephemeral pools between extreme tide events.

Discussion

The presence of ephemeral pools throughout the Chickaloon landscape has the potential to provide important shorebird foraging habitat, especially during spring migration. It is critically important for shorebirds to replenish energy reserves at stopover sites and staging areas to successfully complete a long-distance migration (Skagen and Knopf 1993). Shorebirds migrate along flyways with knowledge of their ever-changing environment and may choose a stopover site based on the occurrence of a flooded landscape that offers potential foraging habitats (Colwell 2010). This importance of water presence at a stopover site emphasizes the significance of the timing, duration, and height of extreme tide events on Chickaloon Flats during spring and fall migration periods.

In addition to the variation of timing, duration, and height of extreme tides, the west-east inundation gradient is a further influence on the location and amount of habitat receiving recharging waters. The variation in water inundation across Chickaloon may be due to a combination of the west-east subsidence and uplift gradients. The 1964 Earthquake registered between 8.3–8.6 on the Richter scale with its epicenter about 129 km east of Chickaloon in the Chugach Mountains. The flats subsided from the earthquake, with a 61 cm drop in the west to 137 cm in the east (Quimby 1972), and has experienced uplift since then from ~30 cm in west to 75–80 cm in east (Jeff Freymueller pers. comm.). These two gradients may help to explain the distribution of available ephemeral pools in relation to amount of recharging waters received from extreme tide events, with the majority occurring on the western portion of Chickaloon. Due to the seasonality of extreme tide occurrences, the timing of these inundations could change the

temporal availability of ephemeral pools, which consequently alters the available shorebird foraging area.

The amount of flooding can also be influenced by wind coming off Turnagain Arm, with excessive winds causing more inundation. When extreme tide events coincided with heavy winds, saltwater inundation was more extensive (pers. obs.). Pools would continuously drain via shallow channels until the next high tide cycle would slow or stop the flow. Pools were recharged with saltwater during extreme tides, so water was typically retained in pools longer following an extreme high tide. The coastal environment of Chickaloon Flats is very unique when considering the amount of subsidence in the aftermath of the earthquake combined with uplift, and the low occurrence of flooding by extreme tide events.

Tides also have an effect on the vegetation patterns (Neiland 1971). The daily change of tidal heights alters the frequency and duration of inundation of vegetated areas, which affects the plant species present in those communities. The infrequency of extreme tide occurrence has the potential to provide just enough salt-water inundation to halt any salt-intolerant plants from being successful and not enough salt-water inundation for success of alkali species. This combination, along with silt deposition, could be a principal reason for changes in vegetated communities. An analysis of sequential Landsat imagery from 1975–2005 suggests that estuary vegetation is gradually being replaced by bare mud, rather than transitioning to other floral communities (see Chapter 3). Because ephemeral pool foraging areas are in vegetated areas, the transition of vegetated habitat to

mud may decrease the area available for sustaining ephemeral pools, therefore reducing overall shorebird foraging habitat and the value of Chickaloon as a stopover site.

In addition to foraging in ephemeral pools, shorebirds were also seen foraging in sloughs, primarily following high tides when prey would be exposed. Sloughs represent another foraging resource on Chickaloon with patchy distribution (Lourenco et al. 2005) and temporal restriction. Sloughs may provide widespread, predictable, and reliable foraging habitats throughout the seasons and inclement weather (Townshend 1981), and may be an important additional foraging habitat, especially when ephemeral pools are not abundant (Myers et al. 1980).

Taking into account the influences (timing, duration, and height of extreme tides, winds, and west-east gradient) involved with recharging the system with saltwater and precipitation helping to sustain the pools, the presence of ephemeral pools may vary markedly across seasons and years. The unreliable nature of ephemeral pools is concerning, and the attraction of this area as a dependable resource for migrating shorebirds may be diminishing. The presence and amount of ephemeral pools, and therefore the overall value of Chickaloon Flats as a feeding area for migrating shorebirds, are at risk due to uplift (Freymueller pers. comm.) and siltation of Turnagain Arm (NMFS 2008). Even with the variable nature of foraging habitat and the potential lower use of the area in the future, Chickaloon can be a critical connection to breeding areas for individuals (Skagen and Knopf 1994a).

Table H.1: Significant factors (extreme tide event, weekly maximum tide, weekly maximum temperature, and/or weekly cumulative precipitation) in determining auto correlated surface areas of 14 ephemeral pools over time ($P \leq 0.10$) between 24 April – 28 August 2010 on Chickaloon Flats, Kenai National Wildlife Refuge, Alaska. Table shows p-values of significant factors.

Factor	Pool ID													
	A	B	C	E	F	H	J	K	L	M	V	Y	Z	ZA
Extreme tide event	0.08	<0.01		0.02	0.01	0.1	0.09	0.09	0.01	0.08	0.02		0.1	0.05
Weekly maximum tide		0.04		0.06										
Weekly maximum temperature														
Weekly cumulative precipitation														

Figure H.1: Outline of Chickaloon Flats with 2 visualizations of extreme tide event inundation. Representation (shaded grey) of difference in July extreme tide inundation between west and east. This shaded extreme tide area only shows marked locations of ground observed inundation, and is not a complete portrayal of extreme tide inundation across the flats. Two time-series photographs of extreme tide showing sheet flow (location 1: July 22, 2009) versus slough breaching (location 2: August 12, 2010) depending on position on flats.

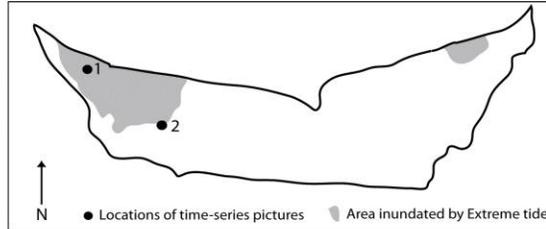


Figure H.2: Visual interpretation of seasonal and annual variations of frequency, duration, and height of extreme tide events from 2004–2010 during spring and fall migration periods. Length of horizontal bars represent duration, in days, of extreme tides. NOAA tide predictions from Fire Island, AK station.

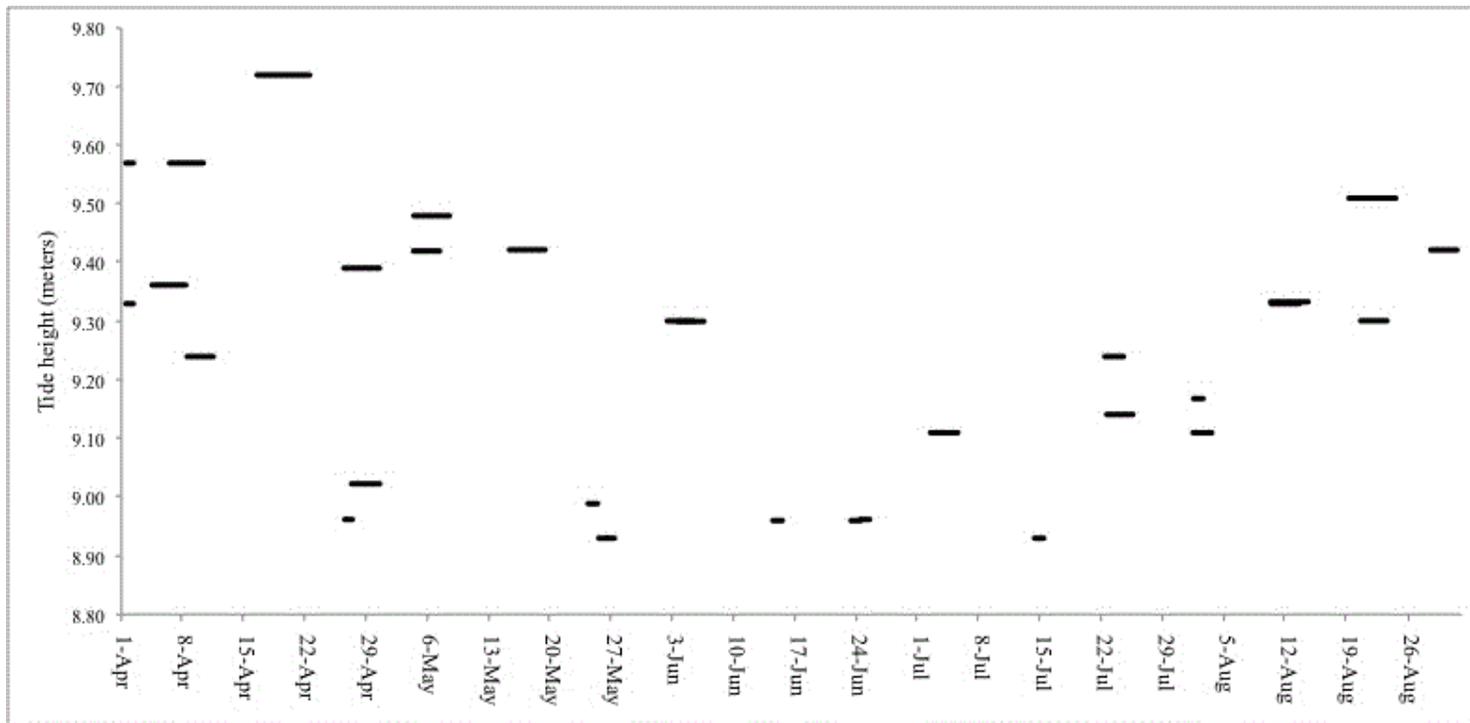
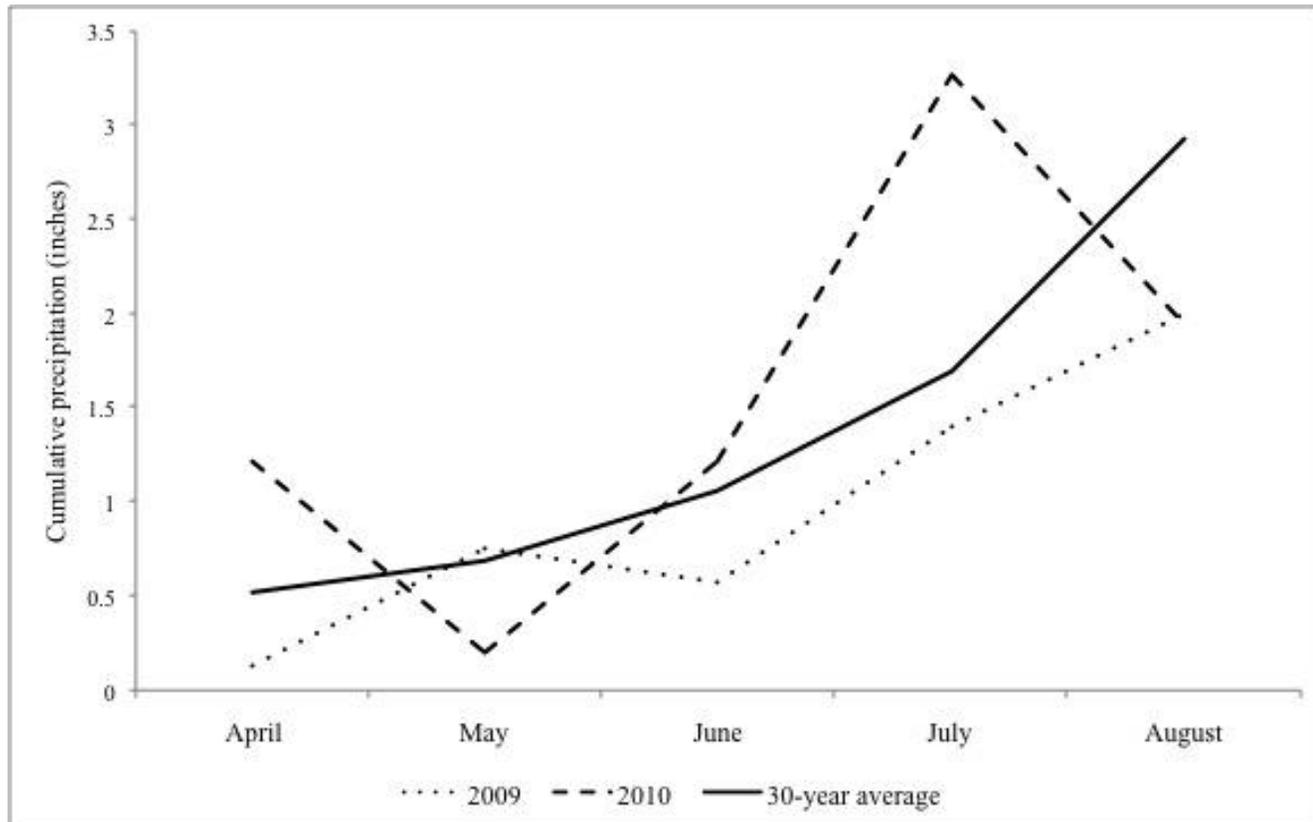


Figure H.3: The monthly cumulative precipitation for 2009 and 2010 and the 30-year monthly average from Anchorage Forecast Office station, NOAA. April through August of 2009 was slightly below average, but followed the 30-year average trend. 2010 was an unusual precipitation year, compared to 30-year average, with most months being above average, with the exceptions of May and August, which fell below.



Appendix I

University of Delaware
Institutional Animal Care and Use Committee
Request to Terminate an Animal Use Protocol

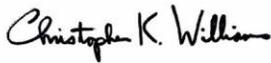
(Please complete below using Arial, size 12 Font.)



Title of Protocol: The use of staging and breeding waterfowl and shorebirds on the Chickaloon Flats, Kenai National Wildlife Refuge, Alaska.	
AUP Number: 1191-2011-T	← (4 digits only)
Principal Investigator: Dr. Christopher K. Williams	

Please indicate the reason for termination:

- Animal work completed
- Animal model no longer appropriate
- Leaving university or research program
- Other:

	6/10/11
_____ Signature of Principal Investigator	_____ Date

Official Use Only	
IACUC Approval Signature: _____	
Date: _____	6-13-11

Rev. 06/2010