THESIS

SHOREBIRD HABITAT USE AND ABUNDANCE ESTIMATES ON MILITARY LANDS IN INTERIOR ALASKA

Submitted by

Ellen C. Martin

Department of Fish, Wildlife, and Conservation Biology

In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Spring 2019

Master's Committee:

Advisor: Paul F. Doherty, Jr.

Calvin F. Bagley
Kim A. Jochum
William L. Kendall
Kenneth Shockley

ABSTRACT

SHOREBIRD HABITAT USE AND ABUNDANCE ESTIMATES ON MILITARY LANDS IN INTERIOR ALASKA

Shorebird populations are declining globally and little is known about habitat use and distribution of breeding species in interior Alaska. In North America, reliable indices of population trends are lacking for 25% of shorebird species and current threats (e.g., climate change) to shorebirds are increasing in severity and frequency. Warming patterns in the Arctic and subarctic are occurring at twice the global rate and decreased availability of wetlands, thawing permafrost, and changes in phenology have disproportionately large effects on higher latitude habitats. Other changes to habitat are occurring as more humans access and utilize shorebird breeding habitat throughout interior Alaska. Understanding important shorebird breeding habitat in the boreal forest and future changes is critical for successful conservation.

The boreal forest in interior Alaska is remote and difficult to access. Thus, few studies have been conducted on shorebird status and trends, and little evidence exists documenting shorebird presence or areas of use in interior Alaska. A shorebird monitoring program for interior Alaska will help meet these information needs. The Program for Regional and International Shorebird Monitoring (PRISM) has developed shorebird survey methodology with most of this effort in the Arctic and little effort in the boreal forest. For my study, I developed a modified PRISM protocol to estimate shorebird species richness, habitat relationships, and abundance in interior boreal forest, specifically on military lands on Tanana Flats Training Area and Donnelly Training Area in Fairbanks and Delta Junction, Alaska. Over 600,000 hectares of

land in interior Alaska are managed by the US Department of Defense, where shorebird densities are predicted to be low. Military training operations occur year-round and are increasing in intensity (i.e., more troops participating in ground-based trainings) and frequency in interior Alaska due to home-stationing and collaborative military exercises.

I used a spatially balanced sampling design and twice surveyed 78 and 142 400 by 400 m plots in 2016 and 2017 respectively to (1) identify shorebird species using military lands in interior Alaska and estimate species richness for our study site, (2) create use models for these species and test hypotheses about species-specific covariate relationships (e.g., elevation, shrub height, distance to water), and (3) estimate shorebird abundance and test hypotheses about variation in abundance. In general, I hypothesized that use and abundance estimates for lowland shorebirds would be higher than for upland shorebirds and would decrease as shrub percent cover increased, increase as distance to water decreased, and increase in wet grassland /open mudflat Viereck habitat. I hypothesized that use and abundance estimates for upland shorebird species would be low and increase as shrub percent cover increased and increase in low shrub Viereck habitat. Although densities are predicted to be low, this area is so large that I hypothesized the boreal forest is an important breeding area for some species of nesting shorebirds and that lowland training areas support high species diversity.

In chapter one, I relied upon occupancy models to estimate species richness for four strata within military training areas. Further, I used occupancy models to estimate and correlate habitat covariates to shorebird use and detection. In my second chapter, I estimated abundance and evaluated if military lands in interior Alaska are important for shorebirds by comparing abundance estimates on interior Alaska military lands to criteria designated by the Western Hemisphere Shorebird Reserve Network. I then correlated habitat covariates with process

variance for shorebird species of conservation concern. Finally, I evaluated my modified Arctic PRISM protocol and discuss possible implementation for interior Alaska boreal forest.

I found that interior Alaska military lands host 12 species of shorebirds. Specifically, it hosts 7 shorebird species of moderate to high conservation concern as listed by the Alaska Shorebird Conservation Plan (American Golden Plover (*Pluvialis dominica*), Black-bellied Plover (*Pluvialis squatarola*), Solitary Sandpiper (*Tringa solitaria*), Lesser Yellowlegs (*Tringa flavipes*), Upland Sandpiper (*Bartramia longicauda*), Whimbrel (*Numenius phaeopus*), and Wilson's Snipe (*Gallinago delicata*) and 4 species of conservation concern as listed by the US Fish and Wildlife Service (Solitary Sandpiper, Lesser Yellowlegs, Upland Sandpiper, and Whimbrel; US Fish and Wildlife Service 2008). Habitat use models suggest that habitat characteristics on plot (i.e., elevation and percent scrub canopy cover) are the most important factors in determining shorebird use. As climate change impacts habitat suitability for shorebirds, my results suggest that suitable habitat for shorebirds such as wetlands and low elevation will be limited as water tables change and shrub encroachment limits higher and lower elevation habitats. Climate change and increasing intensity of military training activities are both changing landscapes in interior Alaska. The military should consider resilience principles upon which to base their management practices, with the goal to ensure future training opportunities and sustainable natural resource management. I recommend changing timing and locations of military training activities during peak shorebird breeding season to avoid areas of high probability of use. Abundance estimates suggest military lands in interior Alaska contain 42,239 (SE = 13,431) lowland shorebirds and 3,523 (SE = 494) upland shorebirds. Tanana Flats Training Area and Donnelly Training Area meet the criteria to be important areas for shorebirds as defined by the Western Hemisphere Shorebird Reserve Network. Ultimately, interior Alaska military lands contain large amounts of breeding habitat for shorebirds of conservation concern. I also found that my modifications to the Arctic PRISM protocol are suitable for surveying shorebirds in the boreal forest and recommend plot sizes and sample sizes be increased in future boreal surveys.

ACKNOWLEDGMENTS

First, I recognize that this project and this thesis could not have been completed without the help and guidance of my advisor, Paul F. Doherty, Jr. I am beyond grateful for your willingness to teach me throughout my time at CSU. I appreciate your availability, help, and your commitment to setting your students up for future success. Kim Jochum and Calvin Bagley at the Center for Environmental Management of Military Lands in both Delta Junction, Alaska and Fort Collins, Colorado, and John Haddix with the Environmental Division, U.S. Army Garrison Alaska, were instrumental collaborators in this project. Thank you for giving me the opportunity to take on this research project with CEMML under your guidance and for providing me with the resources necessary to accomplish it. Thank you to the additional members of my committee, Kenneth Shockley and William Kendall, for offering valuable support throughout this process.

I am grateful to my lab mates, both past and present, particularly Becky Ruzicka, Marina Rodriguez, and Casey Setash. I am grateful for the welcoming space we created in the lab but mostly I am grateful for the inspiration you all are as scientists. Thank you to my fellow graduate students at Colorado State University, an incredible cohort of talented people with every skill and interest imaginable.

Necessary to accomplishing project goals were the many wildlife technicians and CEMML scientists who walked hundreds of miles in the name of shorebirds: Laura Williams, Jacob Pelham, Gerrid Greenwood, Connor White, Nico Castellano, Lara Grevstad, Kyle Testerman, Eric Fotter, Kyle Van Atta, Dan Jenkins, Scott Debruyne, Kim Jochum, and Adam

Davis. Your enthusiasm for the project and your gusto tromping through wetlands amazed me.

Finally, a big thank you to my parents for being proud of me unconditionally.

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CHAPTER 1

SHOREBIRD HABITAT USE OF MILITARY LANDS IN INTERIOR ALASKA

Overview

Shorebird populations are declining globally and little is known about habitat use and distribution of breeding species in interior Alaska. Warming patterns in the Arctic and subarctic are occurring at twice the global rate and decreased availability of wetlands, thawing permafrost, and changes in phenology have disproportionately large negative effects on shorebird habitat at higher latitudes. Other changes to habitat are occurring as more humans access and utilize shorebird breeding habitat throughout interior Alaska. Understanding important shorebird breeding habitat and ecology in the boreal forest and future changes is critical for successful conservation. One of the largest land managers in the boreal forest of interior Alaska is the Department of Defense (DoD). In an effort to maximize military training opportunities while enhancing and protecting bioloical diversity into the future, the DoD documents species on lands they manage and use. Over 600,000 hectares of land in interior Alaska are managed by the US Department of Defense. From 2016 to 2017, I surveyed plots to (1) identify shorebird species using military lands in central Alaska and estimate species richness, (2) test hypotheses about species-specific covariate relationships (e.g., elevation, shrub height, distance to water), and (3) create maps from these models as a tool for the Army to evaluate where proposed training and development could potentially impact or overlap shorebird habitat.

I used a spatially balanced design and repeated sampling to survey interior Alaska boreal forest on military training areas. I twice surveyed 78 and 142 400 by 400 m plots in 2016 and 2017 respectively. I relied upon occupancy models to estimate species richness and detection. I

further used occupancy models to estimate shorebird use as well as to correlate habitat covariates to use and detection.

Shorebirds of conservation concern both nationally and regionally are breeding on military lands, utilizing an estimated 73% of available habitat. Species richness models varied by year and by training area with richness being highest in the mixed and upland habitats of Donnelly Training Area East and West during 2017 and lowest in lowland habitats Tanana Flats Training Area River and Lowlands. Habitat use models suggest that elevation, distance to wetlands, and percent water on plot are the most important factors determining probability of shorebird use. Probability of habitat use for all lowland and upland shorebirds increased as percent water on plot increased and decreased as distance to wetlands increased. Probability of habitat use for upland birds increased as elevation increased.

Suitable habitat for shorebirds is likely to decrease as lakes and wetlands decrease in size due to permafrost thaw and increased evaporation due to the warming climate. I have identified areas of high shorebird use and suggest scheduling military trainings to avoid peak breeding season temporally (i.e., avoid training in some areas May – June) and/or spatially.

Introduction

Shorebirds (families *Charadriidae*, *Haematopodidae*, *Recurvirostridae* & *Scolopacidae*), are of conservation concern because of global population declines (Myers et al. 1987, Brown et al. 2001, Andres et al. 2012). The most recent North American shorebird population assessments suggest that 70% of North American shorebird populations are experiencing long-term declines (Andres et al. 2012, North American Bird Conservation Initiative 2016).

Although abundance and trend estimation have improved with the recent implementation of shorebird monitoring programs (e.g., Program for Regional and International Shorebird

Monitoring and Western Hemisphere Shorebird Reserve Network), indices of population trends are lacking for 25% of all shorebird species (Andres et al. 2012). Additional basic ecological data such as habitat use remain unknown for most species, particularly on their breeding grounds where monitoring has been lacking (Lindström et al. 2015).

Alaska is an important breeding area for shorebirds after they have traveled thousands of kilometers from wintering sites in the southern hemisphere (Meltofte et al. 2007). The warming climate is rapidly changing shorebird habitat in Alaska (Devictor et al. 2008, Martin et al. 2009) and understanding shorebird habitat use will enable land managers to manage for projected habitat changes and novel communities.

The sheer size of the Alaskan interior forest (Bird Conservation Region 4), inaccessibility, and low density of shorebirds compound to make this one of the least studied regions in Alaska for shorebirds (Alaska Shorebird Group 2008), and a high priority for design-based surveys. This region is hypothesized to be an important breeding ground for several species of shorebirds that are of conservation concern (Alaska Shorebird Group 2017) and the interior boreal forest was identified in 2017 as the top priority for future research initiatives. Boreal-wide shorebird surveys have been proposed by the Alaska Shorebird Group and are projected to begin in 2020 (Alaska Shorebird Group 2017). The boreal forest is one of the largest bird conservation units in North America and is potentially vital habitat for shorebirds. Shorebirds that breed and nest in the boreal forest are likely more dispersed than coastal nesting birds, but the large expanse of available, undeveloped land in the interior could ultimately contain large areas of suitable shorebird breeding habitat.

Current Threats to Shorebirds

The climate is warming and landscapes are changing in the Arctic and subarctic. In the Arctic, these changes are occurring at twice the global rate (Scenarios Network for Alaska and Arctic Planning 2011, Collins et al. 2013) and are resulting in pronounced vegetation shifts, decreased availability of wetlands, and changes in phenology in the high latitude boreal forests (Danby and Hik 2007, Hope et al. 2013).

Climate change models predict further dramatic vegetation shifts in the Arctic and subarctic. Tundra habitat availability is expected to decline because of encroachment of shrub species onto former tundra area (Tape et al. 2006). Evidence from aerial photographs from the past 50 years show that alder (*Alnus spp.)*, dwarf birch (*Betula nana)*, and willow (*Salix spp.)* as well as smaller, ericaceous shrubs are increasing their ranges north in Arctic and subarctic Alaska (Naito and Cairns 2015, Tape et al. 2006). In the past 25 years, concomitant increases in the numbers of shrub-associated passerines have been documented in northern Alaska by the North American Breeding Bird Survey (BBS; Tape et al. 2006), and numbers of shrub-associated shorebirds (e.g., Upland Sandpiper and Whimbrel) are expected to follow similar trends. Shorebird predator and competitor expansion into these new shrubby habitats is also predicted (Wauchope et al. 2016).

Mismatch of shorebirds with prey availability is already pronounced in the Arctic and subarctic. Snowmelt patterns and plant growth are disproportionately impacted by changing weather patterns (Sutherland et al. 2012). Shorebirds typically follow traditional corridors of migration and time arrival onto breeding grounds to coincide with the pulse of available food resources (Meltofte et al. 2007, McKinnon et al. 2012). Resources available to shorebirds on their breeding grounds and the timing of their availability are important to shorebird reproduction, impacting both egg production and chick growth (Drent et al. 2003, McKinnon et al. 2012, Visser et al. 2012). Shorebirds are income breeders, requiring resources on the breeding ground to recover from lengthy migrations and prepare for breeding. As a result of climate change, resources such as arthropods needed for breeding are becoming less predictable in space and time (Meltofte et al. 2007). Shorebirds have shown both resistance and susceptibility to annual variability in food availability and snowmelt: The full consequences of the phenological mismatch between Alaskan shorebirds and their prey remains unknown (Visser et al. 2012, Meltofte et al. 2007).

Richness, Habitat Use, and Detection

Species richness can be an important metric of overall biodiversity and can help managers identify habitat to conserve in order to maximize species' persistence (Iknayan et al. 2014). Species richness is often reported as species counts, but such counts do not consider probability of detection. Repeat surveys for species in an occupancy framework can be used to estimate species richness by taking into account species present but undetected (Dorazio and Royle 2005, MacKenzie et al. 2002, 2003).

For some species of shorebirds, habitat requirements are known. For example, Whimbrels breed on hummocks with low, laterally growing vegetation (Ballantyne and Nol 2011, Harwood et al. 2016). For other species (e.g., Black-bellied Plover and Lesser Yellowlegs) habitat use during breeding has not been well studied in the interior boreal forest. Other study sites in the Arctic have shown Black-bellied Plover to nest in sparsely vegetated habitat (i.e., dry heath) with low lateral nest cover (Smith et al. 2007). Previous literature has found shorebird presence to be related to the elevation of study sites (e.g., Andres 2006), with some species preferring upland habitats and others preferring lowland habitats. Some species, such as the Lesser Yellowlegs, are suspected to breed extensively in interior boreal forest (Elphick and Tibbitts 1998, Tibbitts and Moskoff 1999).

Lowland species breed in low, riverine corridors because of available resources and large amounts of biomass associated with wetlands, such as invertebrate prey (Saalfeld et al. 2016). Lowland species are suspected to use and forage in habitat with no to low-density woody vegetation and habitat with nutrient-rich arthropods (Galbraith et al. 2014). Upland shorebird species breed in higher alpine and upland habitats and use low, dense scrub habitat, tundra hummocks to hide nests from predators (e.g., Harwood et al. 2016), or other required nesting habitat such as rocky ridge tops with low ground cover (e.g., Surfbird (*Aphriza virgate*)). Therefore, habitat covariates in the boreal forest (e.g., shrub percent cover, distance to water, and elevation) are likely important determinants of shorebird use and colonization on our study sites. Understanding species-habitat relationships is a crucial step in shorebird conservation.

Estimating shorebird habitat use, colonization, and detection, as well as correlating hypothesized habitat covariates to use and detection, can be achieved with occupancy models (MacKenzie et al. 2002, 2003). Occupancy models estimate the proportion of surveyed sites occupied by the species of interest. Occupancy analysis is appropriate for analyzing habitat use and species richness because it allows estimates to be corrected and account for imperfect detection (i.e., species that were present but not detected; MacKenzie et al. 2002, 2018). A species may be present on plot but undetected for a multitude of reasons including shorebirds' cryptic behavior or calling at low volumes and rates (Kéry and Schmidt 2008, Mackenzie et al. 2018). One important assumption of occupancy models is that the system is closed, i.e., there are no changes in shorebird habitat use during surveys. This closure assumption is untenable in an uncontrolled environment with survey plot sizes small relative to territory size. In such situations without perfect closure, occupancy is viewed as use to recognize that animals can move (Mackenzie 2006). Therefore, I am estimating shorebird habitat use and not assuming perfect closure.

The Department of Defense and Shorebird Conservation

Land managers in the interior boreal forest will need to respond to changes caused by climate change and human impact. One of the largest land managing agencies in interior Alaska is the US Department of Defense (DoD). The DoD manages more than half a million hectacres of interior Alaska boreal forest (Fort Wainwright, Alaska, including Tanana Flats Training Area near Fairbanks, and Donnelly Training Area, near Delta Junction, Alaska) for aerial and ground-based military training (U.S. Army Garrison Fort Wainwright 2013). A large portion of this land is withdrawn from Bureau of Land Management and State of Alaska lands and regulated by the Alaska Army Lands Withdrawal Renewal Act (Center for Environmental Management of Military Lands 1999).

In an effort to maximize military training opportunities while enhancing and protecting biological diversity, the DoD documents species on lands they manage and use (Alaska Army Lands Withdrawl Renewel 1999; Center for Environmental Management of Military Lands 1999). The DoD also takes part in wetland mitigation, training range restoration, and provides hunting and other recreational opportunities (INRMP 2013). Fort Wainwright and its associated lands are the only Army training lands in the boreal forest. In the near future, trainings on Tanana Flats Training Area and Donelly Training Areas are expected to increase in frequency and intensity (>5,000 ground-based troops) due to home-stationing and collaborative large-scale training exercises, often involving soldiers from multiple countries.

No large scale, design-based survey has been carried out to evaluate shorebird habitat relationships or to account for detection in richness or habitat use estimates on military lands in interior Alaska. Given that the DoD is mandated to follow federal environmental laws such as the Endangered Species Act (Department of the Interior 1973), Migratory Bird Treaty Act (U.S. Fish and Wildlife Service 1918), and Sikes Act (Sikes Act 1960), concerns about shorebirds are rising and assessing the status of shorebirds on DoD lands is warranted (Hayden et al. 2008). Knowledge about which species use military lands and their habitat relationships will provide a better understanding of the role and onus the military has in protecting these species and their habitats, and how to best balance training activities with shorebird requirements. Further, understanding habitat use by shorebirds will help the military to maintain the current breadth of habitats they utilize for a diversity of training purposes thus the results of this study will contribute to the military mission.

Objectives and Predictions

My objectives were to (1) identify shorebird species using military lands in interior Alaska and estimate species richness, (2) create habitat use models for these species and test hypotheses about covariate relationships (e.g., elevation, shrub height, distance to wetland), and (3) create maps from these models as a tool for the Army to evaluate how proposed training and development interact with habitat likely to be occupied by shorebirds.

I hypothesized that lowland strata on my study site (i.e., Tanana Flats Training Area River and Tanana Flats Training Area Lowlands) would have higher species richness than upland strata because of proximity to nutrient-rich riverine corridors. I hypothesized that mixed upland strata (i.e., Donnelly Training Area East and Donnelly Training Area West) would have lower species richness because of steep, higher elevation terrain and fewer patches of suspected suitable breeding habitat. I also hypothesized that use by lowland species would decrease as shrub percent cover increased, increase as distance to wetland decreased, and increase in wet grassland /open mudflat Viereck habitat (Viereck et al. 1992). I hypothesized that use for upland shorebird species would increase as percent shrub canopy cover increased and increase in low shrub Viereck habitat (Table 1.1, Table 1.2).

Materials & Methods

Study Site

Fort Wainwright (FWA) military lands in interior Alaska constitute over 600,000 hectares of land and contain 94 uniquely identified habitat types (Viereck et al. 1993). FWA consists of multiple training areas. The two largest training areas and the ones on which I conducted shorebird surveys are Tanana Flats Training Area (TFTA) and Donnelly Training Area (DTA). TFTA is located south of Fairbanks, Alaska. DTA, split into DTA East and DTA West, is located south-west of Delta Junction, Alaska and abuts Fort Greely (Figure 1.1). TFTA spans 267,088 hectares and DTA spans 266,320 hectares. These training areas are characterized by closed boreal forest (*Picea mariana, P. glauca, Populus tremuloides*), both tall (*Alnus* spp., *Salix* spp., *Betula nana*) and low scrub (*Vaccinium vitis-idea, Betula nana*, *V. uliginosum*) as well as ground cover such as moss and lichen. This region is frequently altered by forest fire (Viereck et al. 1993).

TFTA is a lowland, wet, riverine ecosystem with the Tanana River and tribuitaries flowing through the landscape. Elevations in TFTA range from 120 to 360 meters (m). Conversely, the majority of DTA is considered upland habitat (>600 m elevation), containing the Delta River which quickly gains steep elevation on both banks, leveling out to upland scrub hills

(Figure 1.2; Gallant et al. 1995). The foothills of the Alaska Range begin on the south boundary of DTA, where there are numerous alpine ridges. Elevations in DTA range from 360 to 1860 m.

Sampling Design: Survey Protocol

The Arctic PRISM program for shorebird monitoring served as the model for my survey methods. PRISM did not recommend one approach to conduct boreal forest shorebird surveys, but instead offered a list of untested survey methods (Skagen et al. 2003). Suggestions included aerial surveys, mini-Breeding Bird Surveys, and emulation of the Arctic PRISM survey (Skagen et al. 2003). I designed and implemented a modified Arctic PRISM protocol.

The Arctic PRISM protocol includes both rapid and intensive surveys on randomly selected 400 by 400 m plots. For my study, I repeatedly visited randomly selected plots within two training areas, separated into four strata (Tanana Flats Training Area River, Tanana Flats Training Area Lowland, Donnelly Training Area East, and Donnelly Training Area West). Repeat plot visits allow me to estimate both detection and habitat use using methods of MacKenzie et al. (2018).

Sampling Design: Vegetation and Plot Selection

Given information known about shorebird breeding ecology, I excluded non-breeding habitats (e.g., dense closed black spruce forest; Andres et al. 2012) from my sampling frame. I relied on Viereck's classification of Alaskan vegetation cover for exclusion of unsuitable habitat (Viereck et al. 1993). The habitat map was created using Landsat 5 imagery and verified via ground truthing at over 7,000 vegetation plots on military training lands including TFTA, DTA East and West, Black Rapids Training Area (BRTA), Gerstle River Training Area (GRTA), and Yukon Training Area (YTA; U.S. Army Environmental Division Fort Wainwright 2017). I evaluated habitat at third level Viereck classifications to delineate suitable shorebird habitats.

Third level Viereck classifications describe habitat types by dominant vegetation species, percent canopy cover, and ground condition (e.g., mesic, wet, dry). Following Andres et al. (2012), I included open forest, tall scrub, low scrub, dwarf scrub, herbaceous (graminoid/forb), moss/lichen, water, and barren ground cover classifications as suitable habitat. I included water bodies and known rivers as suitable habitat because of shorebirds' likely proximity to water and the imprecision of the GIS layer boundaries for water bodies; rivers within interior Alaska have fluid boundaries, often changing with time of year and differences in snow melt and rainfall. Using TFTA and DTA 21 m Digital Elevation Models, I classified plots by elevation as either uplands (≥ 600 m) or lowlands (≤ 600 m; Gallant et al. 1995). As elevation increases, vegetation shifts from lowland black spruce swamps to upland white spruce (*P. glauca*) and deciduous forests, open low ericaceous and woody shrub lands, and alpine lichen and bare rock (Viereck et al. 1993, Gallant et al. 1995).

Based on elevation and available habitat layers, I selected plots separately within each of the four strata using a spatially balanced sampling tool (Stevens and Olsen 2004, Theobald et al. 2007, ESRI 2011). Spatially balanced sampling enforces maximal spatial coverage within a probability-based method (Stevens and Olsen 2004) and encourages independence of samples (Theobald et al. 2007; Figure 1.3).

Plots were generated independently in four different strata. Based on various sampling access opportunities, three of the strata had equal sample allocation (TFTA Lowlands, DTA East, and DTA West). Plot access in TFTA Lowlands and DTA West was highly dependent on helicopter scheduling and weather. DTA East was accessed exclusively on foot or with 4-wheelers. Boats and rafts were used to access the TFTA River plots, which allowed increased efficiency by sampling more plots in the TFTA River corridor. We defined the TFTA River corridor as within one kilometer of two tributaries (Salchaket Slough, Wood River) of the Tanana River. This buffer was based on previous experience navigating in the Tanana River corridor.

Field Methods

Surveys were initiated on 7 May 2016 and 9 May 2017 to correspond with shorebird arrival and the beginning of breeding activities. The survey initiation date was based on shorebirds first arrival at frequently visited local areas of high shorebird density (i.e., Creamer's Field, Fairbanks, Alaska). Surveys ended 14 July 2016 and 14 July 2017 to align with cessation of breeding and historical shorebird departure from the area (Kessel and Springer 1966, Kessel and Gibson 1978, Haddix 2016).

I followed a dependent double-observer method on each plot (Nichols et al. 2000). A primary observer walked ahead of a secondary observer and indicated verbally where shorebirds were observed, species name, and number in each group (defined as shorebirds within 10 m of each other). The secondary observer recorded the shorebirds observed by the primary observer and any shorebirds that the primary observer missed. The observers walked transects through the entire plot. A plot required six transects to be adequately surveyed, each transect between 50 and 60 m apart. Primary and secondary roles were reversed for observers on subsequent plots. To keep observers independent, the secondary observer feigned shorebird observations and data collection and both observers stopped periodically to scan the plot with binoculars. I pooled encounter histories per visit across observers. Each plot was visited twice per field season and visits were made in ascending numerical order. However, visits were dependent on training area closures and openings which altered visit order at times. Plot access also required substantial travel time so field crews often surveyed nearby plots instead of strictly following numerical order.

In the field, we collected data on iPad Pro tablets using the GISPro application with preloaded data columns and drop down menus (ESRI 2011). The secondary observer on each plot operated the iPad and recorded data. At the end of the survey both observers collaboratively collected habitat data within a 50 m radius of the center of each plot. The team collected data on Viereck classification, shrub height, shrub and tree cover, open water, and dominant vegetation species. A broad vegetation categorization for the entire 16 ha plot was recorded at the end of each survey. The broad vegetation survey classified the three dominant third level Viereck habitat classifications and percentage of plot coverage (for full descriptions of habitat variables see Appendix 1a Table 1.1). For data analysis, I included 7 covariates from these habitat surveys; forest Viereck classification, scrub Viereck classification, forb/lichen/herbaceous Viereck classification, percent scrub canopy cover, elevation, distance to wetland, and percent water on plot (Viereck et al. 1993). These methods were carried out under the Institutional Animal Care and Use Committee (IACUC) Exemption #2016-10.

Data Analysis: Species Richness

I used occupancy models, raw number of species detected on plot during surveys, and detection probability to estimate species richness. *A priori*, I developed and created candidate models to test hypotheses about richness (ψ_r) and detection (p_r) with my main objective to estimate differences in species richness between training areas and years. Species richness in interior Alaska is suspected to be low, giving little power to the data to test more specific questions about habitat relationships.

I assessed species richness by training area to address my hypothesis that lowland strata support more species of shorebirds than upland strata. Using Program MARK (White and Burnham 1999) I investigated species richness with both a single-season random effects occupancy model and a single-season occupancy model in the four different strata, by lowland or upland habitats, and by year. I first investigated a random effects occupancy model to determine if unspecified heterogeneity existed in our data. I was unable to achieve convergence with that model (i.e., could not test hypotheses using this model) and focused on the occupancy model without random effects. I relied upon Akaike's Information Criterion (with a small sample size correction) for model selection (Burnham and Anderson 2002). Program MARK estimates the proportion of species richness (ψ^r) out of the 16 possible shorebirds (Table 1.3) in the community. I thus multiplied this proportion (ψ^r) by 16 for my estimates of species richness.

Data Analysis: Habitat Use Analysis

Underlying assumptions of habitat use models are a closed system, with no species moving into or out of the survey plot, independence of plots, equal probability of use across plots (or explained heterogeneity), and explainable heterogeneity in detection (MacKenzie et al. 2002). In a natural system, ensuring closure of a study site without fences or telemetry is difficult, if not impossible (Bailey et al. 2007). Therefore, I estimated habitat use and did not assume perfect closure of our system (Mackenzie 2006). I addressed the second assumption of independence of plots by employing a spatially balanced sampling design. I addressed the assumptions of equal probability of use and detection across plots, or explainable heterogeneity, by including appropriate covariates in my candidate model set. My hypotheses considered shorebird biology, habitat ecology, and previous literature to represent the likely strongest and most important habitat covariates (e.g., Andres et al. 2012).

I conducted independent analyses for Lesser Yellowlegs, Wilson's Snipe, all lowland shorebirds as a group, and all upland shorebirds as a group. I analyzed my data for grouped species with a dynamic multi-season (robust design) occupancy model with random effects. I was interested in using a random effects model to account for the heterogeneity in detection among species for grouped birds (i.e., all lowland birds and all upland birds). For individual species, (i.e., Lesser Yellowlegs and Wilson's Snipe) I analyzed my data with a dynamic multi-season (robust design) occupancy model in Program MARK (White and Burnham 1999). I selected the model parameterization estimating use, detection, colonization, and deriving extinction. Use and colonization were my principal parameters of interest.

A priori, I developed and created candidate models to test hypotheses about use, colonization, and detection, and focused on covariates such as elevation, distance to water, shrub cover, and habitat classifications (Tables 1.1 and 1.2). I derived my hypotheses (Tables 1.1 and 1.2) from existing literature, personal communication with biologists familiar with the study area and species, as well as personal observations (e.g., Meltofte 2007, Latour et al. 2005, Harwood et al. 2016). Habitat use and colonization hypotheses have similar predicted relationships with covariates (Table 1.1) because literature has shown that there is a relationship between individual decisions and habitat features related to reproductive success (Bled et al. 2011). I hypothesized that detection would vary for upland versus lowland shorebirds, and with habitat covariates. I hypothesized that predictions for detection would be similar for use and colonization. However, I hypothesized that for all shorebirds, regardless of elevation, detection would decrease as shrub percent cover increased (Table 1.2).

I relied upon Akaike's Information Criterion (with a small sample size correction; AIC_c) for model selection (Burnham and Anderson 2002) and used a two-step process for model selection. At each step, within a balanced model set I summed Akaike model weights (w_i) across all models containing a particular variable to determine relative importance of covariates (Burnham and Anderson 2002). I considered variables with cumulative AIC_c weights < 0.50 to be uninformative and culled them from future analyses (Doherty et al. 2012, Bromaghin et al. 2013).

For the first step of model selection on Lesser Yellowlegs and Wilson's Snipe, I held use (ψ) and colonization (γ) constant (.), (where "." indicates no variation) to estimate effects of all possible additive combinations of the five hypothesized habitat covariates and three hypothesized time effects (visit, year, and visit*year) on detection (p). For my analysis focused on all lowland or all upland shorebirds, I relied on a general heterogeneity (σ) model for detection instead of predicting the same habitat relationship strengths across species. This heterogeneity detection model worked for lowland species, but my sample sizes for upland species were inadequate to estimate heterogeneity and I had to assume some constancy across species in detection (see Results: All Upland Birds Habitat Use Model Results). In subsequent models, I held colonization (γ) and detection (p) constant (.) to estimate effects of all possible combinations of seven hypothesized habitat covariates plus a year effect on habitat use (ψ). I followed this same pattern for evaluating the full set of hypothesized covariates on colonization (γ). For each parameter (φ, γ, p), variables or time structures with cumulative variable weights $\geq$ 0.50 were retained for the second step of model selection. Occasionally, models were too complex for the available data and models would not converge, so it was necessary to limit the number of parameters in some models to fewer covariates.

The global model I used in step two of model selection included all variables retained from step one. From this global model, I constructed all possible additive combinations of variables on all parameters and evaluated both cumulative variable weights and top models in selecting important variables. Following Barbieri and Berger (2004), my predictive model included variables with cumulative variable weights, or importance values, ≥ 0.50 and my figures are based on these models.

I ran goodness of fit tests using c-hat ($\hat{c}$; Cooch and White 2013). The goodness of fit tests ensured that the most saturated model in my candidate model sets sufficiently fit the data and met model assumptions.

Data Analysis: Habitat Use Maps

I used vegetation data taken during plot surveys and remotely sensed data along with my predictive model to create habitat use maps for my study sites. I used the raster calculator in ArcGIS and included all predictive variables in each top model for Lesser Yellowlegs, Wilson's Snipe, all lowland shorebirds, and all upland shorebirds (ESRI 2011). I then used interpolative co-kriging to create raster layers of all habitat covariates found in my predictive models, namely, percent scrub canopy, percent water on plot, distance to wetland, and elevation. Co-kriging is a technique which interpolates (i.e., takes inverse weighted distance of closest three input points) a continuous surface to unmeasured surfaces from a scattered set of values (Queiroz et al. 2008). Co-kriging produces a representative surface layer by allowing a secondary variable in the interpolation model. Multivariate co-kriging allows accuracy of interpolation, particularly given that most of my top predictive models included more than one variable. I checked data for autocorrelation.

I calculated number of hectares used by shorebirds by modeling the habitat use estimate of each group (Lesser Yellowlegs, Wilson's Snipe, all lowland shorebirds, and all upland shorebirds) within each strata. Detections of birds on plots was low, so I shared detection across years for upland, lowland, Lesser Yellowlegs, and Wilson's Snipe. Shared hypotheses also allowed me to share detection between all lowland shorebirds, Lesser Yellowlegs, and Wilson's Snipe. I multiplied stratum-specific habitat use estimates by the total number of hectares of military lands in the sampling frame within each of the four strata. Military lands excluded from the sampling frame were 23,000 hectares of impact area in TFTA, 70,131 hectares of impact area in DTA, and 69,857 hectares of closed, dense spruce forest in both TFTA and DTA. 195,970 hectares of TFTA River and TFTA Lowland (out of 267,088 hectares; 73.40%) were considered surveyable and included in the sampling frame. 174,450 hectares of DTA East and West (out of 266,320 hectares; 65.50%) were considered surveyable and included in the sampling frame.

Results

Raw Survey Results

We surveyed 78 plots in 2016 and 142 plots in 2017. After preliminary data analysis in 2016, we doubled our survey effort in 2017 to achieve a more desirable coefficient of variation. In 2016, 23.61% of plots surveyed were in Tanana Flats Training Area River corridor, 18.06% of plots surveyed were in Tanana Flats Training Area Lowlands, 36.11% of plots surveyed were in Donnelly Training Area East, and 22.22% of plots surveyed were in Donnelly Training Area West. In 2017, 14.08% plots surveyed were in Tanana Flats Training Area River corridor, 23.23% of plots surveyed were in Tanana Flats Training Area Lowlands, 33.80% of plots surveyed were in Donnelly Training Area East, and 28.87% of plots surveyed were in Donnelly Training Area West (Appendix 1a Table 1.2). There were no goodness of fit issues with my data. There was no adjustment of variance needed because all c-hat goodness of fit values were < 1 (Table 1.4).

Field crews observed 107 shorebirds on 78 surveyed plots in 2016 and 344 shorebirds on 142 surveyed plots in 2017. The species observed on the highest number of plots were Wilson's Snipe (2016 n = 14 plots, 2017 n = 44 plots), followed by Lesser Yellowlegs (2016 n = 7 plots, 2017 n = 27 plots), and Spotted Sandpiper (2016 n = 7 plots, 2017 n = 11 plots). All other species were detected on ≤ five plots each year (Table 1.3). Lowland species of shorebirds were detected on more plots (31, 87) than upland species (3, 10) in both 2016 and 2017 respectively (Table 1.3).

Species Richness

Within all plots and across all training areas, we observed 12 species of shorebirds out of 16 possible predicted species during survey periods (Table 1.3). Specifically, military lands in interior Alaska host 7 shorebird species of moderate to high conservation concern as listed by the Alaska Shorebird Conservation Plan (American Golden Plover, Black-bellied Plover, Solitary Sandpiper, Lesser Yellowlegs, Upland Sandpiper, Whimbrel, and Wilson's Snipe) and 4 species of conservation concern as listed by the US Fish and Wildlife Service (Solitary Sandpiper, Lesser Yellowlegs, Upland Sandpiper, and Whimbrel).

My limited data only allowed a simple model on species richness, as random effect heterogeneity models would not converge. The most supported species richness model indicated species richness varied by year and by strata (Table 1.5 and Table 1.6). In 2017, species richness in Donnelly Training Areas East (species richness = 10.960, SE = 3.344) and West (species richness = 8.208, SE = 3.008) was higher than Tanana Flats Training Area Lowland (species richness = 6.528, SE = 2.144) and Tanana Flats Training Area River (species richness = 4.352, SE = 1.904). Compared to 2016, species richness estimates in 2017 for three strata were higher (Table 1.6).

Lesser Yellowlegs Habitat Use Model Results

Variables retained from step one for further habitat use modeling (i.e., those with cumulative weights ≥ 0.50) were elevation, percent scrub canopy cover, and year. For colonization, retained variables from step one of model selection were elevation, forb/lichen/herbaceous, and distance to wetland. For detection, retained variables were percent scrub canopy cover, percent water on plot, scrub, and visit (Table 1.7).

In the second step of model selection, I analyzed all possible combinations of covariates retained from first step of model selection. I detected no goodness of fit issues (Table 1.4) and did not need to adjust my model set. Variables with cumulative weights ≥ 0.50 for habitat use in the final analysis were elevation (cumulative $AIC_c\ w_i = 0.914$) and percent scrub canopy cover (cumulative $AIC_c\ w_i = 0.838$). Colonization had no variables with cumulative $AIC_c\ w_i \geq 0.50$. For detection, percent water on plot (cumulative $AIC_c\ w_i = 0.754$), scrub (cumulative $AIC_c\ w_i = 0.534$), and visit (cumulative $AIC_c\ w_i = 0.582$) were the top predictor variables (Table 1.8 and Table 1.9).

Use estimates for Lesser Yellowlegs decreased as elevation increased (Figure 1.4; $\beta = -0.010$, SE = 0.003) and decreased as percent scrub canopy increased (Figure 1.5; $\beta = -0.076$, SE = 0.031).

Detection was higher during visit one than during visit two (visit one p = 0.390, SE = 0.086, visit two p = 0.228, SE = 0.063). Detection estimates for Lesser Yellowlegs increased as percent water on plot increased (Figure 1.6; $\beta = 0.039$, SE = 0.012) and increased when the dominant vegetation type on plot was scrub (with scrub p = 0.558, SE = 0.109; without scrub p = 0.240, SE = 0.075).

The estimate of colonization was 0.159 (SE = 0.002). The derived estimate of extinction was 0. In our data, there were only two plots out of 29 plots which had birds detected in 2016 and on which no detections occurred in 2017. To double check my extinction estimate, I re-ran the model with a derived colonization estimate and a direct estimate of extinction. The estimate of extinction remained zero in this model.

Wilson's Snipe Habitat Use Model Results

Variables retained from step one for further habitat use modeling (i.e., those with cumulative weights ≥ 0.50) were distance to wetland, elevation, percent water on plot, and percent scrub canopy cover. No variables were retained for colonization and colonization was considered as a constant in further models (Table 1.10). The only variable retained from step one for detection was percent of water on plot. To avoid estimation problems or lack of convergence, I restricted the number of parameters possible in each model to ≤ five.

In the second step of model selection, I analyzed all possible combinations of covariates retained from the first step of model selection. The only variable with cumulative weight ≥ 0.50 on habitat use in the final analysis was elevation (cumulative $AIC_c\ w_i$ = 0.705). Colonization was kept constant as no variables were retained after step one. The variable with cumulative weight ≥ 0.50 on detection in the final analysis was percent water on plot (cumulative $AIC_c\ w_i$ = 0.999; Table 1.11, Table 1.12). Again, parameter count was restricted to ≤ five to ensure model convergence.

Habitat use estimates for Wilson's Snipe decreased as elevation increased (Figure 1.7; β = -0.003, SE = 0.001). Detection estimates for Wilson's Snipe increased as percent water on plot increased (Figure 1.6; β = 0.052, SE = 0.011). The derived estimate for extinction was 0.086 (SE = 0.200). The estimate of colonization was 0.085 (SE = 0.200).

All Lowland Birds Habitat Use Model Results

Variables retained from step one for further habitat use modeling (i.e., those with cumulative weights ≥ 0.50) were percent water on plot, year, and distance to wetland. For colonization, no variables had cumulative weights ≥ 0.50. I relied upon a heterogeneity parameter (σ) to model detection as the strength of variable relationships would not be common across species (Table 1.13).

In the second step of model selection, I analyzed all possible combinations of covariates retained from the first step of model selection in a global model. Variables with cumulative weights ≥ 0.50 on habitat use in the final analysis were percent water on plot (cumulative $AIC_c\ w_i$ = 0.999), year (cumulative $AIC_c\ w_i$ = 0.982), and distance to wetland (cumulative $AIC_c\ w_i$ = 0.806). Colonization was kept constant as no variables had cumulative weights ≥ 0.50 in step one. No variables were tested against detection (Table 1.14, Table 1.15).

Habitat use for all lowland shorebirds was positively correlated with percent water on plot (Figure 1.8; β = 0.200, SE = 0.054) and negatively correlated with distance to wetlands (Figure 1.9; β = -0.001, SE = 0.0003).

The estimate for colonization was 0.137 (SE = 0.093). The derived estimate of extinction was 0. In our data, there were only two out of 63 occupied plots on which no detections occurred in 2017. To double check my extinction estimate, I re-ran the model with a derived colonization estimate and a direct estimate of extinction. The estimate of extinction remained zero in this model.

All Upland Birds Habitat Use Model Results

The dataset for upland shorebird species was sparse (n = 29 observations). A heterogeneity (σ) model would not fit the sparse dataset, so I relied upon a robust design occupancy model without heterogeneity. Variables retained for habitat use in step two were elevation, and percent water on plot. For colonization, elevation was retained. No variables for step two of model selection for detection were retained (Table 1.16).

In the second step of model selection, I analyzed all possible combinations of covariates retained from first step of model selection in a global model. Variables with cumulative weights ≥ 0.50 in the final model were elevation (cumulative $AIC_c\, w_i = 0.939$), and percent water on plot (cumulative $AIC_c\, w_i = 0.834$) on habitat use. Colonization and detection were constant (Table 1.17, Table 1.18).

Use by all upland shorebirds increased as elevation increased (Figure 1.10; $\beta = 0.006$, SE = 0.001) and increased as percent water on plot increased ($\beta = 0.197$, SE = 0.116). The estimate of colonization was 0, as was the derived estimate of extinction. Only two plots surveyed of 14 which were occupied had extinction events between 2016 and 2017.

Habitat Use Maps

Habitat use maps for Lesser Yellowlegs, Wilson's Snipe, and lowland shorebirds are similar and show the highest use areas concentrated around lower elevation habitat on all training areas, particularly concentrated around rivers or wetlands. The lowest use estimates are concentrated around ridgetops and higher elevation areas in Donnelly Training Area West (Figures 1.11, 1.12, 1.13).

Habitat use maps for upland shorebirds show the highest use concentrated around areas of mid- to high elevation and areas with predominant scrub habitat (Figure 1.14).

Of the 533,000 hectares of total military lands in my sampling frame, 386,377 total hectares were classified as suitable shorebird habitat on military lands. From 2017 data, I estimate that Lesser Yellowlegs use 123,308 hectares (SE = 33,204), Wilson's Snipe use 206,772 hectares (SE

= 52,597), all lowland shorebirds use 273,430 hectares (SE = 48,283), and all upland shorebirds use 98,379 hectares (SE = 86,036; Table 1.19, Figure 1.15).

Discussion

I will discuss objectives in order, namely, my first objective identifying shorebird species using military lands and estimating species richness, followed by my second objective identifying important habitat predictors of use, colonization, and detection. I will end with a discussion of management implications for the Department of Defense.

Objective One: Identify Species Using Military Lands in Interior Alaska and Estimate Species Richness

Shorebirds of conservation concern are using large amounts of military land in interior Alaska. Alterations made to Arctic PRISM protocol enabled me to effectively survey in the wide variety of habitat types we encountered in the interior boreal forest (n = 79 different Viereck habitat classifications encountered during plot surveys). During surveys, we detected 12 of the hypothesized 16 shorebird species, including several species of concern (Table 1.3; U.S. Fish and Wildlife Service 2008). Only shorebird species hypothesized to be using interior Alaska were detected during surveys or incidental to surveys (i.e., no surprising migrants or breeders). These data are consistent with historic records of shorebirds seen on military lands (Mason 2016), and are consistent with literature on suspected boreal breeders (Sinclair et al. 2004, Elliott et al. 2010).

In 2017, species richness was highest in Donnelly Training Area East (estimated richness = 10.960, SE = 3.344) and Donnelly Training Area West (estimated richness = 8.208, SE = 3.008; Figure 1.16). This result is opposite from my hypothesis, where I hypothesized a higher species richness in Tanana Flats Training Area Lowland and Tanana Flats Training Area River.

This difference could be a result of higher habitat diversity in Donnelly Training Area and that this area contains both upland and lowland classifications of habitats and plots. The wider range of elevations and the associated wider suite of habitat characteristics could provide more habitat for different shorebird species with different life history requirements.

Currently, most shorebird conservation is focused on managing lowland or coastal habitat. Our richness results suggest that if the Department of Defense wants to manage for biodiversity and increased species richness, targeting uplands or training areas with habitats between 400 and 700 m in elevation like Donnelly Training Area, and specifically Donnelly Training Area East, will be better than managing for richness on exclusively lowland training areas.

All richness estimates increased from 2016 to 2017 except for Tanana Flats Training Area River richness (2016 richness = 6.528, SE = 2.144; 2017 richness = 4.352, SE = 1.904). The decrease in richness between 2016 and 2017 for Tanana Flats Training Area River is likely because of the decreased effort in surveying this training area in 2017. There were two fewer plots surveyed in 2017 because of flooding and dangerous boating conditions. Conversely, the increase in richness between the two years for all other training areas is likely because of the doubled effort in 2017 and the increase in diversity of habitats surveyed in 2017. A well-studied relationship exists between an increase in species diversity and an increase in vertical vegetation structure and height (Handel et al. 2009, Mccain and Grytnes 2010, Amundson et al. 2018). Upland habitats in our study site do not have more structural diversity than lowland habitats, with vegetation in the upland typically being < 2 m shrubs and lichen. Davies et al. (2007), in studies of montane breeding birds, found that species richness was best predicted by topographical variability (i.e., heterogeneity in vegetation and elevation). This also seems to be the case for our study area.

At minimum, seven species of shorebirds of conservation concern are using large amounts of military land in interior Alaska. Comparatively, species richness on military lands in interior Alaska is high. In an Arctic PRISM study of the Arctic Coastal Plain of Alaska, Johnson et al. (2007) found 19 species of shorebirds using an area of 10,700,000 hectares, approximately 21 times the size of our study site. Similarly, in another study of the Arctic Coastal Plain, Andres et al. (2016) reported 13 different species of shorebirds in a study site of 18,620,000 hectares. I recommend targeting military lands in interior Alaska for monitoring or managing species of conservation concern in the future, as many different species of conservation concern can likely be monitored in the same area simultaneously.

Objective Two: Estimate Habitat Use

I estimated that lowland shorebirds used 73% of all military lands in interior Alaska and therefore these lands are likely an important site. The Western Hemisphere Shorebird Reserve Network defines a site of regional importance as one which receives at least 20,000 shorebirds annually or at least 1% of a species' biogeographic population (Duncan 2006). With shorebirds using so much of military lands, further investigation into population sizes is warranted to determine if military lands could be a candidate site of importance. This designation can be determined by estimating abundance (see Martin Chapter 2).

My data supported my prediction that habitat use by lowland shorebirds (2017 = 0.684, SE = 0.072) was greater than habitat use by upland shorebirds (2017 = 0.204, SE = 0.077). This result is consistent with previous findings from breeding bird surveys and incidental observations recorded in the training areas and surrounding habitats (Jochum and Smith 2018). Previous surveys and inventories on or near the study site found higher occurrence of lowland birds such as Wilson’s Snipe and Lesser Yellowlegs and far fewer occurrences of upland shorebirds (Handel and Sauer 2017). Our results, based on a rigorous sampling design, support this relationship.

My result is also consistent with available population data. Shorebird species which use lowland habitat in interior Alaska have higher estimated population sizes than species which use upland habitats, making the probability of encountering lowland shorebirds higher than the probability of encountering upland shorebirds on a random survey (Alaska Shorebird Group 2008). Lesser Yellowlegs and Wilson’s Snipe, both lowland shorebirds, have estimated North American population sizes of 400,000 individuals and 2,000,000 individuals respectively, with an estimated 25% to 50% of those breeding in Alaska. Conversely, upland shorebird species such as Surfbird and Whimbrel have estimated population sizes of 70,000 and 26,000 respectively (Alaska Shorebird Group 2008). Of all upland shorebirds hypothesized to be using military lands, the highest population estimate is that of the Pectoral Sandpiper, estimated at 500,000 individuals in North America (Alaska Shorebird Group 2008). This species, like other birds known to breed in higher elevations, was rarely encountered on plot surveys (n = 1 individual).

More research has been conducted on shorebird habitat use during migration at lower latitudes than on breeding grounds in Alaska (e.g., Webb et al. 2010). My research found that many of the same habitat variables that dictate migration stopover site selection and informed initial hypotheses (e.g., vegetation height, shrub cover, proximity to wetlands, and wetland size) also are important determinants in shorebird breeding site use (Steen et al. 2018).

Climate change will impact species distribution and habitat use due to resulting habitat changes. Wauchope et al. (2016) predicted that climatically suitable breeding conditions for

Arctic shorebird species in 2070 will shift or decline with 66% to 83% of species losing the majority of their suitable breeding area. These shifting conditions will impact locations and availability of habitat variables of importance found in my analysis.

Habitat Use: Elevation

Elevation was a top predictor variable for three of the four groups analyzed: Lesser Yellowlegs, Wilson's Snipe, and all upland shorebirds. For Lesser Yellowlegs and Wilson's Snipe, as elevation increased, probability of use decreased. For all upland shorebirds, the opposite pattern was observed. These results support initial hypotheses about elevation. Lowland shorebird observations such as Lesser Yellowlegs and Wilson's Snipe tended to be more clustered around river corridors, with the majority of our lowland shorebird observations occurring during river surveys. Upland shorebird observations were more dispersed and less concentrated around a geographic feature. These results are consistent with current knowledge about lowland shorebird use of habitat across North America (Gillespie and Fontaine 2017). Lowland shorebirds, including Lesser Yellowlegs and Wilson's Snipe, are often associated with river corridors, which are more often found at low elevations (< 600 m) on both Tanana Flats Training Area and Donnelly Training Area. These birds are suspected to utilize lower habitat areas that retain water and support food resources (Skagen and Knopf 1994). Elevation is hypothesized to be an important variable for upland shorebirds because the high tussock tundra provides opportunities for nest crypsis and predator defense (Ballantyne and Nol 2011, Harwood et al. 2016).

Along elevation gradients, the suite of habitat characteristics found are currently changing because of climate change. Characteristics once found below certain elevations and temperature thresholds are now moving up in elevation: shrub line is moving higher, higher elevations are wetter, and trees are moving northward (Post et al. 2009, Myers-Smith et al. 2011, Elmendorf et al. 2012). Overall, shifts in species distributions in Alaska trend towards higher elevations or the poles in response to warming temperatures and vegetation encroachment (Parmesan 2007, Pearson et al. 2013). In Alaska, breeding distributions will be bounded by the Arctic Ocean or the tops of mountains (Wauchope et al. 2016). The results of the warming Arctic and vegetation shift are consequential for shorebirds and are predicted to result in novel community structure in the Arctic and subarctic (Swift et al. 2017). I predict there will be less available breeding habitat for upland shorebirds which require tundra habitat (e.g., Surfbird) as the tundra and alpine areas decrease in size because of encroaching treelines and shrublines.

Habitat Use: Percent Scrub Canopy Cover

Percent scrub canopy cover was a top predictor variable for Lesser Yellowlegs and supported my hypothesis that as percent scrub cover on plot increased, probability of habitat use of lowland shorebirds, like Lesser Yellowlegs, would decrease. As climate change progresses, a change from lowland graminoid habitats to more shrubby dominated habitats is projected (Sturm et al. 2005, Elmendorf et al. 2012). This “greening” projection results in less suitable breeding habitat for lowland shorebirds, especially for species using lowland graminoid habitats (i.e., low percent scrub canopy cover). This “greening” trend could potentially extend the distances required for lowland shorebirds to migrate to suitable breeding habitats.

Conversely, this greening effect could cause an increase in suitable habitat available for species associated with shrubs, such as Baird’s Sandpipers or upland shorebirds. Increases in shrub range in the Arctic and subarctic could result in more available breeding habitat for upland shorebird species known to use low shrub habitats (e.g. Upland Sandpipers and Whimbrels), while currently suitable low shrub habitat will likely transition into unsuitable tall shrub habitat.

Habitat Use: Distance to Wetland and Percent Water on Plot

As hypothesized, distance to wetland and percent water on plot were strong predictors of habitat use by lowland shorebirds. As distance to a wetland increased, probability of use decreased, and as percent water on plot increased, so did probability of use.

Overall, my results align with current literature. Gillespie and Fontaine (2017) found that for *Calidris* shorebird species (e.g., stilts and sandpipers), which are typically classified as lowland shorebirds, wetland availability and proximity was the top predictor in habitat use. Webb et al. (2010) found that wetland area was a top performing variable in their models and had a positive influence on species richness and habitat use in their study sites.

Upland shorebird probability of use also increased as percent water on plot increased. High elevation habitats on Donnelly Training Area East and West contain large quantities of habitat classified as wetland. This is probably due to widespread fragmented permafrost (particularly on northern-facing slopes) and resulting thermokarst throughout our study site (Hall et al. 1994). The permafrost layer acts as a barrier to water movement and maintains a layer of water at or near the surface. Although wetland habitat is typically associated with low elevations and lowland areas, in interior Alaska there are areas of high elevation wetland and plateaus which are also classified as wetland (Hall et al. 1994).

Climate change models predict a decreased availability of wetlands or shifts in available wetlands due to permafrost thawing. In the future, this ultimately results in decreased availability or shifted availability of suitable breeding grounds for both lowland shorebirds and upland shorebirds (Roach et al. 2011).

Detection

Lesser Yellowlegs detection increased in scrub dominant vegetation presence and all lowland birds' detection increased as percent scrub canopy percent increased. I hypothesized the opposite relationship: I suspected that the denser shrub habitat provided more cryptic ground covering for nests than other habitat types, such as forb/herbaceous or barren ground and thus observers would be less likely to see the birds when nesting. One explanation for this result is that on a plot with dominant scrub, Lesser Yellowlegs or all lowland species were more likely to be perched or flying, making them more obvious for detection. Similarly, the relationship between abundance and detection may result in increased detection probability; more Lesser Yellowlegs were occupying scrub habitat. Other research has found that as density of vegetation increases on survey plots, probability of shorebird detection decreases (Webb et al. 2010).

Management on Military Lands

I found support for my hypothesis that military lands in interior Alaska contain suitable habitat for breeding shorebirds. The Department of Defense is responsible for managing their lands and associated species. Often, managing these lands/species and acquiring baseline information is challenging because of remoteness and lengthy or unpredictable training area closures on military lands (Dertien et al. 2017). Between 2015 and 2017, I was able to conduct research on difficult to access military lands and evaluate shorebird habitat use on military lands for the first time. These data are informative and novel for both military lands in interior Alaska and the boreal forest ecoregion.

On these training areas, there is moderate military and recreational activity year-round, with trapping and hunting in the fall and winter as well as high use from aerial gunnery in the spring and summer. The time period of peak military training and exercise use coincides with shorebird nest initiation and breeding territory establishment (U.S. Army Garrison Fort Wainwright 2013). Habitat use maps identified general areas of where it would be best for troops to train in May and June without impacting shorebird nesting or disrupting protected migratory birds. Elevation, wetland/open water, and scrub cover are habitat variables that can be considered by the military to avoid shorebirds when making training location and timing decisions regarding shorebird habitat use. Continued monitoring and restoration of habitats which experience damage as a result of training is recommended to ensure resilience of the ecosystem, pertinent to conducting future training exercises. Into the future, the military can continue to monitor habitat and shorebird use on their lands in order to detect changes to shorebird populations or to the habitat which they occupy.

Specific shorebird management goals impact training recommendations. Generally, if trying to avoid all shorebirds, intermediate elevations (between 500 and 700 m) are the best at which to train. Middle elevation trainings will avoid the higher habitat use at lower elevations by lowland shorebird species and will avoid the higher habitat use at highest elevations by upland shorebird species (Figures 1.11, 1.12, 1.13, and 1.14). Although there is some probability of habitat use by both lowland and upland species of shorebirds ($\psi = 0.4 – 0.6$), training at intermediate elevations will result in fewer disturbances than at other elevations which contain higher probabilities of use by both groups. If the management goal is to avoid a particular species of shorebird (for example, a species listed by the US Fish and Wildlife Service as threatened or endangered) more targeted elevation training recommendations can be made to avoid either lowland or upland habitat by using the corresponding maps (Figures 1.11, 1.12, 1.13, and 1.14). The current method used to create these maps is coarse. Using spatially balanced sampling, our plots are representative of the study unit as a whole, but are naturally spread out across the landscape and are few in number. Ultimately, I sampled less than one percent of our entire study area over two years, and the coarseness of the maps should be considered when delineating boundaries and making spatially explicit recommendations.

Further, there are specific training goals and activities that occur on our study site which dictate explicit elevations. High-angle marksmanship training occurs on Donnelly Training Area West in areas of high probability of use by upland shorebirds, training entails shooting from a low elevation to a higher elevation. Because of the necessity of training at elevation, we recommend limiting such trainings during the May through early July peak breeding season for shorebirds.

Current regulations apply to the destruction and use of wetlands and the military adheres to these wetland regulations by either avoiding wetlands or mitigating areas which they do use and damage. These regulations are important for shorebird management, as distance to wetland and open water on plot were both top predictive covariates for lowland and upland species. Further adherence to these regulations and avoidance of wetland areas is recommended. I recommend that the Department of Defense consider shorebirds' biological requirements when designing wetland mitigation plans. Habitat variables to consider, such as the percent water on plot required to increase probability of habitat use for lowland shorebirds (> 25% water on plot for a probability of habitat use > 50%) and for upland shorebirds (> 90% water on plot for a probability of habitat use > 50%) should be considered when creating wetlands in either upland or lowland habitats. Further, consideration of which species of conservation concern or guild of species to target can guide elevation at which to select new wetland creation.

Although habitat covariates are important determinants of habitat use, future studies investigating use of shorebirds could investigate other covariates, both abiotic and biotic, as important predictors for shorebird use or richness. Lowland and upland shorebirds likely select breeding sites for habitat characteristics not investigated in this study. Shorebirds may select breeding sites for reasons other than habitat preferences. Factors like competition and species interactions were not investigated in this study but have been shown to be important determinants in shorebird use or competitive exclusion (Herzog et al. 2018, Cunningham et al. 2016).

Environmental changes are occurring on military lands in interior Alaska because of both climate change and military training exercises. Changes are predicted to impact all the habitat covariates identified as important determinants of shorebird use. Some of these projected changes can be addressed with environmental manipulation and management, while others can be addressed by timing trainings differently or locating trainings in different places during peak breeding season. The military needs to consider managing for changes to wetlands and water on their lands and consider monitoring habitat and shorebird use into the future to ensure the diversity of habitat types they have on their land persists for both military training opportunities and for wildlife. Our recommendations help support the military mission by encouraging adherence to federal regulations and supporting the military's stated goal of conservation.

Tables

Table 1.1. Lowland and upland shorebird covariate predictions (positive (+), negative (-), or not applicable (*NA*)) for use and colonization. Habitat classifications are from Viereck et al. (1993) which describe habitat types by dominant vegetation, percent canopy cover, and ground condition (e.g., mesic, wet, dry). Included in the survey habitat classes were open forest, tall scrub, low scrub, dwarf scrub, herbaceous (graminoid/forb), moss/lichen, water, and barren ground cover classifications.

	Species	**Elevation (meters)**	**Distance to wetland (0 - 5300m)**	**Percent water on plot (0 – 100%)**	**Percent shrub cover (0 - 100%)**	**Most used/colonized Viereck Classification**	**Year**
Lowland	Least Sandpiper Spotted Sandpiper Solitary Sandpiper Lesser Yellowlegs Short-billed Dowitcher Wilson's Snipe Semipalmated Plover Dunlin	-	-	+	-	Wet, grassland / open mudflat	Equal across years
Upland	American Golden-Plover Black-bellied Plover Wandering Tattler Whimbrel Surfbird Upland Sandpiper Pectoral Sandpiper Baird’s Sandpiper	+	*NA*	*NA*	+	Low shrub	Equal across years

Table 1.2. Lowland and upland shorebird covariate predictions (positive (+), negative (-), or not applicable (*NA*)) for detection in use models. Habitat classifications are from Viereck et al. (1993) which describe habitat types by dominant vegetation, percent canopy cover, and ground condition (e.g., mesic, wet, dry). Included in the survey habitat classes were open forest, tall scrub, low scrub, dwarf scrub, herbaceous (graminoid/forb), moss/lichen, water, and barren ground cover classifications.

	Species	**Percent water on plot (0 – 100%)**	**Percent shrub cover (0 - 100%)**	**Highest detection probability Viereck Classification**	**Visit**	**Year**
Lowland	Least Sandpiper Spotted Sandpiper Solitary Sandpiper Lesser Yellowlegs Short-billed Dowitcher Wilson's Snipe Semipalmated Plover Dunlin	+	-	Wet, grassland / open mudflat	1st visit > 2nd visit	Equal across years
Upland	American Golden-Plover Black-bellied Plover Wandering Tattler Whimbrel Surfbird Upland Sandpiper Pectoral Sandpiper Baird's Sandpiper	*NA*	-	Low shrub	1st visit > 2nd visit	Equal across years

Table 1.3. Lowland and upland shorebird species presence on plots from 2016 and 2017 and conservation status from Alaska Shorebird Conservation Plan and the United States Fish and Wildlife Service (USFWS) Birds of Conservation Concern list.

Species	**Upland vs Lowland**	**2016 Plots Used (of 72)**	**2017 Plots Used (of 142)**	**AK Shorebird Conservation Plan**	**USFWS Birds of Conservation Concern**
Wilson’s Snipe (*Gallinago delicata*)	Lowland	14	44	✓	✓
Lesser Yellowlegs (*Tringa flavipes*)	Lowland	7	27		
Spotted Sandpiper (*Actitis macularius*)	Lowland	7	11		
Solitary Sandpiper (*Tringa solitaria*)	Lowland	2	4	✓	✓
Semipalmated Plover (*Charadrius semipalmatus*)	Lowland	2	2		
Least Sandpiper (*Calidris minutilla*)	Lowland	0	1		
Dunlin (*Calidris alpina*)	Lowland	1	0	✓	
Wandering Tattler (*Tringa incana*)	Lowland	0	0		
Whimbrel (*Numenius phaeopus*)	Upland	1	5	✓	✓
Upland Sandpiper (*Bartramia longicauda*)	Upland	1	2	✓	✓
American Golden-Plover (*Pluvialis dominica*)	Upland	0	1	✓	
Baird's Sandpiper (*Calidris bairdii*)	Upland	0	1		
Pectoral Sandpiper (*Calidris melanotos*)	Upland	0	1		
Black-bellied Plover (*Pluvialis squatarola*)	Upland	1	0		
Surfbird (*Aphriza virgata*)	Upland	0	0	✓	
Wandering Tattler (*Tringa incana*)	Upland	0	0		
Total		36	135		

Table 1.4 Goodness of fit tests for all models.

Model	**Median $\hat{c}$ Value**
All Lowland Shorebirds	1.0
All Upland Shorebirds	< 1.0
Lesser Yellowlegs	< 1.0
Wilson's Snipe	1.0

Table 1.5. Species richness (ψ_r) and detection (p_r) table of model results. All models tested are included. I relied upon Akaike's Information Criterion (AIC_c) with a small sample size correction for model selection and used AIC_c weights and Δ AIC_c to identify most important covariates and top model.

Model	**AIC_c**	**Δ AIC_c**	**AIC_c Weights**	**Model Likelihood**	**Num. Parameters**	**Deviance**
ψ_r (8 groups: year * 4 strata) p_r (TFTA vs. DTA)	242.663	0.000	0.249	1.000	10	34.423
ψ_r (8 groups: year * 4 strata) p_r (4 strata)	242.820	0.157	0.230	0.924	12	29.747
ψ_r (4 groups: 4 strata) p_r (4 strata)	243.252	0.589	0.186	0.744	8	39.682
ψ_r (4 groups: 4 strata) p_r (year * 4 strata)	244.397	1.733	0.105	0.420	12	31.324
ψ_r (4 groups: 4 strata) p_r (year * TFTA vs. DTA)	244.912	2.249	0.081	0.324	8	41.342
ψ_r (2 groups: TFTA vs. DTA) p_r (year * 4 strata)	244.976	2.313	0.078	0.314	10	36.736
ψ_r (year * 2 groups: TFTA vs. DTA) p_r (year * 4 strata)	245.802	3.139	0.052	0.208	12	32.729
ψ_r (year * 4 groups: 4 strata) p_r (year * 4 strata)	248.118	5.455	0.016	0.065	16	24.858

Table 1.6. Species richness table of species estimates by year and training area. Richness estimates and standard error estimates from top model (see Table 1.5). Richness and standard error estimates are the proportion of species richness (ψ_r) and standard error estimate multiplied by the number of hypothesized species on survey sites (n=16). Actual count is actual number of observed species during plot surveys by year and training area.

Year	**Stratum**	**ψ_r Estimate**	**Standard Error**	**Richness Estimate**	**Richness Standard Error**	**Actual Count**
2016	TFTA River	0.408	0.134	6.528	2.144	6
	TFTA Lowlands	0.136	0.090	2.176	1.440	2
	DTA East	0.171	0.117	2.736	1.872	2
	DTA West	0.257	0.141	4.112	2.256	3
2017	TFTA River	0.272	0.119	4.352	1.904	4
	TFTA Lowlands	0.408	0.134	6.528	2.144	6
	DTA East	0.685	0.209	10.96	3.344	8
	DTA West	0.513	0.188	8.208	3.008	6

Table 1.7. Cumulative AIC_c weights for covariates (i) analyzed in step one of model selection for Lesser Yellowlegs habitat use (ψ), colonization (γ), and detection probability (p). Extinction (ε) was derived. I relied upon Akaike's Information Criterion (with a small sample size correction; AIC_c) for model selection and used cumulative variable weights (w_i) to identify most important covariates. Bolded numbers indicate covariates retained for second step of model selection (cumulative $AIC_c\ w_i \geq 0.50$). Covariates for which we had no hypotheses for a particular parameter are noted with *NA* (Not Applicable).

Covariate	**Habitat Use (ψ)** Cumulative $AIC_c\ w_i$	**Colonization (γ)** Cumulative $AIC_c\ w_i$	**Detection (p)** Cumulative $AIC_c\ w_i$
Elevation	**0.979**	**0.810**	*NA*
Percent scrub canopy	**0.809**	0.458	**0.936**
Percent water on plot	0.249	0.371	**0.840**
Distance to wetland	0.191	**0.604**	*NA*
Forest	0.086	0.171	0.039
Scrub	0.044	0.041	**0.677**
Forb/Lichen/Herbaceous	0.023	**0.678**	0.224
Visit	*NA*	*NA*	**0.525**
Year	**0.550**	*NA*	0.227
Year*Visit	*NA*	*NA*	0.185

Table 1.8. Cumulative AIC_c weights for covariates (i) analyzed in step two of model selection for Lesser Yellowlegs habitat use (ψ), colonization (γ), and detection probability (p). Extinction (ε) was derived. I relied upon Akaike's Information Criterion (with a small sample size correction; AIC_c) for model selection and used cumulative variable weights (w_i) to identify most important covariates. Bolded numbers indicate covariates retained for second step of model selection (cumulative $AIC_c\ w_i \geq 0.50$). Covariates for which we had no hypotheses for a particular parameter are noted with *NA* (Not Applicable).

Covariate	**Habitat Use (ψ)** Cumulative $AIC_c\ w_i$	**Colonization (γ)** Cumulative $AIC_c\ w_i$	**Detection (p)** Cumulative $AIC_c\ w_i$
Elevation	**0.914**	0.387	*NA*
Percent scrub canopy	**0.838**	0.001	0.241
Percent water on plot	*NA*	*NA*	**0.754**
Distance to wetland	*NA*	0.173	*NA*
Forest	*NA*	*NA*	*NA*
Scrub	*NA*	*NA*	**0.534**
Forb/Lichen/Herbaceous	*NA*	0.344	*NA*
Visit	*NA*	*NA*	**0.582**
Year	0.002	*NA*	*NA*
Year*Visit	*NA*	*NA*	*NA*

Table 1.9. Lesser Yellowlegs table of model results for habitat use (ψ), colonization (γ), and detection (p). Included are all individual models with Δ AIC_c < 5. I relied upon Akaike's Information Criterion (with a small sample size correction; AIC_c) for model selection and used AIC_c weights and Δ AIC_c to identify most important covariates and top model.

Model	**AIC_c**	**Δ AIC_c**	**AIC_c Weights**	**Model Likelihood**	**Num. Parameters**	**Deviance**
ψ (elevation + percent scrub canopy) γ (.) p (visit + scrub + percent water on plot)	219.415	0.000	0.199	1.000	8	202.709
ψ (elevation + percent scrub canopy) γ (.) p (scrub + percent water on plot)	221.069	1.654	0.087	0.437	7	206.523
ψ (year + elevation + percent scrub canopy) γ (.) p (visit + percent water on plot)	221.600	2.185	0.067	0.335	8	204.894
ψ (elevation + percent scrub canopy) γ (distance to wetland) p (scrub + percent water on plot)	221.679	2.264	0.064	0.322	8	204.973
ψ (year + elevation + percent scrub canopy) γ (.) p (scrub + percent water on plot)	221.861	2.446	0.058	0.294	8	205.155
ψ (elevation + percent scrub canopy) γ (forb/lichen/herbaceous) p (scrub + percent water on plot)	221.971	2.556	0.055	0.279	8	205.265
ψ (elevation + percent scrub canopy) γ (elevation) p (scrub + percent water on plot)	222.581	3.166	0.041	0.205	7	205.875

ψ (elevation + percent scrub canopy) γ (.) p (scrub + percent water on plot)	222.589	3.174	0.041	0.205	7	205.883
ψ (year + elevation + percent scrub canopy) γ (elevation) p (percent water on plot)	223.265	3.851	0.029	0.146	8	206.560
ψ (year + elevation + percent scrub canopy) γ (elevation) p (percent water on plot)	224.087	4.672	0.019	0.097	8	209.541

Table 1.10. Cumulative AIC_c weights for covariates (i) analyzed in step one of model selection for Wilson's Snipe habitat use (ψ), colonization (γ), and detection probability (p). Extinction (ε) was derived. I relied upon Akaike's Information Criterion (with a small sample size correction; AIC_c) for model selection and used cumulative variable weights (w_i) to identify most important covariates. Bolded numbers indicate covariates retained for second step of model selection (cumulative AIC_c $w_i \geq 0.50$). Covariates for which we had no hypotheses for a particular parameter are noted with *NA* (Not Applicable).

Covariate	**Habitat Use (ψ)** Cumulative AIC_c w_i	**Colonization (γ)** Cumulative AIC_c w_i	**Detection (p)** Cumulative AIC_c w_i
Elevation	**0.962**	0.245	*NA*
Percent scrub canopy	**0.597**	0.413	0.041
Percent water on plot	**0.840**	0.433	**0.999**
Distance to wetland	**0.998**	0.239	*NA*
Forest	0.230	0.179	0.041
Scrub	0.181	0.144	0.041
Forb/Lichen/Herbaceous	0.165	0.230	0.041
Visit	*NA*	*NA*	0.166
Year	0.284	*NA*	0.427
Year*Visit	*NA*	*NA*	0.128

Table 1.11. Cumulative AIC_c weights for covariates (i) analyzed in step two of model selection for Wilson's Snipe habitat use (ψ), colonization (γ), and detection probability (p). Extinction (ε) was derived. I relied upon Akaike's Information Criterion (with a small sample size correction; AIC_c) for model selection and used cumulative variable weights (w_i) to identify most important covariates. Bolded numbers indicate covariates retained for second step of model selection (cumulative $AIC_c\ w_i \geq 0.50$). Covariates for which we had no hypotheses for a particular parameter are noted with *NA* (Not Applicable).

Covariate	**Habitat Use (ψ)** Cumulative $AIC_c\ w_i$	**Colonization (γ)** Cumulative $AIC_c\ w_i$	**Detection (p)** Cumulative $AIC_c\ w_i$
Elevation	**0.705**	*NA*	*NA*
Percent scrub canopy	0.352	*NA*	*NA*
Percent water on plot	0.301	*NA*	**0.999**
Distance to wetland	0.425	*NA*	*NA*
Forest	*NA*	*NA*	*NA*
Scrub	*NA*	*NA*	*NA*
Forb/Lichen/Herbaceous	*NA*	*NA*	*NA*
Visit	*NA*	*NA*	*NA*
Year	0.400	*NA*	*NA*
Year*Visit	*NA*	*NA*	*NA*

Table 1.12**.** Wilson’s Snipe habitat use table of model results for habitat use (ψ), colonization (γ), and detection (p). Included are all individual models with Δ AIC$_c$ $<$ 5. I relied upon Akaike’s Information Criterion (AIC$_c$) with a small sample size correction for model selection and used AIC$_c$ weights and Δ AIC$_c$ to identify most important covariates and top model.

Model	**AIC$_c$**	**Δ AIC$_c$**	**AIC$_c$ Weights**	**Model Likelihood**	**Num. Parameters**	**Deviance**
ψ (elevation) γ (.) p (percent water on plot)	365.700	0.000	0.536	1.000	5	355.410
ψ (elevation + scrub) γ (.) p (percent water on plot)	367.690	1.983	0.199	0.371	6	355.280
ψ (elevation) γ (scrub) p (percent water on plot)	370.220	4.521	0.056	0.104	6	357.820

Table 1.13. Cumulative $\mathrm{AIC_c}$ weights for covariates (i) analyzed in step one of model selection for all lowland shorebirds habitat use (ψ), colonization (γ), heterogeneity (σ), and detection probability (p). Extinction (ε) was derived. I relied upon Akaike's Information Criterion (with a small sample size correction; $\mathrm{AIC_c}$) for model selection and used cumulative variable weights (w_i) to identify most important covariates. Bolded numbers indicate covariates retained for second step of model selection (cumulative $AIC_c\ w_\mathrm{i} \geq 0.50$). Covariates for which we had no hypotheses for a particular parameter are noted with *NA* (Not Applicable).

Covariate	**Habitat Use (ψ)** Cumulative $AIC_c\, w_i$	**Colonization (γ)** Cumulative $AIC_c\, w_i$	**Detection (p)** Cumulative $AIC_c\, w_i$	**Heterogeneity (σ)** Cumulative $AIC_c\, w_i$
Elevation	0.484	0.063	*NA*	*NA*
Percent scrub canopy	0.236	0.062	*NA*	*NA*
Percent water on plot	**0.965**	0.070	*NA*	*NA*
Distance to wetland	**0.645**	0.124	*NA*	*NA*
Forest	0.052	0.028	*NA*	*NA*
Scrub	0.224	0.036	*NA*	*NA*
Forb/Lichen/Herbaceous	0.373	0.083	*NA*	*NA*
Visit	*NA*	*NA*	*NA*	*NA*
Year	**0.915**	*NA*	*NA*	*NA*
Year*Visit	*NA*	*NA*	*NA*	*NA*

Table 1.14. Cumulative AIC_c weights for covariates (i) analyzed in step two of model selection for all lowland shorebirds habitat use (ψ), colonization (γ), heterogeneity (σ), and detection probability (p). Extinction (ε) was derived. I relied upon Akaike's Information Criterion (with a small sample size correction; AIC_c) for model selection and used cumulative variable weights (w_i) to identify most important covariates. Bolded numbers indicate covariates retained for second step of model selection (cumulative $AIC_c\ w_i \geq 0.50$). Covariates for which we had no hypotheses for a particular parameter are noted with *NA* (Not Applicable).

Covariate	**Habitat Use (ψ)** Cumulative $AIC_c\ w_i$	**Colonization (γ)** Cumulative $AIC_c\ w_i$	**Detection (p)** Cumulative $AIC_c\ w_i$	**Heterogeneity (σ)** Cumulative $AIC_c\ w_i$
Elevation	*NA*	*NA*	*NA*	*NA*
Percent scrub canopy	*NA*	*NA*	*NA*	*NA*
Percent water on plot	**0.999**	*NA*	*NA*	*NA*
Distance to wetland	**0.806**	*NA*	*NA*	*NA*
Forest	*NA*	*NA*	*NA*	*NA*
Scrub	*NA*	*NA*	*NA*	*NA*
Forb/Lichen/Herbaceous	*NA*	*NA*	*NA*	*NA*
Visit	*NA*	*NA*	*NA*	*NA*
Year	**0.982**	*NA*	*NA*	*NA*
Year*Visit	*NA*	*NA*	*NA*	*NA*

Table 1.15. Lowland shorebird habitat use table of model results for habitat use (ψ), colonization (γ), and detection (p). I relied upon Akaike's Information Criterion (AIC_c) with a small sample size correction for model selection and used AIC_c weights and Δ AIC_c to identify most important covariates and top model. All models tested included in table.

Model	**AIC_c**	**Δ AIC_c**	**AIC_c Weights**	**Model Likelihood**	**Num. Parameters**	**Deviance**
ψ (year + distance to wetland + percent water on plot) γ (.) p (.)	406.972	0.000	0.792	1.000	6	392.436
ψ (year + water on plot) γ (.) p (.)	409.829	2.856	0.189	0.239	5	397.429
ψ (distance to wetland + percent water on plot) γ (.) p (.)	414.999	8.026	0.014	0.018	5	402.599
ψ (water on plot) γ (.) p (.)	417.722	10.750	0.003	0.004	4	407.438
ψ (year + distance to wetland) γ (.) p (.)	429.534	22.562	0.000	0.000	5	417.134
ψ (year) γ (.) p (.)	437.083	30.110	0.000	0.000	4	426.799
ψ (distance to wetland) γ (.) p (.)	440.862	33.889	0.000	0.000	4	430.577

Table 1.16**.** Cumulative AIC_c weights for covariates (i) analyzed in step one of model selection for all upland shorebirds habitat use (ψ), colonization (γ), and detection probability (p). Extinction (ε) was derived. I relied upon Akaike's Information Criterion (with a small sample size correction; AIC_c) for model selection and used cumulative variable weights (w_i) to identify most important covariates. Bolded numbers indicate covariates retained for second step of model selection (cumulative AIC_c $w_i \geq 0.50$). Covariates for which we had no hypotheses for a particular parameter are noted with *NA* (Not Applicable). This dataset had fewer observations.

Covariate	**Habitat Use (ψ)** Cumulative AIC_c w_i	**Colonization (γ)** Cumulative AIC_c w_i	**Detection (p)** Cumulative AIC_c w_i
Elevation	**0.877**	**0.495**	*NA*
Percent scrub canopy	0.154	0.331	0.397
Percent water on plot	**0.694**	0.416	0.465
Distance to wetland	0.168	0.233	*NA*
Forest	0.151	0.154	0.181
Scrub	0.142	0.179	0.179
Forb/Lichen/Herbaceous	0.146	0.243	0.232
Visit	*NA*	*NA*	0.261
Year	0.226	*NA*	0.251
Year*Visit	*NA*	*NA*	0.032

Table 1.17. Cumulative AIC_c weights for covariates (i) analyzed in step two of model selection for all upland shorebirds habitat use (ψ), colonization (γ), and detection probability (p). Extinction (ε) was derived. I relied upon Akaike's Information Criterion (with a small sample size correction; AIC_c) for model selection and used cumulative variable weights (w_i) to identify most important covariates. Bolded numbers indicate covariates retained for second step of model selection (cumulative AIC_c $w_i \geq 0.50$). Covariates for which we had no hypotheses for a particular parameter are noted with *NA* (Not Applicable). This dataset had fewer observations.

Covariate	**Habitat Use (ψ)** Cumulative $AIC_c\ w_i$	**Colonization (γ)** Cumulative $AIC_c\ w_i$	**Detection (p)** Cumulative $AIC_c\ w_i$
Elevation	**0.939**	0.354	*NA*
Percent scrub canopy	*NA*	*NA*	*NA*
Percent water on plot	**0.834**	*NA*	*NA*
Distance to wetland	*NA*	*NA*	*NA*
Forest	*NA*	*NA*	*NA*
Scrub	*NA*	*NA*	*NA*
Forb/Lichen/Herbaceous	*NA*	*NA*	*NA*
Visit	*NA*	*NA*	*NA*
Year	*NA*	*NA*	*NA*
Year*Visit	*NA*	*NA*	*NA*

Table 1.18. Upland shorebird habitat use table of model results for habitat use (ψ), colonization (γ), and detection (p I relied upon Akaike's Information Criterion (AIC_c) with a small sample size correction for model selection and used AIC_c weights and Δ AIC_c to identify most important covariates and top model. All models tested included in table.

Model	**AICc**	**Δ AIC_c**	**AIC_c Weights**	**Model Likelihood**	**Num. Parameters**	**Deviance**
ψ (elevation + percent water on plot) γ (.) p (.)	146.887	0.000	0.509	1.000	5	136.604
ψ (elevation + percent water on plot) γ (elevation) p (.)	147.937	1.043	0.301	0.591	6	135.537
ψ (elevation) γ (.) p (.)	150.169	3.287	0.098	0.193	4	141.980

Table 1.19. Hectares of habitat used on FWA military lands (Tanana Flats Training Area (TFTA) and Donnelly Training Area (DTA)) by shorebirds. Estimates of habitat use are from the model with no habitat or time covariates and using 2017 data. All estimates given in hectares (ha).

Stratum	**Stratum Area (ha)**	**Area Sampled (ha)**	**Total Plots in Training Area**	**Plots Sampled**	**Lesser Yellowlegs Use (ha)**	**Wilson's Snipe Use (ha)**	**Lowland Shorebird Use (ha)**	**Upland Shorebird Use (ha)**
TFTA River	9,023	320	563	20	6,546 (SE = 1,504)	8,851 (SE = 1,115)	8,219 (SE = 951)	0 (SE = 0.000)
TFTA Lowlands	186,947	528	11,684	33	103,312 (SE = 18,788)	135,630 (SE = 18,133)	161,335 (SE = 16,656)	20,377 (SE = 18,694)
DTA East	15,503	768	968	48	4,216 (SE = 3,120)	6,340 (SE = 4,308)	10,573 (SE = 2,382)	9,813 (SE = 5,193)
DTA West	158,947	656	9,934	41	9,218 (SE = 9,791)	55,949 (SE = 29,039)	93,301 (SE = 28,292)	68,188 (SE = 62,148)
Total	370,420	2,272	23,148	142	123,292 (SE = 33,203)	206,770 (SE = 52,595)	273,428 (SE = 48,281)	98,379 (SE = 86,035)

Figures

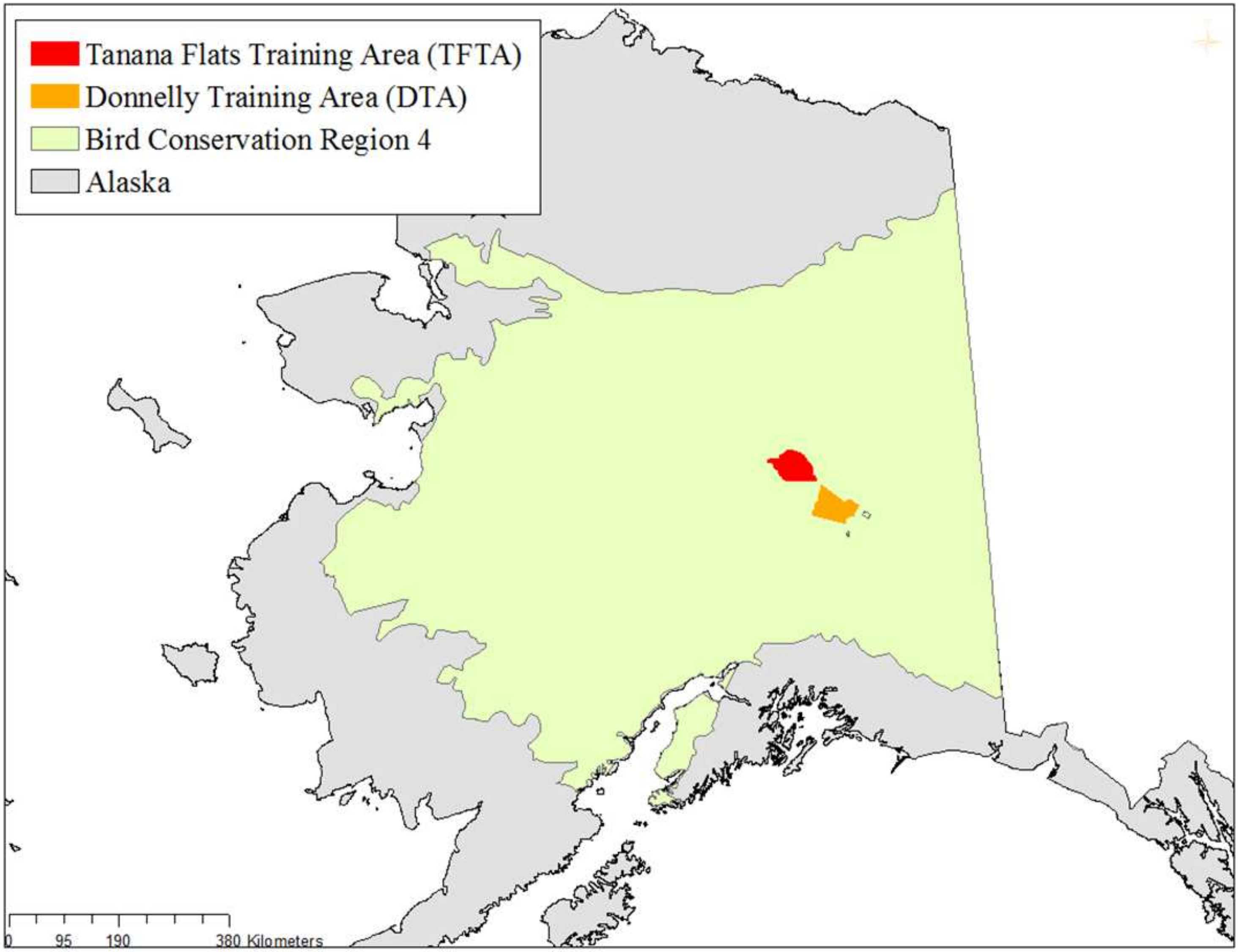


Figure 1.1. Study area within Alaska and Bird Conservation Region 4.

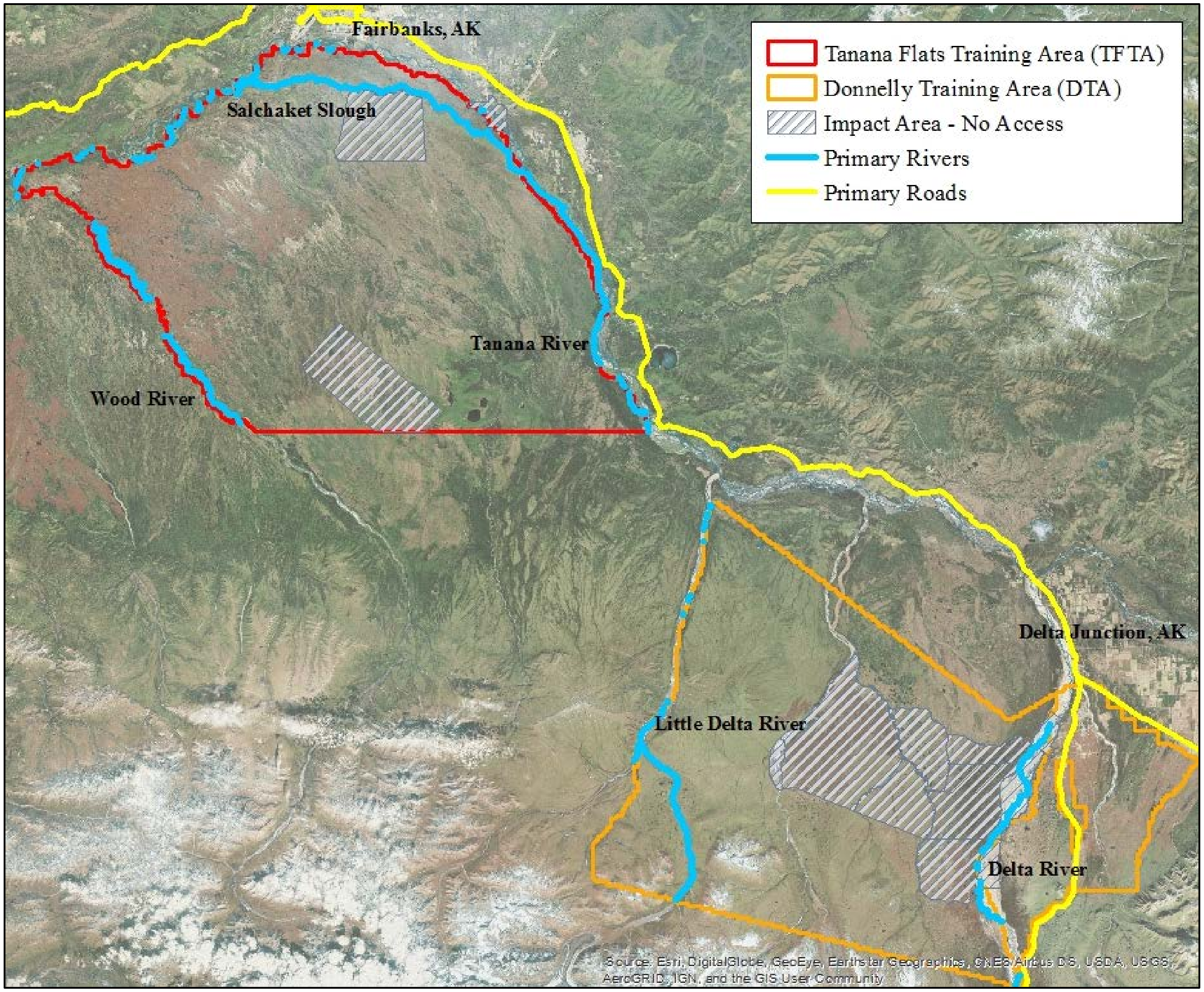


Figure 1.2. Study sites Tanana Flats Training Area (TFTA) near Fairbanks, Alaska and Donnelly Training Area (DTA) near Delta Junction, Alaska. Large rivers are labeled with portions of the Tanana River, Salchaket Slough, Wood River, Delta River, and Little Delta River included in survey.

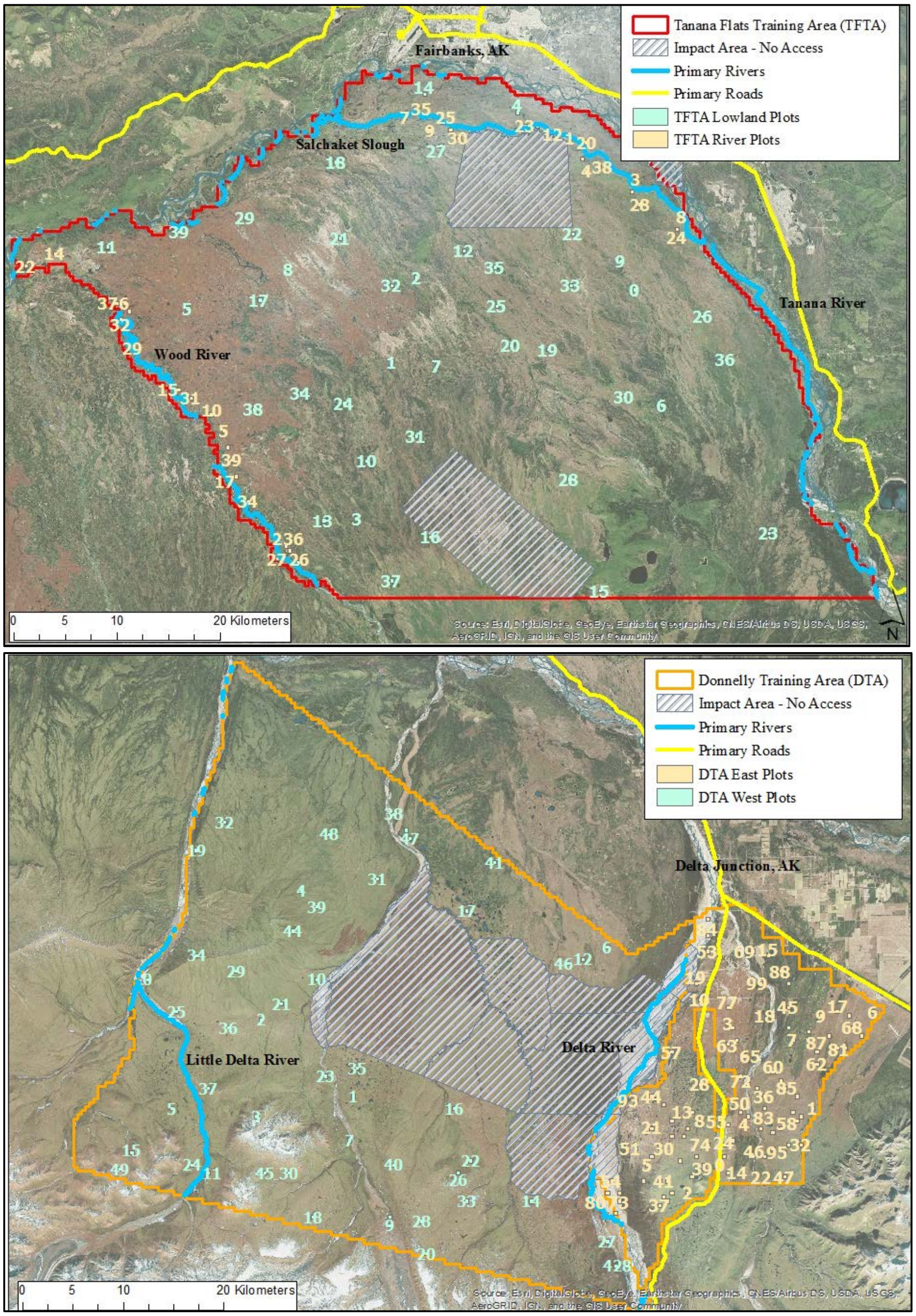


Figure 1.3 Spatially balanced sampling tool plot generation and associated random numbers. Plots were visited within each sampling area beginning with lowest number and working numerically higher. Plots were generated independently in four different strata. Three of the sampling areas had equal sample allocation (TFTA Lowlands, DTA East, and DTA West). Boats were needed for river access and this allowed us to improve efficiency by sampling more plots in the TFTA River corridor, defined as within one kilometer of two tributaries (Salchaket Slough, Wood River) of the Tanana River.

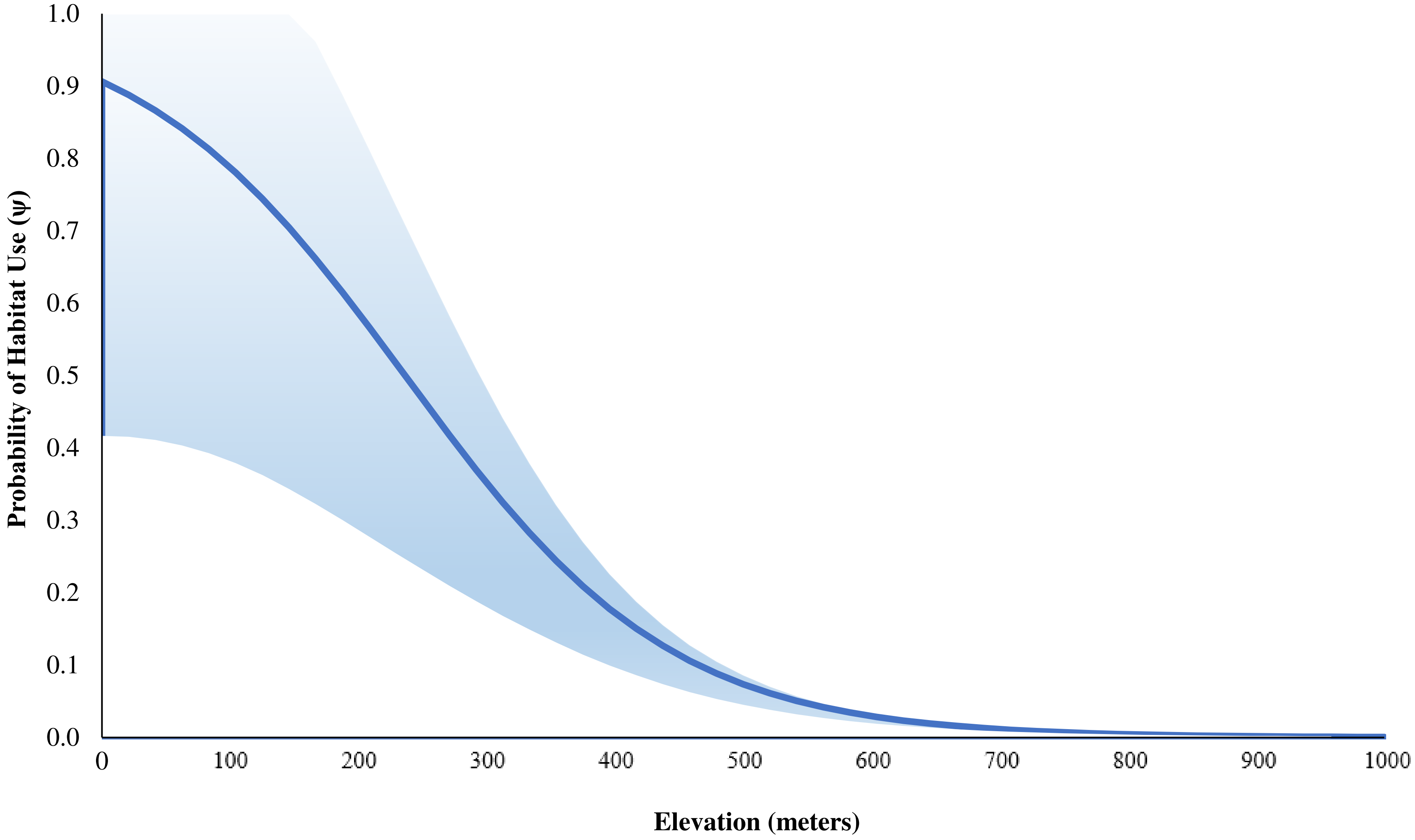


Figure 1.4. Probability of habitat use for Lesser Yellowlegs decreased as elevation increased. Figure results are from model containing all variables with cumulative variable weights ≥ 0.50. All other covariates in the model were held at average values. 95% confidence intervals shown.

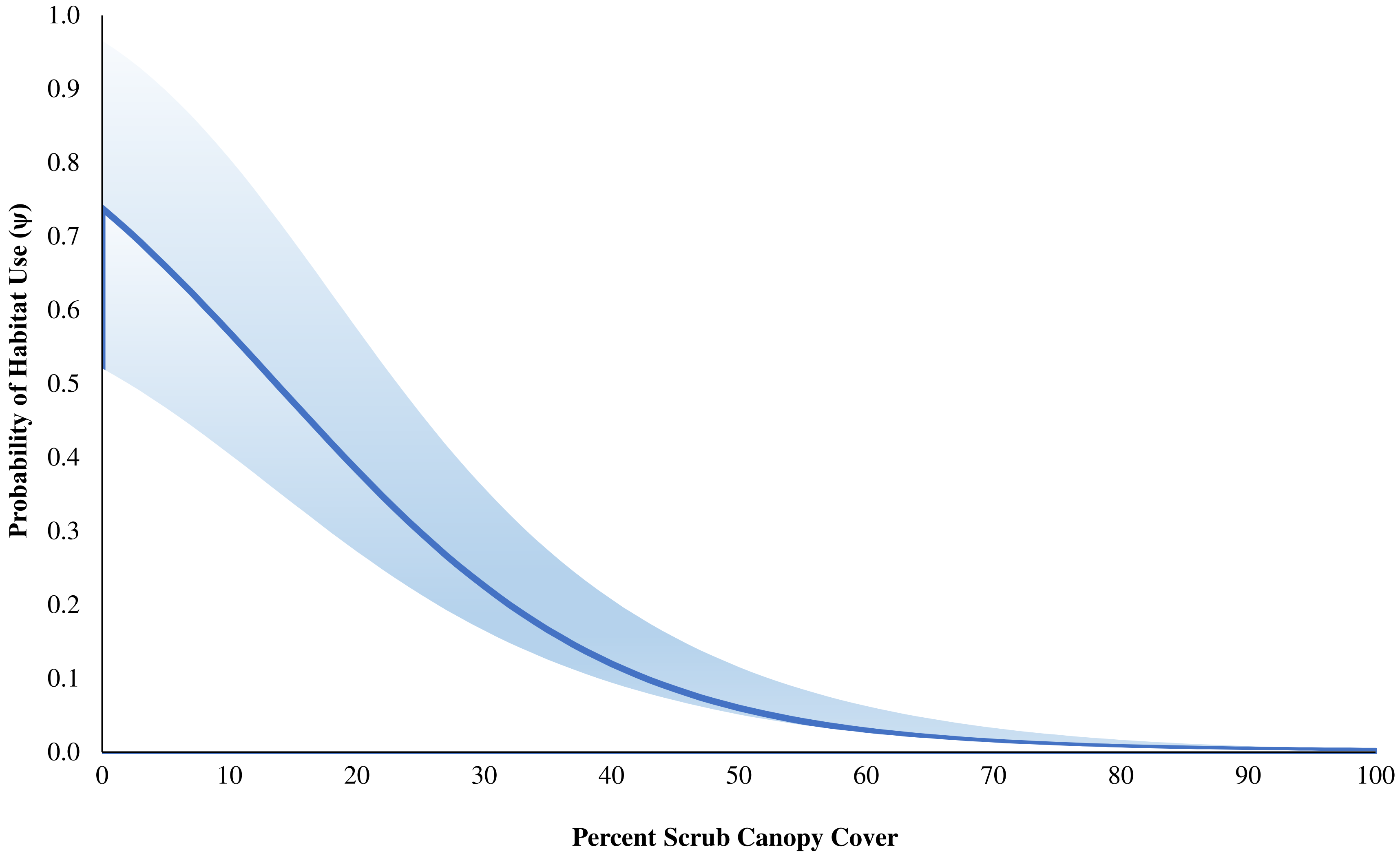


Figure 1.5. Probability of habitat use for Lesser Yellowlegs decreased as percent scrub canopy cover increased. Figure results are from model containing all variables with cumulative variable weights ≥ 0.50. All other covariates in the model were held at average values. 95% confidence intervals shown.

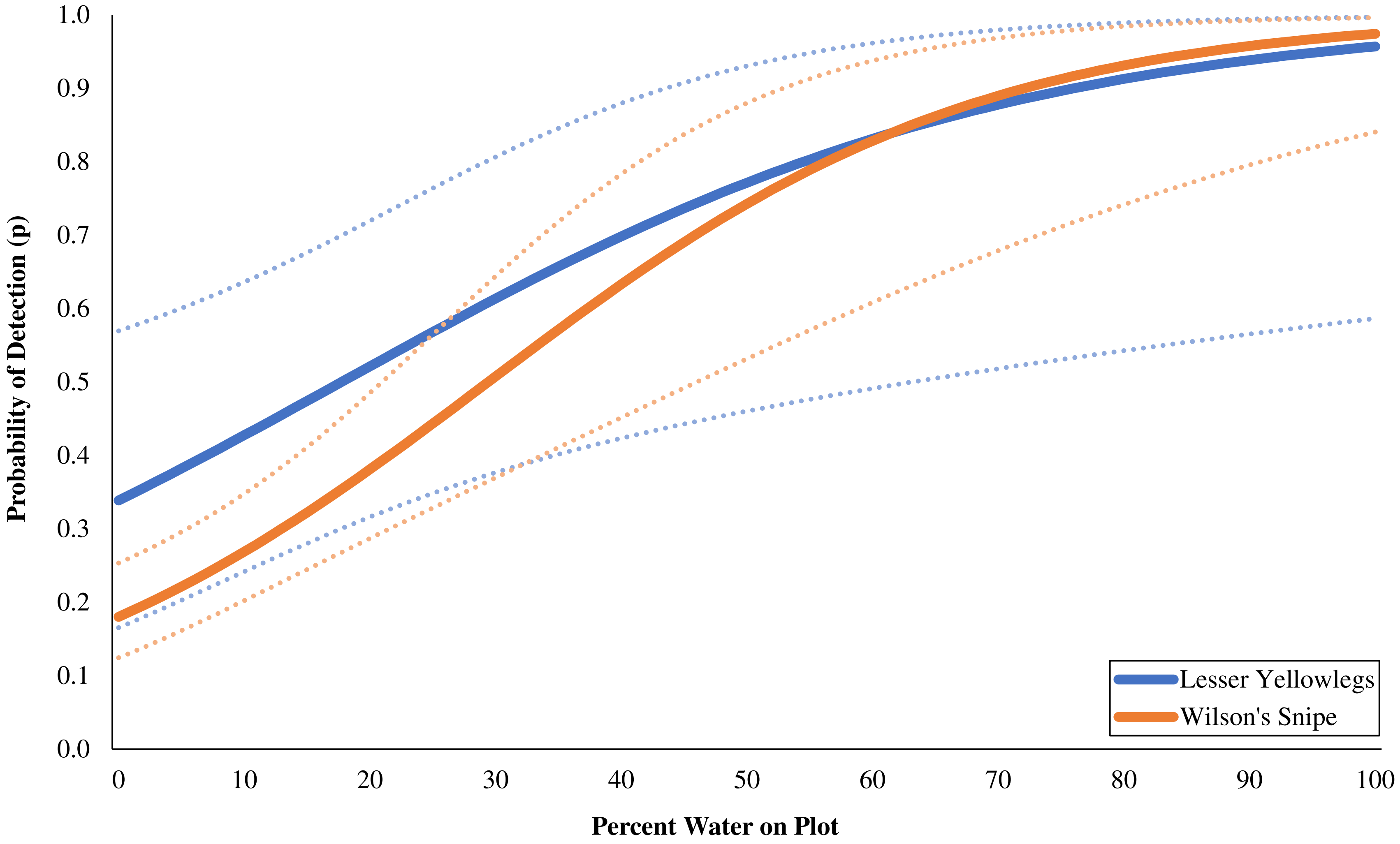


Figure 1.6. Probability of detection for Lesser Yellowlegs and Wilson's Snipe increased as percent water on plot increased. Figure results are from model containing all variables with cumulative variable weights ≥ 0.50. All other covariates in the model were held at average values. 95% confidence intervals shown.

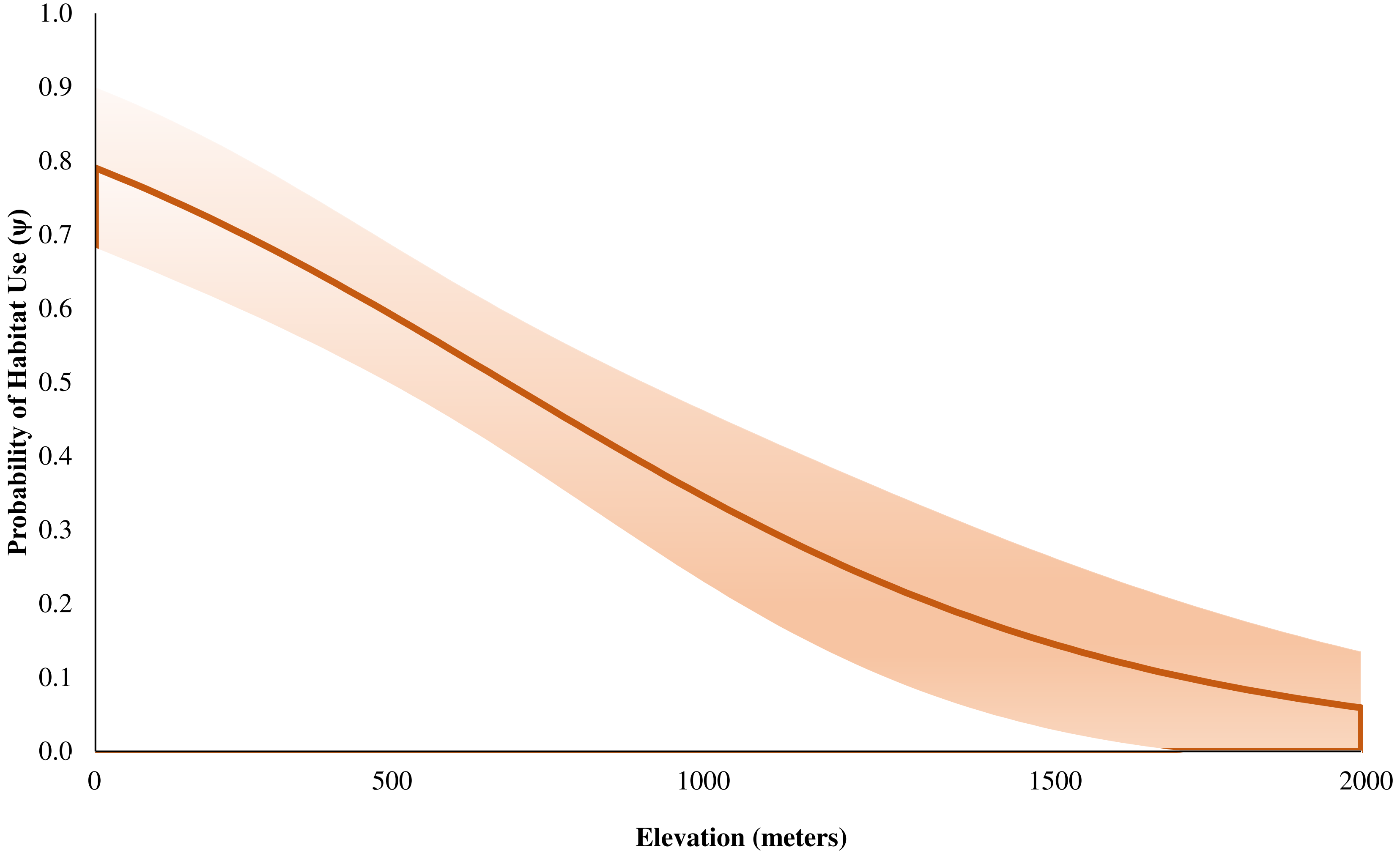


Figure 1.7. Probability of habitat use by Wilson’s Snipe decreased as elevation increased. Figure results are from model containing all variables with cumulative variable weights ≥ 0.50. All other covariates in the model were held at average values. 95% confidence intervals shown.

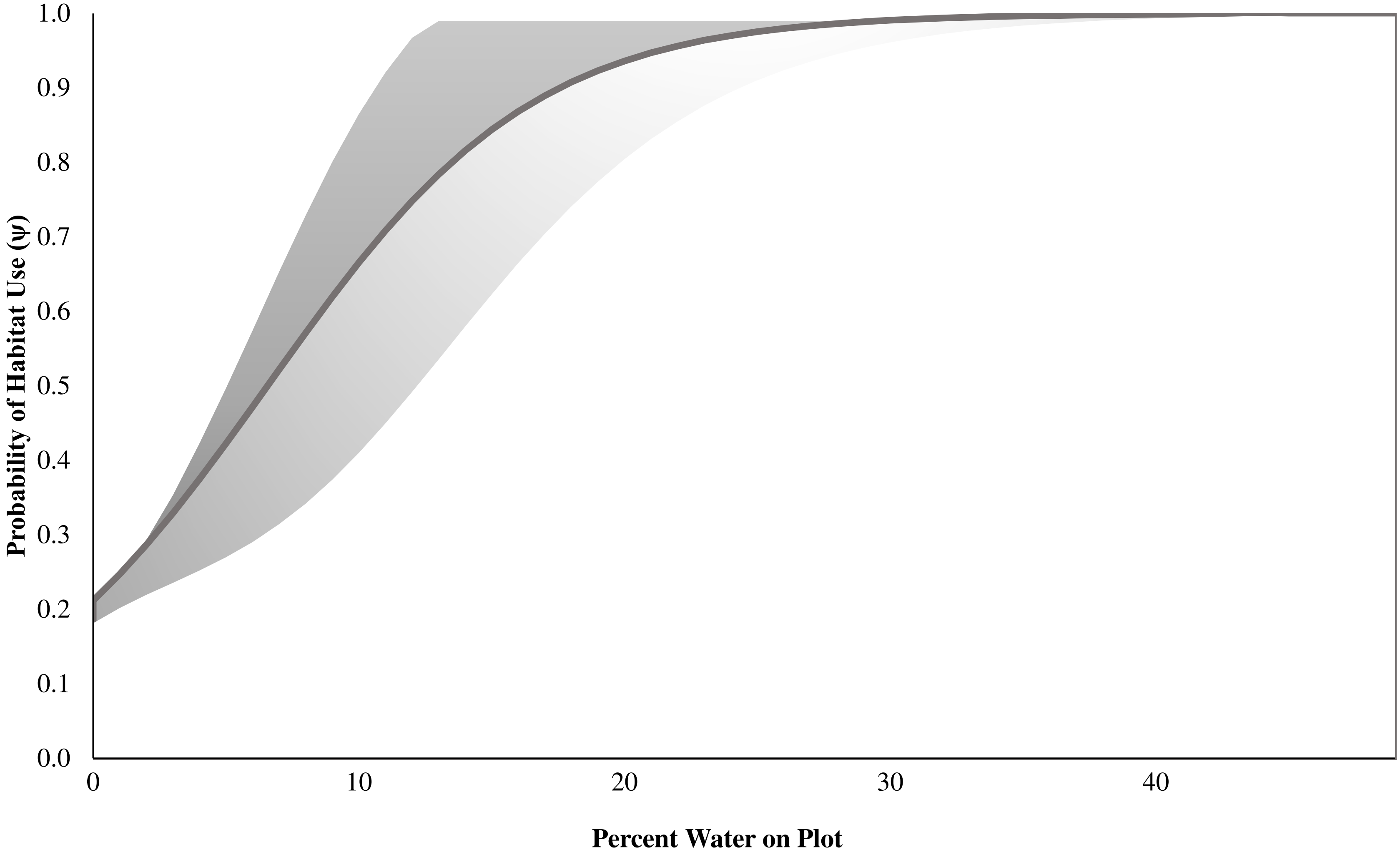


Figure 1.8. Probability of habitat use by all lowland shorebirds increased as percent water on plot increased. Figure results are from model containing all variables with cumulative variable weights ≥ 0.50. All other covariates in the model were held at average values. 95% confidence intervals shown.

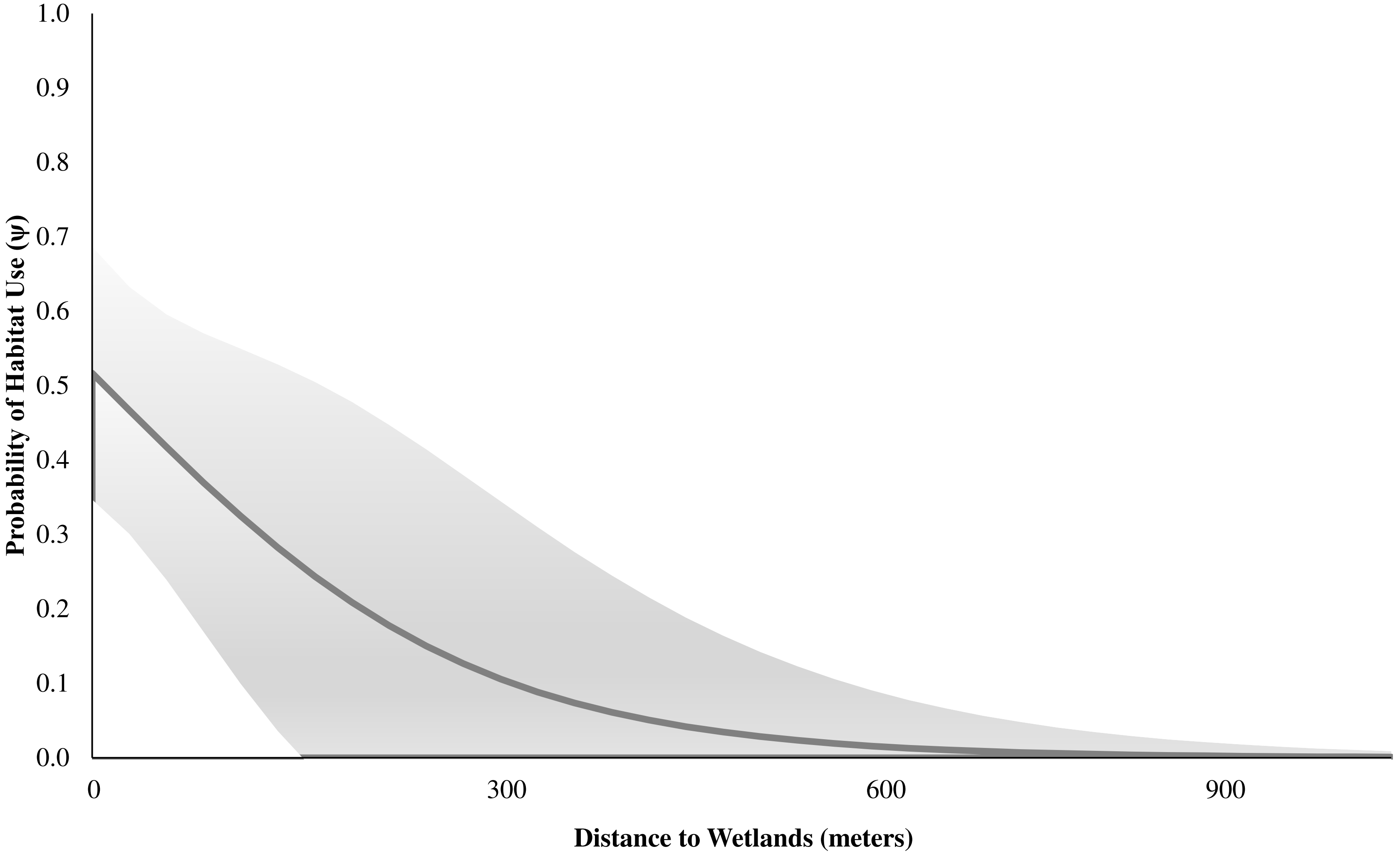


Figure 1.9. Probability of habitat use of all lowland shorebirds decreased as distance to wetlands increased. Figure results are from model containing all variables with cumulative variable weights ≥ 0.50. All other covariates in the model were held at average values. 95% confidence intervals shown.

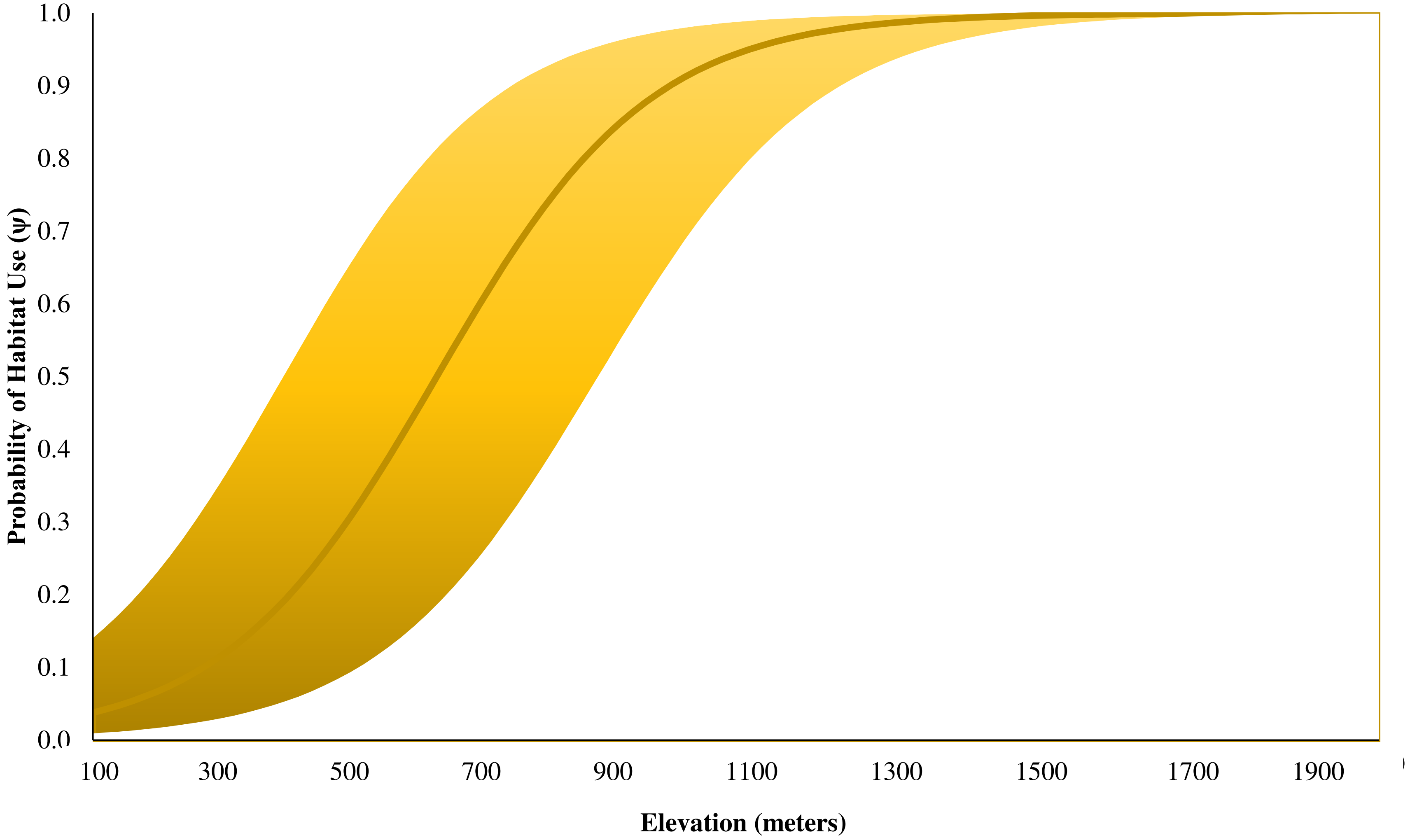
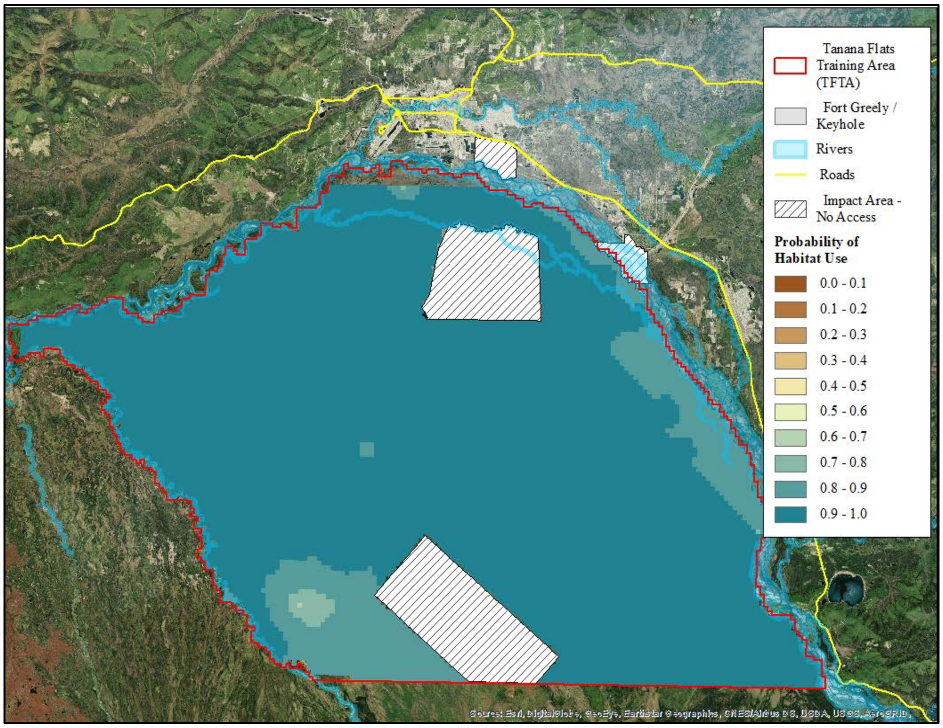


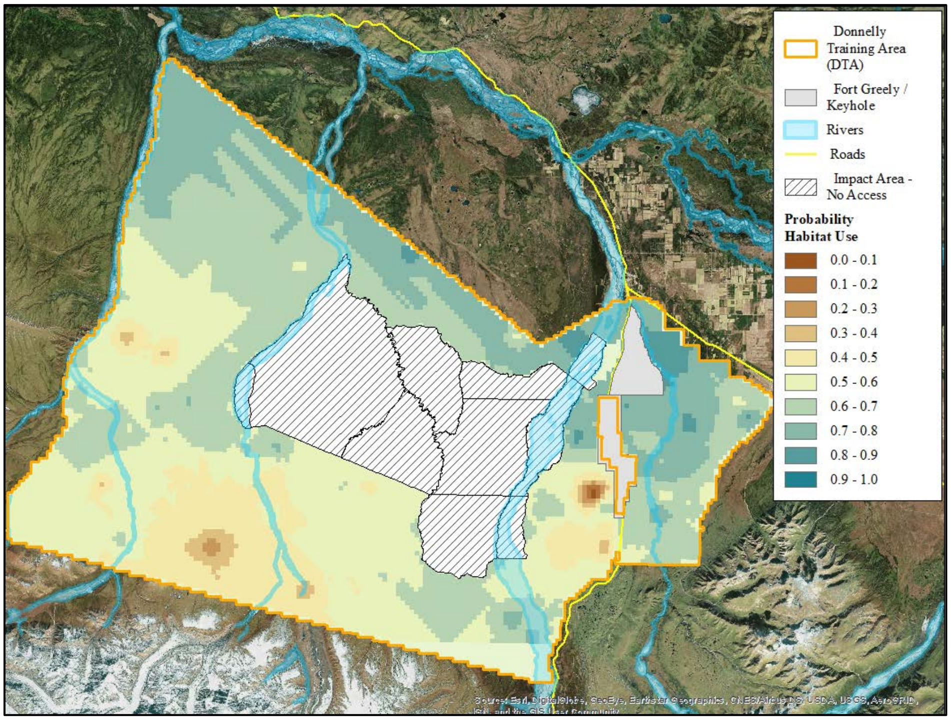
Figure 1.10**.** Probability of habitat use of all upland shorebirds increased as elevation increased. Figure results are from model containing all variables with cumulative variable weights ≥ 0.50. All other covariates in the model were held at average values. 95% confidence intervals shown.

a. Tanana Flats Training Area



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID,

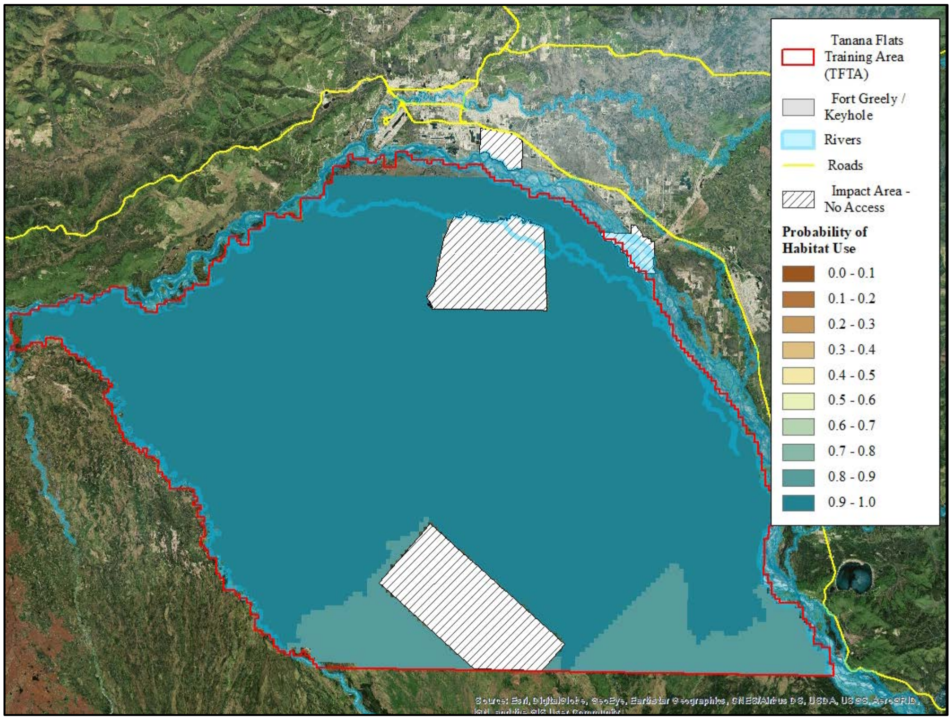
b. Donnelly Training Area



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 1.11. Habitat use probability maps for Lesser Yellowlegs in Tanana Flats Training Area (a) and Donnelly Training Area (b). Low probability of habitat use (0.0) to high probability of habitat use (1.0). See Figure 1.3 for location of surveyed plots.

a. Tanana Flats Training Area



b. Donnelly Training Area

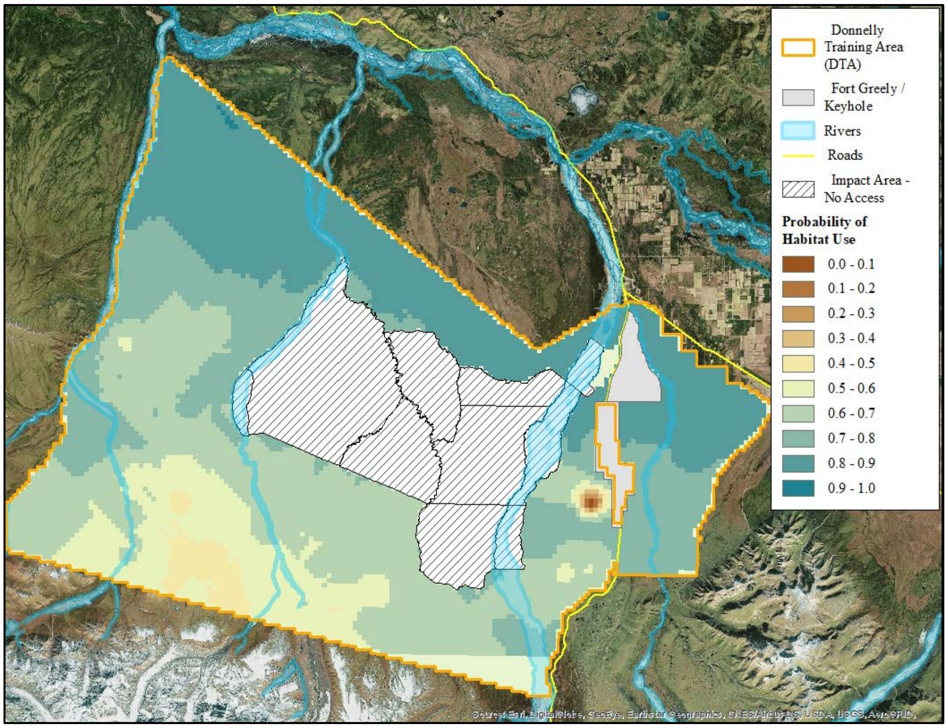
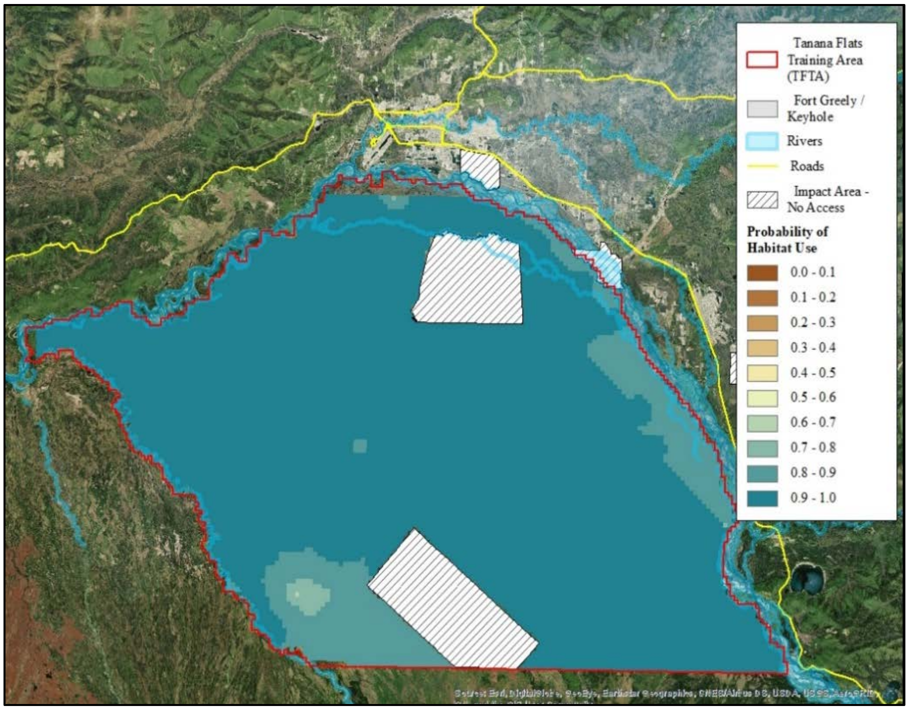


Figure 1.12. Habitat use probability maps for Wilson's Snipe in Tanana Flats Training Area (a) and Donnelly Training Area (b). Low probability of habitat use (0.0) to high probability of habitat use (1.0). See Figure 1.3 for location of surveyed plots.

a. Tanana Flats Training Area



b. Donnelly Training Area

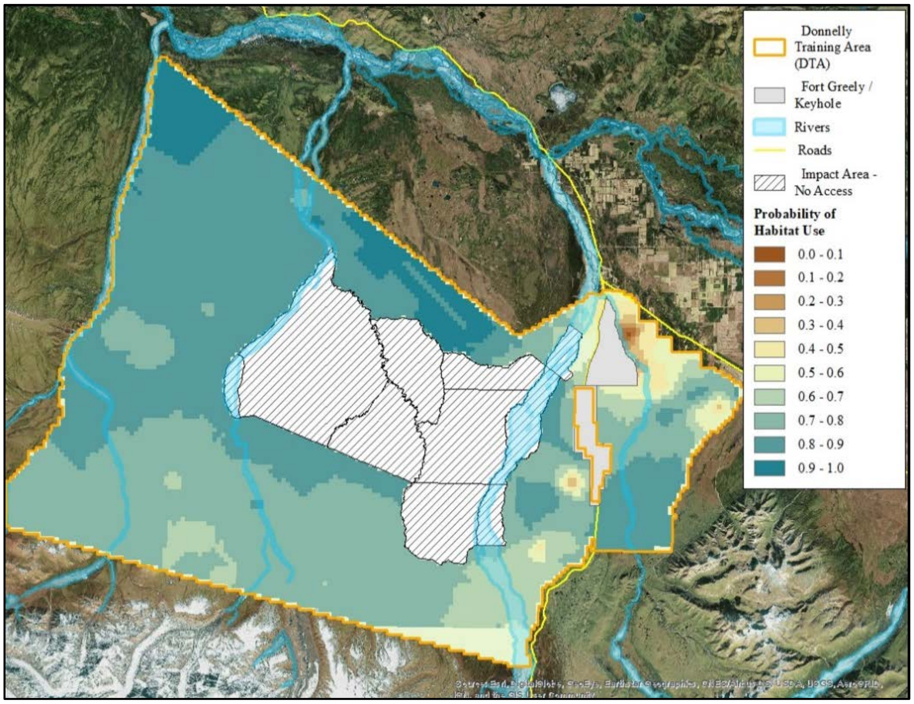
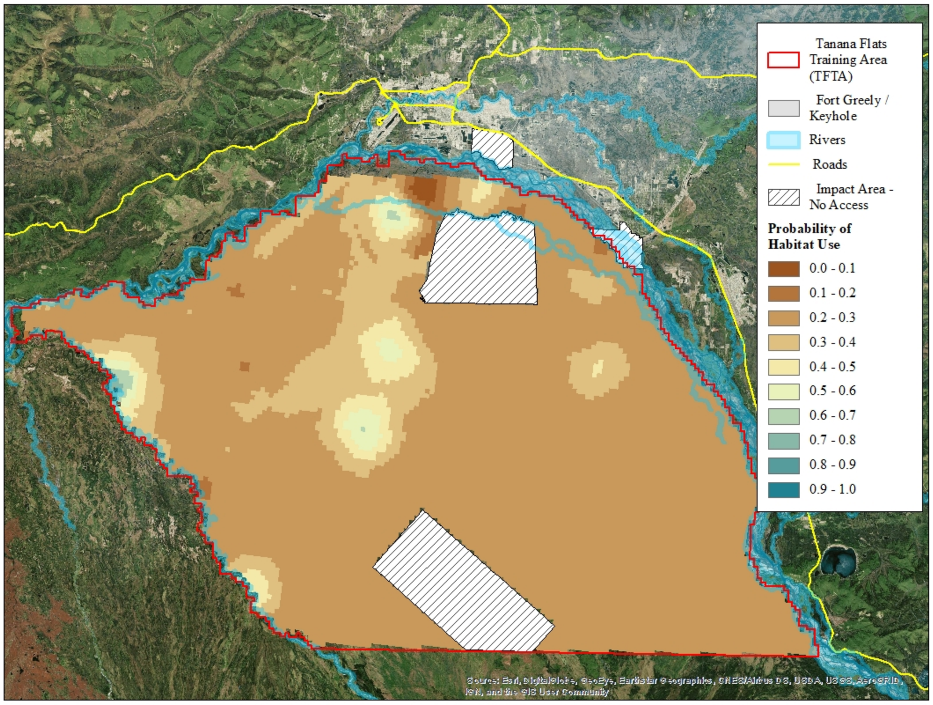


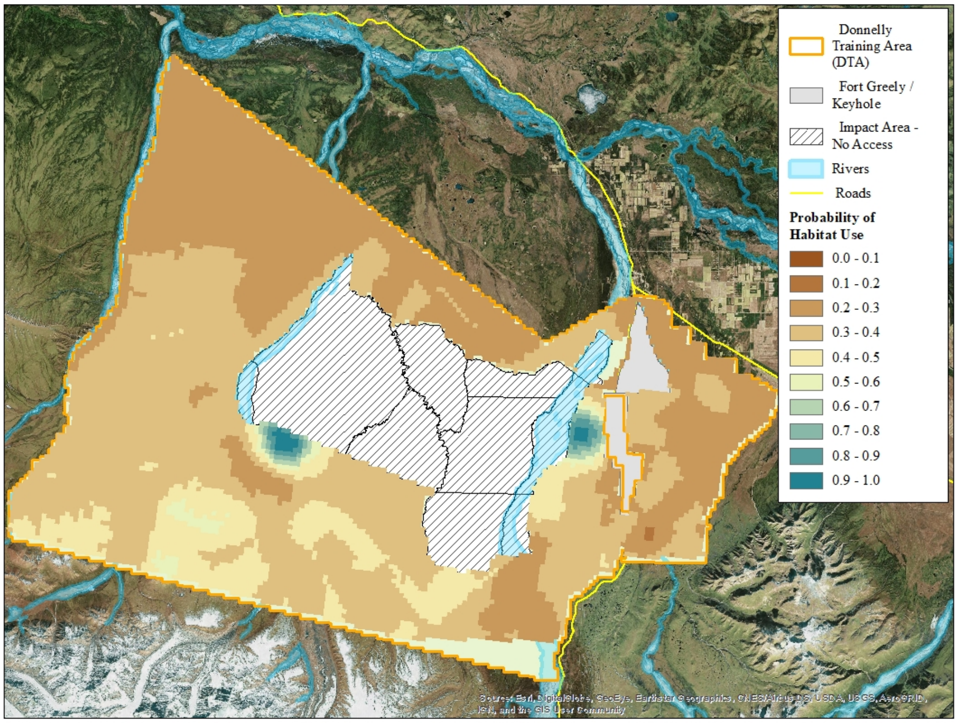
Figure 1.13. Habitat use probability maps for lowland shorebirds in Tanana Flats Training Area (a) and Donnelly Training Area (b). Low probability of habitat use (0.0) to high probability of habitat use (1.0). See Figure 1.3 for location of surveyed plots.

a. Tanana Flats Training Area



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

b. Donnelly Training Area



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 1.14. Habitat use probability maps for upland shorebirds in Tanana Flats Training Area (a) and Donnelly Training Area (b). Low probability of habitat use (0.0) to high probability of habitat use (1.0). See Figure 1.3 for location of surveyed plots.

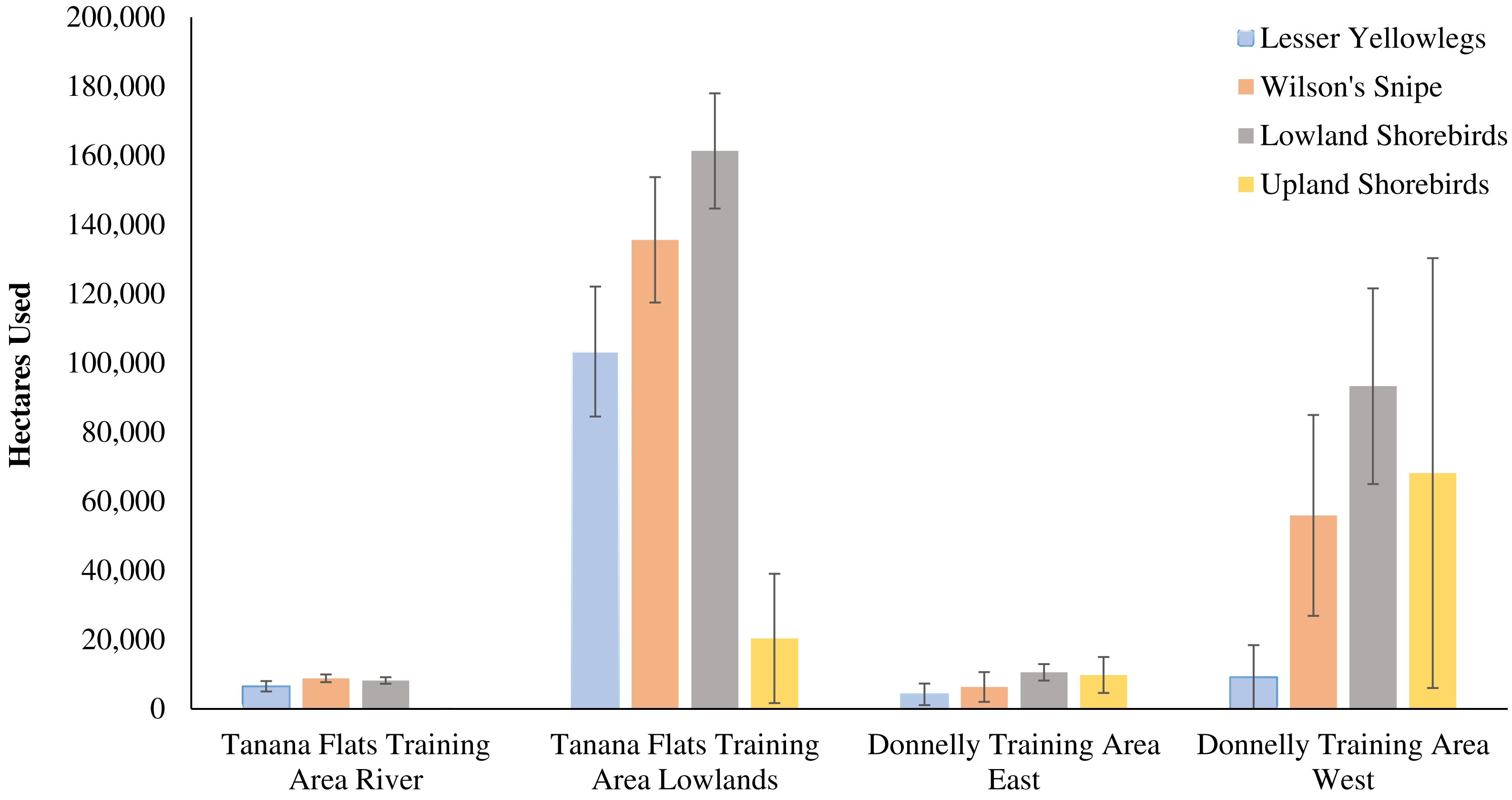


Figure 1.15. 2017 habitat use estimates for Lesser Yellowlegs, Wilson's Snipe, all lowland birds, and all upland shorebirds in study site. Estimated hectares occupied by each group and the standard error adjusted for stratification.

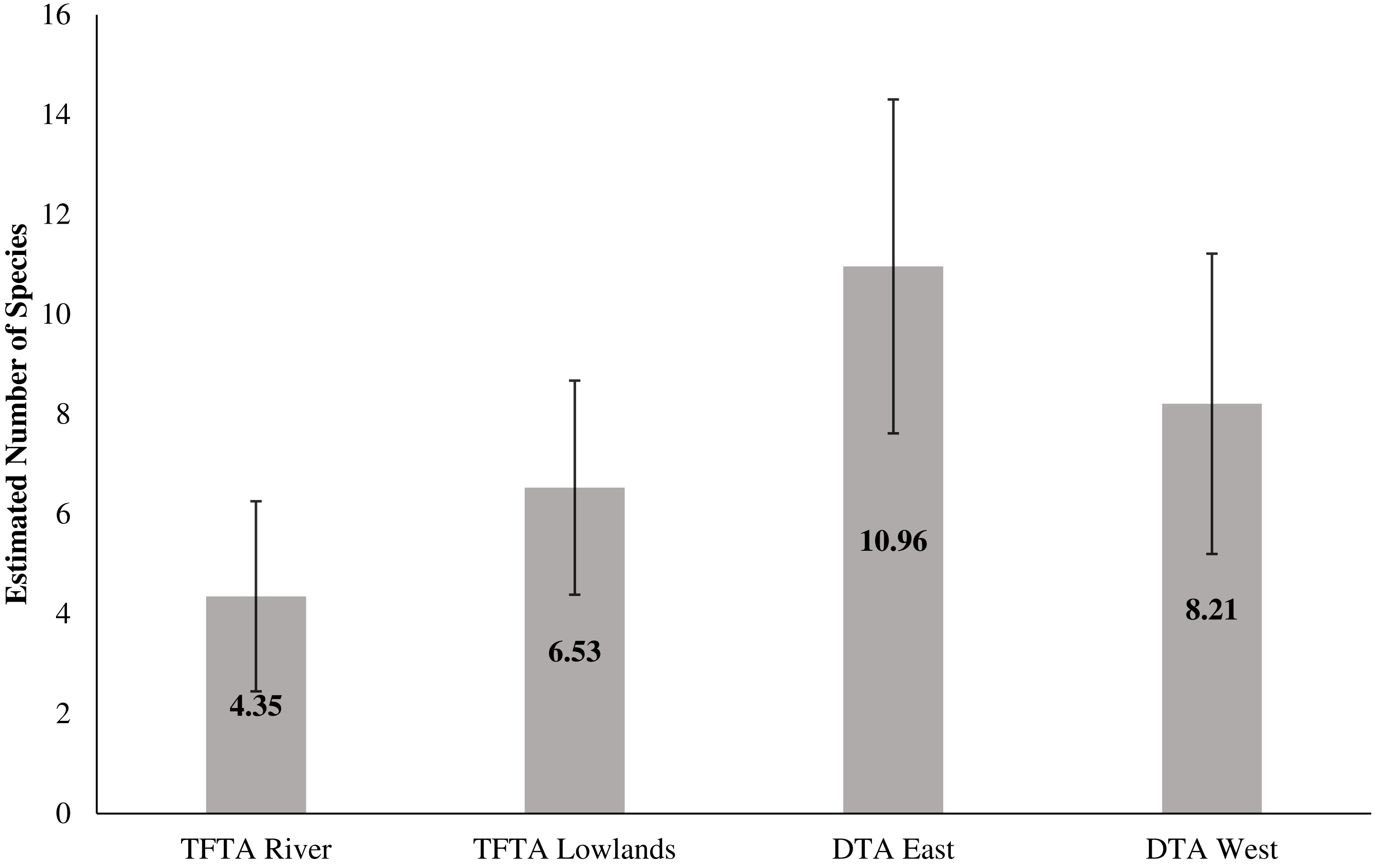


Figure 1.16. Species richness differed across strata in 2017. Donnelly Training Area East and West had the highest species richness estimates. Tanana Flats Training Area River and Lowlands had the lowest species richness estimates.

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CHAPTER 2

SHOREBIRD ABUNDANCE ESTIMATES ON MILITARY LANDS IN INTERIOR ALASKA

Overview

Shorebird studies in Alaska have been concentrated along the coasts, with less effort in the interior of the state. Interior Alaska is the least studied region for breeding shorebirds because of challenging accessibility and expectations of low abundances. Currently, no shorebird sites of importance, such as those designated by the Western Hemisphere Shorebird Reserve Network (WHSRN), have been identified in interior Alaska and little is known about associated shorebird distribution and abundance. The Department of Defense (DoD), a major land manager in interior Alaska, is a partner in avian conservation and has an interest in and legal obligation to manage resources on the land they use. This study is the first design-based comprehensive shorebird survey to estimate shorebird population sizes on DoD lands in interior Alaskan boreal forest. No established protocol exists for conducting boreal forest shorebird surveys. Therefore I modified a well-established protocol used in the Arctic, the Arctic Program for Regional and International Shorebird Monitoring (PRISM), which was designed to sample in homogenous landscapes and on plots with high densities of shorebirds. My modifications addressed the increased diversity of habitat types in the boreal forest and low density of shorebirds.

From April 2016 to August 2017, I used a probability-based sampling design to survey 78 and 142 400 by 400 m plots respectively. Each plot was surveyed twice, with two dependent observers walking line transects within plots to estimate detection probability and abundance. I estimated abundance using Huggins closed captures models in Program MARK. I estimated shorebird abundance for Lesser Yellowlegs, Wilson’s Snipe, all lowland shorebirds together, and all upland shorebirds together. Using a variance components approach, I further investigated how plot-level abundance process variance varied with habitat covariates. Finally, I discuss how my modified Arctic PRISM survey protocol performed in the interior boreal forest.

In 2017, I estimated average Lesser Yellowlegs (*Tringa flavipes*) abundance to be 12,478 (SE = 6,498) and Wilson's Snipe (*Gallinago delicata*) to be 21,036 (SE = 6,178) on the 370,420 hectares of military lands in my sampling frame. Abundances of all lowland shorebirds and all upland shorebirds were 42,239 (SE = 13,431) and 3,523 (SE = 494) respectively. I conclude that shorebirds are using military lands in interior Alaska in high abundances (45,762; SE = 13,925). Although densities of shorebirds were low, the military lands in interior Alaska are so large that, taken as a whole, they contain large numbers of breeding shorebirds as defined by the WHSRN (≥ 20,000 shorebirds annually) and therefore meet qualifications for designation as a WHSRN regionally important site. Process variation in shorebird abundances was best explained by a positive correlation with elevation for upland shorebirds, a negative correlation with elevation for lowland shorebirds, negative correlations with scrub canopy and distance to wetland for Lesser Yellowlegs, and a positive correlation with percent water on plot for Wilson's Snipe. Overall, habitat variables explain ≤ 20% of the process variance in plot-level species abundance. My modified Arctic PRISM protocol was effective in the boreal forest and I recommend continued use of these modifications in tandem with partner agencies throughout the boreal forest for future shorebird surveys.

Introduction

Only 52% of 37 shorebird species recognized as typical Arctic and subarctic breeders have known estimates of population size (Meltofte et al. 2007). Of species with known population sizes, 44% are decreasing (Morrison et al. 2001). Johnson et al. (2007) found significant population declines in several Arctic and subarctic breeding birds with Black Bellied Plover (*Pluvialis squatarola*), American Golden Plover (*Pluvialis dominica*), Solitary Sandpiper (*Tringa solitaria*), Upland Sandpiper (*Bartramia longicauda*), and Pectoral Sandpiper (*Calidris melanoto*) all showing negative trends. Given this concern, surprisingly few studies have been conducted on shorebird status and trends and no design-based studies exist estimating shorebird population sizes in the difficult-to-access interior Alaskan boreal forest (Bird Conservation Region 4; Alaska Shorebird Group 2008, Andres et al. 2016). Interior Alaska is suspected to provide breeding habitat for 16 species of shorebirds, several of which are of conservation concern (i.e., Whimbrel (*Numenius phaeopus*) and Lesser Yellowlegs (*Tringa flavipes*), Andres et al. 2012). Shorebirds that breed and nest in the boreal forest are typically more dispersed than coastal nesting birds, but the large expanse of available, undeveloped land in the interior could ultimately contain large areas of suitable shorebird breeding habitat and large numbers of shorebirds. Ultimately, the boreal forest could be an import breeding area for shorebirds.

The Western Hemisphere Shorebird Reserve Network (WHSRN) designates three levels of site importance for shorebirds. A site is of hemispheric importance if at least 500,000 shorebirds annually use it or if it supports at least 30% of the biogeographic population of a species. A site is of international importance if at least 100,000 shorebirds annually use it or if it supports at least 10% of the biogeographic population of a species. A site is of regional importance if at least 20,000 shorebirds annually use it or if it supports at least 1% of the biogeographic population of a species (Boere et al. 2006). The intent of designating these important bird sites is to conserve shorebirds and their habitats through a connected network of sites that play a role in shorebird wintering, migrating, and breeding seasons. There are five

WHSRN sites in Alaska, all concentrated along the southern coastline. Currently, no important shorebird areas have been designated in interior Alaska (Duncan 2006).

Landowner or land manager cooperation is also required to designate a site for inclusion in the WHSRN framework. Although no legal mandates exist, once designated as a site of importance, site landowners are expected to agree to make shorebird conservation a priority, protect and manage the site for shorebirds, and keep the WHSRN informed of changes to the site boundaries (Duncan 2006). One of the largest land managing agencies in interior Alaska is the US Department of Defense (DoD). The DoD manages more than half a million hectacres of interior Alaskan boreal forest (Figure 2.1; Fort Wainwright, Fairbanks, Alaska and Fort Greely, Delta Junction, Alaska). Given that the DoD is mandated to follow federal environmental laws such as the Endangered Species Act (United States Government 1973), Migratory Bird Treaty Act (U.S. Fish and Wildlife Service 1918), and Sikes Act (Stein et al. 2008), concerns about shorebirds are rising and assessing the status of shorebirds on DoD lands is warranted (Hayden et al. 2008). The DoD is a partner in bird conservation and has previously identified areas on military lands as important bird areas (Department of Defense 2018). The Department of Defense Partners in Flight endorses identification of important bird areas on military installations, with the intent to manage natural resources to benefit bird populations (Department of Defense 2018). Estimating population sizes of birds using military lands as breeding grounds is the first step in managing for these species and assessing sites for WHSRN status.

Abundances of shorebirds on breeding grounds are influenced by local habitat characteristics, including vegetative structure, cover patterns, and moisture (Taft and Haig 2006, Cunningham et al. 2016, Martin Chapter 1). Elsewhere, many lowland species breed in low, riverine corridors because of available resources and large amounts of biomass associated with wetlands, such as invertebrate prey and emergent vegetation (Fairbairn and Dinsmore 2001, Saalfeld et al. 2016) and several species of lowland shorebirds are considered wetland obligates (Taft and Haig 2006). Interior Alaska contains lowland, riverine corridors which lowland birds such as Lesser Yellowlegs use. Lowland species are suspected to use and forage in micro-habitats with no to low-density woody vegetation (Galbraith et al. 2014). Conversely, many upland species are selecting for higher elevation plateaus which still have shallow water or are mostly composed of high elevation wetlands (Martin Chapter 1). For example, Whimbrels breed on high elevation plateaus containing hummocks with low, laterally growing vegetation (Ballantyne and Nol 2011, Harwood et al. 2016). Beyond elevation, other covariates such as percent scrub canopy cover, percent water in a habitat, distance to wetland, and dominant habitat cover classification are all suspected to be important in predicting shorebird use of a site and therefore important determinants of abundances in the interior boreal forest. Identifying shorebirds and their associated habitat characteristics in the interior boreal forest will fill this information gap.

History of Shorebird Surveys

Systematic North American shorebird surveys began in 1970 when the United States and Canada set up the International Shorebird Survey (ISS), a widespread observer network spanning zones used during shorebird migration (Andres et al. 2012, Bart 2005). The Western Hemisphere Shorebird Reserve Network (WHSRN), Shorebird Recovery Project, and other organizations now facilitate and coordinate shorebird survey projects both nationally and globally (Brown et al. 2001). In 2001 the United States Shorebird Conservation Plan was created as a coordinated national initiative and was the impetus for publishing the first comprehensive synthesis of shorebird population estimates in North America (Brown et al.

2001). Subsequent updates were published in 2006 and 2012 (Morrison et al. 2001, 2006, Andres et al. 2012). As part of this initiative, the Alaska Shorebird Conservation Plan was created by the Alaska Shorebird Working Group in 2000. Efforts by the United States and Canada to develop an Arctic and near-Arctic ecoregion sampling protocol have resulted in the Program for Regional and International Shorebird Monitoring (PRISM; Bart 2005, Bart et al. 2005).

PRISM data assist land managers with conservation goals by identifying shorebird species at risk, understanding distributions and habitat use, estimating abundance at stopover and breeding sites, and monitoring trends and numbers (Bart et al. 2005). Since 2002, PRISM collaborators have developed a protocol for Arctic shorebird surveys, with boreal, temperate, and non-temperate shorebird survey protocols in various stages of development (Bart et al. 2005). PRISM continues to be the standard method of shorebird surveys in the Arctic and has been frequently implemented across Alaska and Canada (Bart and Johnston 2012).

Large PRISM survey efforts on the Arctic coasts and southern coasts of Alaska have documented key breeding habitat and high concentrations of shorebirds (Andres et al. 2006, Bart and Johnson 2012). Conversely, interior Alaska remains largely unsurveyed because it is so vast, remote, and difficult-to-access (Alaska Shorebird Group 2008).

Shorebirds that breed and nest in the boreal forest are typically more dispersed than coastal and Arctic nesting birds, but the large expanse of land in the interior could ultimately contain large shorebird numbers. As no design-based survey has been conducted in the boreal forest, I used a modified Arctic PRISM protocol to sample birds in the interior boreal forest of Alaska.

I selected the PRISM method as the model for my shorebird survey design because it is widely supported throughout the shorebird research community and it has a ten-year history of implementation in the Arctic (Bart et al. 2005). At the time of creation, PRISM did not recommend one approach to conducting boreal forest shorebird surveys, but instead offered a list of untested survey methods (Skagen et al. 2003). Suggestions included aerial surveys, mini-Breeding Bird Surveys, and an emulation of the Arctic PRISM survey (Skagen et al. 2003). Including a probability-based sampling design to choose survey plots and accounting for imperfect detection on surveyed plots are two important, but often overlooked elements in abundance survey designs (Nichols et al. 2000, Williams et al. 2002). I used an adjusted Arctic PRISM survey protocol to fit the boreal forest survey requirements while ensuring a stratified, random design with a spatially balanced sampling tool (Stevens and Olsen 2004, Theobald et al. 2007, ESRI 2011) and a dependent double observer method (Nichols et al. 2000).

Objectives and Predictions

My objectives were to (1) estimate abundances of shorebirds breeding on military lands and determine if military lands in interior Alaska are important for shorebirds, (2) explain variation in plot abundances with habitat covariates, and (3) assess the applicability of my modified Arctic PRISM protocol for future boreal forest shorebird surveys. I hypothesized shorebird abundances were highest in lowland areas. Specifically, I hypothesized that Tanana Flats Training Area had the largest shorebird populations using military lands because of the higher biomass of food resources, such as invertebrates, in these lowland, wet habitats. I hypothesized that Donnelly Training Area had fewer birds because it contains less food-rich habitats. I also hypothesized that variation in plot level abundance was explained by elevation, dominant vegetation type, and amount of water on plot, all important predictors of plot-level habitat use (Table 2.1, Brown et al. 2016, Martin Chapter 1).

Materials & Methods

Sampling Design: Vegetation and Plot Selection

For inclusion of habitat types in my sampling frame, I evaluated third level Viereck habitat classifications across military lands. Third level Viereck habitat classifications describe habitat types by dominant vegetation, percent canopy cover, and ground condition (e.g., mesic, wet, dry). I used a military lands habitat map created from Landsat 5 imagery and verified via ground truthing at over 7,000 vegetation plots on TFTA and DTA East and West, Yukon Training Area (YTA), Gerstle River Training Area (GRTA), and Black Rapids Training Area (BRTA). Habitat classifications included as suitable shorebird habitat were open and woodland forest, low density shrub cover, high density shrub cover, grassland, sedge meadows, moss/lichen, water, and barren ground cover classifications following Andres et al. (2012). The only habitat classification excluded was dense, closed black spruce forest.

I divided the two training areas (Tanana Flats Training Area and Donnelly Training Area) into four strata for plot allocation, namely Tanana Flats Training Area (TFTA) Lowlands, Tanana Flats Training Area (TFTA) River, Donnelly Training Area (DTA) West, and Donnelly Training Area (DTA) East. Using a spatially balanced sampling tool, I randomly chose 400 by 400 m plots separately within each of the four strata (Figure 2.2; Theobald 2004, Stevens and Olson 2004, ESRI 2011). Spatially balanced sampling enforces maximal spatial coverage within a probability-based method and encourages independence of samples (Stevens and Olson 2004). Three of the strata had equal sample allocation (TFTA Lowlands, DTA East, and DTA West). Plot access in TFTA Lowlands and DTA West was highly dependent on helicopter scheduling and weather. DTA East was accessed exclusively on foot or with 4-wheelers. I sampled the TFTA River corridor at a higher rate because access to these plots was by boat and sampling was more time efficient. I defined the TFTA River corridor plots within one kilometer of two tributaries (Salchaket Slough, Wood River) of the Tanana River. This buffer threshold was based on previous experience navigating in the Tanana River corridor.

Study Site

This study took place on military lands in interior Alaska. The military lands included in this study are Tanana Flats Training Area (TFTA) and Donnelly Training Area (DTA). TFTA south of Fairbanks, Alaska spans 258,900 hectares. DTA (DTA East and DTA West), south-west of Delta Junction, Alaska span 267,000 hectares. This region is characterized by closed boreal forest (*Picea mariana, P. glauca, Populus tremuloides*), both tall (*Alnus* spp.*, Salix* spp.*, Betula nana*) and low (*Vaccinium vitis-idea, Betula nana*, *V. uliginosum*) scrub as well as ground cover such as moss and lichen. This area is frequently altered by forest fire (Viereck et al. 1993).

TFTA is a lowland, wet, riverine ecosystem with the Tanana River and tribuitaries flowing through the landscape. Elevations in TFTA range from 120 to 360 meters (m). Conversely, the majority of DTA is considered upland habitat (> 600 m elevation), containing the Delta River which quickly gains steep elevation on both banks, leveling out to upland scrub hills. Donnelly Training Area East contains both lowland and upland habitat. The foothills of the Alaska Range begin on the south boundary of the training area, where there are numerous alpine ridges. Elevations in DTA range from 360 to 1860 m (Gallant et al. 1995).

Sampling Design: Survey Protocol and Field Methods

The Arctic PRISM protocol is a double sampling protocol (Bart and Earnst 2002) that includes both rapid and intensive surveys on randomly selected 400 by 400 m plots. Rapid survey PRISM protocol dictates a strict 98 minute, single-observer survey of the 400 by 400 m plot. A subset of these 400 by 400 m plots are selected for intensive surveys, where two observers remain camped near a plot and conduct daily surveys for up to a month in which all individual birds breeding on plot are assumed to be detected. Counts from intensive surveys assume all individuals are detected and are used to adjust density estimates on the rapidly surveyed plots for detection < 1 (Bart et al. 2005).

I first modified the Arctic PRISM protocol to allow for variable plot completion time. Arctic PRISM is conducted in habitats with relatively homogenous, low, dense vegetation. Conversely, the boreal forest biome has many more diverse habitats (e.g., thick white spruce forest, alpine muskegs, lichen-covered slopes). In Arctic PRISM surveys, a strict 98-minute plot sampling time limit is enforced in order to ensure equal effort of sampling across plots. My modified protocol allowed for variable time for plot completion and enforced a standard six transects, each between 50 and 60 meters apart to ensure equal sampling effort across plots.

Another modification was that I accounted for detection of shorebirds by using a dependent double-observer sampling approach instead of a subset of intensively surveyed plots (Nichols et al. 2000). This dependent double-observer protocol uses two surveyors with two roles. A primary observer walked ahead of a secondary observer, and indicated verbally where shorebirds were observed, species name, and number in each group (defined as more than one shorebird within 10 m of each other). The secondary observer recorded the shorebirds observed by the primary observer and any shorebirds that the primary observer missed. The observers walked transects through the entire plot. A plot required six transects to be adequately surveyed. Dependent double-observers surveyed each plot, and primary and secondary roles were reversed for observers on subsequent plots. To keep observers independent, the secondary observer feigned shorebird observations and data collection and both observers stopping periodically to scan the plot with binoculars.

Surveys were initiated on 7 May 2016 and 9 May 2017 to correspond with shorebird arrival and the beginning of breeding activities. Surveys ended 14 July 2016 and 14 July 2017 to align with historical shorebird departure from the area (Kessel and Gibson 1978). Each plot was visited twice per field season, with dates for repeat visits dependent on training area closures and openings. I aimed to visit plots in ascending numerical order as designated by the spatially balanced sampling tool in ESRI (Figure 2.2; ESRI 2011). However, at times plot access required substantial travel time and in these cases, field crews surveyed the nearby plots to the next chronologically low number instead of strictly following numerical order.

In the field, we collected data on iPad Pro tablets using the GISPro application with preloaded data columns and drop down menus (ESRI 2011). The secondary observer on each plot operated the iPad and recorded data. At the end of the survey both observers collaboratively collected habitat data within a 50 m radius of the center of each plot. We collected data on Viereck classification, shrub height, shrub and tree cover, open water, dominant species, and a broad vegetation categorization for the entire 16 hectare (ha) plot. The broad vegetation survey classified the three dominant third level Viereck habitat classifications and percentage of plot coverage (for full descriptions of habitat variables see Appendix 2a Table 2.1). For data analysis, I included seven covariates from these habitat surveys; forest Viereck classification, scrub Viereck classification, forb/lichen/herbaceous Viereck classification, percent scrub canopy cover, elevation, distance to wetland, and percent water on plot.

Data Analysis: Detection and Abundance

Unbiased estimates of abundance consider detection probability of an individual, assume closure, and use a probability-based sampling design to allow extrapolation over the entire area of interest (Thompson 2012). For abundance estimation I used data collected on first visits to plots surveyed in 2016 and 2017. These data are most likely to meet the closure assumption (i.e., a population is constant over the period of investigation; Otis et al. 1978) because of the territoriality and site fidelity breeding shorebirds exhibit early in the breeding season. Observing more than one shorebird on plot was uncommon, so there was little possibility of confusing one individual shorebird with another. To further avoid misidentification problems, technicians spent over one week conducting training surveys and spent over two weeks learning shorebird auditory and visual cues.

I estimated and modeled detection probability (p) and derived plot-level abundance (N) using Huggins closed captures models in Program MARK (Huggins 1989, 1991, White and Burnham 1999). One advantage to using the Huggins model is that individual covariates are used to model capture and recapture probabilities. *A priori*, I constructed candidate models representing hypotheses for abundance and detection for each species. I derived my hypotheses (Table 2.1 and Table 2.2) from existing literature, personal communication with biologists familiar with the study area and species, as well as personal observations (e.g., Meltofte 2007, Latour et al. 2005, Harwood et al. 2016). For all habitat covariates, I examined correlations with other variables. I tested hypotheses on detection using seven habitat covariates for Lesser Yellowlegs, Wilson’s Snipe, all lowland shorebirds, and all upland shorebirds. I did not examine differences in detection among observers because detection was very high and technicians went through two weeks of training prior to the beginning of surveys in both 2016 and 2017. I ran goodness of fit tests using a median c-hat ($\hat{c}$) procedure (Cooch and White 2013).

For each group (i.e., Lesser Yellowlegs, Wilson's Snipe, all lowland shorebirds, and all upland shorebirds) I used Akaike's Information Criterion with a small sample size correction (AIC_c) to select the most parsimonious model among constant (.) or habitat covariate varying models on detection. Due to sparse data in all data sets, I was unable to investigate plot-varying detection. I set recapture probability (c) to zero to account for the dependence of the second observer during surveys. I investigated all possible combinations of habitat covariates on detection (Burnham and Anderson 2002), and summed Akaike weights (w_i) across all models containing a specific variable to determine relative importance of covariates (Burnham and Anderson 2002). I considered variables with cumulative AIC_c weights < 0.50 to be uninformative and excluded them from the model used to derive abundance estimates (Doherty et al. 2012, Bromaghin et al. 2013). The model containing all variables with cumulative AIC_c weights ≥ 0.50 was used to derive abundance estimates for my study area. I derived plot-level densities and extrapolated abundances for each group to all surveyable habitat (i.e., sampling frame) for each of the four strata (TFTA River, TFTA Lowlands, DTA East, and DTA West; Table 2.3). I accounted for survey effort and excluded closed forest and impact areas from surveyable habitat and excluded this from extrapolated abundances. Variance estimates were calculated following Bowden et al. (2003) to account for detection covariance structures across plots within strata.

Variance components analysis allowed me to separate sampling variance from biological process variance and focus on investigating the process variance explained by each covariate. In the Huggins model, abundance (N) is a derived parameter. Because abundance is derived, the effect of habitat factors cannot be tested using model selection; instead I used an analysis of deviance approach to investigate process variance in abundance caused by hypothesized covariates (White and Burnham 1999). Specifically, in Program MARK, I ran a variance components analysis on the derived abundance estimates from the mean model for each group (i.e., model with no covariates, intercept model) to determine the maximum biological process variability possible in my data (White and Burnham 1999). From this maximum variability, I subtracted the amount of process variance explained by each covariate individually and divided by total variance to determine the percent of variability explained by each habitat covariate.

Results

Raw Survey Results

We surveyed 78 plots in 2016 and 142 plots in 2017. Field crews observed a total of 107 shorebirds on 78 surveyed plots in 2016 and a total of 344 shorebirds on 142 surveyed plots in 2017. The species observed with the highest frequency was Wilson’s Snipe (2016 n = 41 observations, 2017 n = 153 observations), followed by Lesser Yellowlegs (2016 n = 43 observations, 2017 n = 144 observations), and Spotted Sandpiper (2016 n = 10 observations, 2017 n = 21 observations). Lowland individuals were detected more frequently (99, 324) than upland individuals (8, 20) in both 2016 and 2017 respectively (Table 2.4).

Lesser Yellowlegs Abundance Estimates

I analyzed all possible combinations of habitat covariates on detection (percent scrub on plot, percent water on plot, distance to wetland, forest Viereck classification, scrub Viereck classification, and forb/lichen/herbaceous Viereck classification). The only variable with cumulative weight ≥ 0.50 for detection was percent water on plot (Table 2.5 and Table 2.6). I detected no goodness of fit issues (Table 2.7) and did not need to adjust my model set. Lesser Yellowlegs abundances were calculated using the model $p_{percent\ water\ on\ plot} N_{plot}$. Percent water on plot had weak positive relationship with detection (β = -0.132, SE = 0.059) and average detection for Lesser Yellowlegs was 0.752 (SE = 0.132; Table 2.8). Estimated number of Lesser Yellowlegs on occupied plots ranged from one to seven birds (Appendix 2a Table 2.2). Extrapolated to the entire study site, in 2017 the estimated number of Lesser Yellowlegs ranged from 104 (SE = 71) individuals in Donnelly Training Area East stratum to 11,863 (SE = 6,098) individuals in Tanana Flats Training Area Lowland stratum. In 2017, total abundance of Lesser Yellowlegs across our study site was 12,478 (SE = 6,494) individuals. In 2016, total abundance of Yellowlegs across our study site was 5,748 (SE = 936) individuals (Table 2.9).

Variance components analysis suggest that distance to wetland explains the most variation in Lesser Yellowlegs plot abundance (20.37%), followed by percent scrub canopy cover (9.24%), and habitat (6.55%; Table 2.10).

Wilson's Snipe Abundance Estimates

I analyzed all possible combinations of habitat covariates on detection (percent scrub on plot, percent water on plot, distance to wetland, forest Viereck classification, scrub Viereck classification, and forb/lichen/herbaceous Viereck classification). The variable with cumulative weight ≥ 0.50 for detection which was used in the abundance estimation model was distance to wetland (Table 2.5 and 2.11). I detected no goodness of fit issues (Table 2.7) and did not need to adjust my model set.

I calculated Wilson's Snipe abundance using the model $p_{distance\ to\ wetland} N_{plot.}$. Distance to wetland had a weak relationship with detection (β = -0.006, SE = 0.003) and average detection for Wilson's Snipe was 0.868 (SE = 0.045; Table 2.8). Estimated number of Wilson's Snipe on occupied plots ranged from one to ten birds (Appendix 2a Table 2.3). Extrapolated to the entire study site, estimated number of Wilson's Snipe ranged from 17,456 (SE = 5,319) in 2017 in Tanana Flats Training Area Lowlands stratum to 342 (SE = 276) in Donnelly Training Area East stratum in 2017. Across military training lands in 2017, estimated abundance of Wilson's Snipe was 21,036 (SE = 6,178) individuals and in 2016 estimated abundance was 5,881 (SE = 2,489) individuals (Table 2.12).

Variance components analysis suggests that percent water on plot explains the most variation in Wilson's Snipe plot abundance (3.96%), followed by elevation (2.21%), percent scrub canopy cover, (1.17%), and habitat (0.09%; Table 2.13).

All Lowland Shorebirds Abundance Estimates

I analyzed all possible combinations of habitat covariates on detection (percent scrub on plot, percent water on plot, distance to wetland, forest Viereck classification, scrub Viereck classification, and forb/lichen/herbaceous Viereck classification). Variables with cumulative weights ≥ 0.50 for detection which were used in the abundance estimation model were distance to wetland, elevation, and habitat (Table 2.5 and Table 2.14). I detected no goodness of fit issues (Table 2.7) and did not need to adjust my model set.

All lowland shorebird abundances were calculated using the model $p_{elevation\ +\ distance\ to\ wetland\ +\ habitat}\ N_{plot}$. Elevation (β = -0.006, SE = 0.003), distance to wetland (β = -0.005, SE = 0.003), and habitat (β = -2.029, SE = 1.180) had weak relationships with detection and average detection for all lowland shorebirds was 0.883 (SE = 0.033; Table 2.8). Estimated number of all lowland shorebirds on occupied plots ranged from one to ten birds (Appendix 2a Table 2.4). Estimated number of all lowland shorebirds using training areas ranged from 510 (SE = 112) individuals in

2017 in Donnelly Training Area East stratum to 36,191 (SE = 13,005) individuals on Tanana Flats Training Area Lowlands stratum. In 2017 I estimated that 42,239 (SE = 13,431) lowland birds used military lands in interior Alaska and in 2016 I estimated abundance of lowland birds at 12,298 (SE = 1,854; Table 2.15).

Variance components analysis suggest that elevation explains the most variation in all lowland shorebird plot abundance (5.38%), followed by percent scrub canopy (4.72%), and percent water on plot, (0.10%; Table 2.16).

All Upland Shorebirds Abundance Estimates

I analyzed all possible combinations of habitat covariates on detection (percent scrub on plot, percent water on plot, distance to wetland, forest Viereck classification, scrub Viereck classification, and forb/lichen/herbaceous Viereck classification). No variables had cumulative weights ≥ 0.50 for detection, thus constant(.) was used on detection for abundance estimation (Table 2.5). I detected no goodness of fit issues (Table 2.7) and did not need to adjust my model set.

All upland shorebird abundances were calculated using the model $p_{(.)}\ N_{plot.}$ Estimated number of all upland shorebirds on occupied plots ranged from one to four birds (Appendix 2a Table 2.5). Average detection for all upland shorebirds was 0.938 (SE = 0.064; Table 2.8). Estimated number of all upland shorebirds using training areas ranged from zero individuals in 2017 in Tanana Flats Training Area River stratum to 2,668 (SE = 287) individuals on Donnelly Training Area West stratum. In 2017 on military lands, estimated abundance of all upland birds was 3,423 (SE = 494) and in 2016 estimated abundance was 1,813 (SE = 265; Table 2.17).

Variance components analysis suggest that elevation explains the most variation in all upland shorebird plot abundance (13.01%), followed by distance to wetland (4.95%; Table 2.18).

Discussion

Abundance Estimates

These are the first unbiased abundance estimates for shorebirds in interior Alaska and they are informative for future research in the boreal forest. Densities and abundances of shorebirds on plot were low, but when extrapolated to the entire sampling frame (370,420 hectares), were substantially large estimated abundances. Overall, military lands in interior Alaska contain 42,239 (SE = 13,431; Table 2.15) lowland shorebirds and 3,523 (SE = 494; Table 2.17) upland shorebirds, an estimated total of 45,762 (SE = 13,925) shorebirds.

Further, I estimate that there are 12,478 (SE = 6,498) Lesser Yellowlegs and 21,036 (SE = 6,178) Wilson's Snipe using military lands. My estimates for Lesser Yellowlegs and Wilson's Snipe fall within the estimated number of each species breeding in the state; of the estimated 400,000 Lesser Yellowlegs in the North American population, 25% to 50% are suspected to breed in Alaska (Alaska Shorebird Group 2008). Lesser Yellowlegs are currently considered high conservation concern (i.e., red listed by the Alaska Natural Heritage Program) because of suspected declines in population numbers based on available data, mostly taken from the Breeding Bird Survey (Alaska Shorebird Group 2008, Alaska Natural Heritage Program 2013). Current data show a population decline of 17.1% annually between 1980 and 2007 (Matsuoka and Pardieck 2009). The number of Lesser Yellowlegs estimated on our study site is large (12,478, SE = 6,498) and meets the criteria of a regional Western Hemisphere Shorebird Reserve Network site by containing more than 1% of the Lesser Yellowlegs biogeographic population. An estimated 3% of the North American population of Lesser Yellowlegs are breeding on our study site (12,478 of an estimated 400,000 birds), and a conservative estimate of 6% of all biogeographic breeders (i.e., those which breed in Alaska) are on military lands in the interior

(12,478 out of an estimated 200,000 Alaska breeding birds). This site will be important for future species-specific studies if Lesser Yellowlegs populations continue to experience declines (Alaska Natural Heritage Program 2013).

Similarly, of the estimated 2,000,000 Wilson's Snipe in the North American population, 25% to 50% are suspected to breed in Alaska. I estimated 21,036 (SE = 6,178) Wilson's Snipe on military lands in interior Alaska, also qualifying military lands as regionally important for containing 1% of North America's population of Wilson's Snipe. Conservatively, I estimate that military lands contain 2% of all biogeographic breeding Wilson's Snipe (21,036 out of 1,000,000 Alaska breeding birds). Wilson's Snipe is one of the most widespread and commonly encountered species in Alaska, and is currently ranked by the Alaska Shorebird Conservation Plan as a species of moderate concern (Walton et al. 2012).

Of my four strata, Tanana Flats Training Area Lowland stratum had the highest number of shorebirds. Lowest abundance of all shorebirds was on Donnelly Training Area East stratum (Figure 2.3). My hypothesis that lowland training areas such as Tanana Flats Training Area Lowland and River strata have higher abundances than upland training areas such as Donnelly Training Areas East and West was supported. This result may be because the increased availability of food biomass in the lowland, wetland systems which birds are preferentially selecting (Meltofte et al. 2007). Tanana Flats Training Area Lowland and River strata have more area covered by wetland than Donnelly Training Areas East and West. Although a substantial mass of the upland strata is covered in wetland (307,600 hectares in DTA West; 16,673 hectares of DTA East), more of the lowland strata are covered by this preferential habitat type (Martin Chapter 1; 547,578 hectares of TFTA).

The difference in abundance estimates could also be a result of the larger population sizes of lowland shorebirds than upland shorebirds, making the probability of encounter greater. Upland species of shorebirds such as Surfbird and Whimbrel have estimated population sizes of 70,000 and 26,000 respectively (Alaska Shorebird Group 2008). Of all upland shorebirds hypothesized to be using military lands, the highest population estimate is that of the Pectoral Sandpiper, estimated at 500,000 individuals in North America (Alaska Shorebird Group 2008). This species, like other birds hypothesized to breed in the tundra, was rarely encountered on plot surveys (n = 1 individual).

Variance Components Analysis

Distance to wetland explained 20.37% of process variance in Lesser Yellowlegs plot-level abundance and explained 4.95% of process variance in all upland shorebird abundance. Percent water on plot explained the most process variance in Wilson's Snipe plot-level abundance (3.96%) and a small amount of process variance in all lowland bird abundance (0.10%). *A priori*, I hypothesized that these two water-related habitat covariates would explain variation in plot abundances, with more water on plot and closer wetland correlated to increased abundances. Overall, my results align with current literature. Gillespie and Fontaine (2017), Webb et al. (2010), and other studies found that for shorebird species (e.g., stilts and sandpipers) which are typically classified as lowland shorebirds, wetland availability and proximity was the top predictor variable. Wetland and open water provide foraging opportunities for shorebirds and are regularly found to be top predictors of site use (Martin Chapter 1, Reiter et al. 2015)

Percent scrub canopy explained a moderate amount of process variance in Lesser Yellowlegs plot-level abundance (9.25%), some variance in all lowland bird abundance (4.72%), and a small amount of variance in Wilson's Snipe plot-level abundance (1.17%). As hypothesized *a priori,* a higher percent scrub canopy on plot was correlated to decreased abundances on plot for lowland shorebirds, and specifically for Lesser Yellowlegs and Wilson's Snipe. One reason for this result is that these species are not selecting for habitat which gives them nest crypsis or protection from aerial predators in the form of shrub cover. In the lowland habitat types in which all lowland birds are typically found, there is a large range of vertical vegetative structural diversity. Taller grasses and trees available for nest crypsis could preclude the need for shrubs. A predator defense strategy attributed to many species of lowland shorebirds is early detection of aerial and ground-based predators (Colwell and Oring 1990). Lower percent shrub on plot and less vegetative obstruction aligns with this defensive strategy.

Elevation explained 13.01% of process variance in all upland shorebird plot-level abundance, 5.39% of process variation in all lowland bird abundance, and 2.21% of process variation in Wilson's Snipe plot-level abundance. Following my *a priori* hypotheses, elevation was correlated to abundance for upland shorebirds and lowland shorebirds, specifically Wilson's Snipe. This follows with current literature, which shows that most species classified as upland shorebirds prefer to breed on upland, vegetated plateaus at higher elevations (Wauchope et al. 2016), whereas lowland shorebirds prefer to breed in lower elevation river corridors (Meltofte et al. 2007).

Detection

Detection for all groups of shorebirds was high (0.74 to 0.94; Table 2.8) in my boreal forest study area and higher than other areas. For example, Farmer and Durbian (2006) in Missouri found highly variable detection probabilities for shorebirds with estimates ranging from 0.07 to 0.82. Like hypothesized, covariates of importance in predicting detection were percent water on plot, distance to wetland, elevation, and habitat (Martin Chapter 1).

Designation of Site of Importance

These estimated abundances qualify interior Alaska as a site of regional importance and meet the Western Hemisphere Shorebird Reserve Network criteria of use by ≥ 20,000 shorebirds annually. Our study site supports more than 1% of the biogeographic populations of Lesser Yellowlegs and Wilson's Snipe, meeting additional requirements to be designated as a site of regional importance. Currently, most Western Hemisphere Shorebird Reserve Network sites of importance are located along a shorebird's migratory path: only five sites of importance are on Alaskan breeding grounds, none of which are in the interior. The important sites designated along a shorebird's migratory path are selected for large abundances of birds concentrated in a small area. Conversely, in interior Alaska, the same number of birds are using a large breeding area, leading to a low density of birds. Our abundance estimates suggest that consideration of a site as important ought to consider habitat extent and geographic boundaries, not exclusively consider a site as important by evaluating the density of birds using it.

No estimates exist of abundance in the interior boreal forest of Alaska against which to compare our estimates. My estimates of abundance provide novel population estimates which can be used into the future to update shorebird population estimates and to inform boreal-wide shorebird surveys planned for 2020 (Alaska Shorebird Group 2017). Further research on shorebird abundances in the boreal forest is necessary to determine which habitat types within the boreal forest, if not the entire forest as a whole, meet the qualifications for a designation as a regional site of importance. Collaborative research and continued monitoring in the boreal forest among different landowners will help to identify if the entire boreal forest ecoregion supports this regionally important abundance of shorebirds.

Arctic PRISM Modifications

I followed Arctic PRISM's designation of a standard plot size (400 by 400 m) but made alterations to the survey protocol within plots. I allowed for variable time for plot completion, a standard number of transects to ensure equal survey effort, and used dependent double-observers to estimate detection. My modifications to Arctic PRISM protocol enabled me to effectively survey in the diversity of boreal forest habitats while also meeting a requirement for two technicians working in close proximity to one another for safety.

Arctic PRISM protocol accounts for effort across plots by requiring a plot survey to take exactly 98 minutes. I allowed variable plot completion time and walked a standard number of transects on plot (six), each between 50 and 60 meters apart to ensure equal effort and coverage across plots. The time to complete plot surveys in the boreal forest varied because of habitat differences and difficulty in maneuverability. In open lichen habitat interspersed with low scrub, two observers needed as few as 38 minutes. In wet tussock with tall dense scrub, two observers needed up to 178 minutes. This method allowed each plot to be searched in its entirety, as there were many plots which would have not been completed in challenging habitat had our cutoff time been 98 minutes.

Following Arctic PRISM protocol, I selected 400 by 400 m (16 hectare) square plots. The perimeter to area ratio (i.e., edge effect) is small and minimized bias of estimates related to identifying individuals as in or out of the plot (Thompson et al. 1998). Many species of shorebird, like the Lesser Yellowlegs, actively defend their nests and will respond to predator presence from over 250 meters away (Rowan 1929, Clay et al. 2012). However, in the boreal forest, where shorebird densities are lower than the Arctic coast, a 400 by 400 m plot contains few birds: most plots surveyed had zero birds present and detected. Increased plot size will increase likelihood of having shorebirds on plot. Using my estimate of the average density of shorebirds per hectare on military lands, I calculated plot-level abundance for all lowland shorebirds under different plot size scenarios. Using my plot size of 400 by 400 m, to achieve a CV of 0.30, a sample size of 160 plots is needed. To achieve a CV of 0.10, a sample size of 1,441 plots is needed (Table 2.20).

Our plot surveys were considered partial counts with incomplete detectability. My modifications to Arctic PRISM protocol enabled an estimation of detection probabilities from dependent double observers instead of a subset of intensive plots, typical for Arctic PRISM surveys. For safety reasons, technicians were not able to survey independently. In simulation studies, double observer methods have been shown to be accurate when detection probabilities are greater than 20%. In the boreal forest, we found detection probabilities to be substantially higher than this, ranging from 75% to 94%. I recommend the application of dependent double observer methods in the boreal forest for safety and for more time efficient sampling.

In conclusion, evaluating the tradeoffs between plot size and sample size is an important consideration when designing and planning shorebird surveys in the interior boreal forest. Given enough resources, larger plot sizes and increased sample sizes will yield better estimates.

Timing of surveys in 2016 and 2017 was contingent upon river thawing, historic shorebird arrival onto the study site, and observations of shorebird first arrivals onto frequently visited wetlands around Fairbanks and Delta Junction, Alaska. In the future, initiation and timing of surveys is going to change because of climate change. Further, between 2016 and 2017, I learned about the importance of timing surveys in different training areas to best observe early breeding nest initiations. In 2017 in the Tanana Flats Training Area, we altered surveys to mid-May instead of mid-June and the result was a higher abundance estimate. Consideration of habitats, remaining ice and snow presence, and temperature ought to guide future survey planning.

Recommendations for Military Lands

The Department of Defense is managing an important area for shorebirds. Designation as a WHSRN site is contingent upon land owners' voluntary commitment to conserving habitat and making shorebird conservation a priority (Duncan 2006). The Department of Defense meets requirements to be considered a site of regional importance as defined by WHSRN. The DoD has historically been a conservation partner, and this designation is not unprecedented on military lands. On Joint Base Lewis-McChord outside of Tacoma, Washington, commanders incorporated scientific recommendations in an effort to conserve the horned lark (Stinson 2016). Military commanders instructed soldiers to incorporate areas being used by the horned lark into training and to treat these nesting areas as they would hospitals or schools as a training scenario (Stinson 2016). Further, a conservation site specifically for shorebirds was designated on Vandenberg Air Force Base in California in an effort to protect important Wandering Tattler (*Tringa incana*), Snowy Plover (*Charadrius nivosus*), and Ruddy Turnstone (*Arenaria interpres*) breeding habitats (Robinette et al. 2014). Ultimately, designation of these military lands as a site of regional importance would probably lead to continued monitoring and evaluation of the large number of shorebirds using this habitat.

Compared to other WHSRN sites, the interior boreal forest and the military land within it are massive. Current qualifications for WHSRN sites do not consider density of shorebirds or size of area, but consider counts. If we extrapolated the abundance estimates to the boreal forest as a whole, the boreal forest would be a candidate site for importance designation. The scale of designation of a site of importance becomes a relevant question as either more intensive habitat use surveys need to occur throughout the interior boreal forest to determine if specific habitat types or areas within the boreal forest (i.e., Tanana Flats River) are important or if the entire boreal forest meets the qualification.

Tables

Table 2.1. Lowland and upland shorebird covariate predictions (positive (+), negative (-), or not applicable (*NA*)) for abundance. Habitat classifications are from Viereck et al. (1993) which describe habitat types by dominant vegetation, percent canopy cover, and ground condition (e.g., mesic, wet, dry). Included in the survey habitat classes were open forest, tall scrub, low scrub, dwarf scrub, herbaceous (graminoid/forb), moss/lichen, water, and barren ground cover classifications.

	Species	**Elevation (meters)**	**Percent water on plot (0 – 100%)**	**Distance to wetland (0 - 5300m)**	**Percent shrub cover (0 - 100%)**	**Most used/colonized Viereck Classification**
Lowland	Least Sandpiper	-	+	-	-	Wet, grassland / open mudflat
	Spotted Sandpiper					
	Solitary Sandpiper					
	Lesser Yellowlegs					
	Short-billed Dowitcher					
	Wilson's Snipe					
Upland	American Golden-Plover	+	*NA*	*NA*	+	Low shrub
	Black-bellied Plover					
	Wandering Tattler					
	Whimbrel					
	Surfbird					
	Upland Sandpiper					
	Pectoral Sandpiper					
	Baird's Sandpiper					

Table 2.2. Lowland and upland shorebird covariate predictions for detection in abundance models. Habitat classifications are from Viereck et al. (1993) which describe habitat types by dominant vegetation, percent canopy cover, and ground condition (e.g., mesic, wet, dry). Included in the survey habitat classes were open forest, tall scrub, low scrub, dwarf scrub, herbaceous (graminoid/forb), moss/lichen, water, and barren ground cover classifications.

	Species	**Percent water on plot (0 – 100%)**	**Distance to wetland (0 - 5300m)**	**Percent shrub cover (0 - 100%)**	**Highest detection probability Viereck Classification**	**Year**
Lowland	Least Sandpiper Spotted Sandpiper Solitary Sandpiper Lesser Yellowlegs Short-billed Dowitcher Wilson's Snipe Semipalmated Plover Dunlin	+	-	-	Wet, grassland / open mudflat	Equal across years
Upland	American Golden-Plover Black-bellied Plover Wandering Tattler Whimbrel Surfbird Upland Sandpiper Pectoral Sandpiper Baird's Sandpiper	*NA*	*NA*	-	Low shrub	Equal across years

Table 2.3. Distribution of plots and area of the four strata used to estimate the abundance on military lands in interior Alaska. Amount of surveyable habitat (hectares) and number of plots within in each strata exclude habitat outside of the sampling frame (i.e., closed spruce forest and impact areas).

Strata	Sample Frame Area (hectares)	Area included in Samples (hectares)	Total Plots in Sampling Frame	Plots Sampled
Tanana Flats Training Area River	9,023	320	563	20
Tanana Flats Training Area Lowlands	186,947	528	11,684	33
Donnelly Training Area East	15,503	768	968	48
Donnelly Training Area West	158,947	656	9,934	41

Table 2.4. Lowland and upland shorebird species presence on plots from 2016 and 2017 and conservation status from Alaska Shorebird Conservation Plan and the United States Fish and Wildlife Service (USFWS) Birds of Conservation Concern list.

	Species	**2016 Count**	**2017 Count**	**AK Shorebird Conservation Plan**	**USFWS Birds of Conservation Concern**
Lowland	Lesser Yellowlegs (*Tringa flavipes*)	43	144	✓	✓
	Wilson's Snipe *(Gallinago delicata)*	41	153		
	Spotted Sandpiper (*Actitis macularius*)	10	21		
	Solitary Sandpiper (*Tringa solitaria*)	4	5	✓	✓
	Dunlin (*Calidris alpina*)	1	0	✓	
	Least Sandpiper (*Calidris minutilla*)	0	1		
Upland	Whimbrel (*Numenius phaeopus*)	5	11	✓	✓
	Black-bellied Plover (*Pluvialis squatarola*)	2	3		
	Upland Sandpiper (*Bartramia longicauda*)	1	3	✓	✓
	American Golden-Plover (*Pluvialis dominica*)	0	1	✓	
	Baird's Sandpiper (*Calidris bairdii*)	0	1		
	Pectoral Sandpiper (*Calidris melanotos*)	0	1		
	Surfbird (*Aphriza virgata*)	0	0	✓	
	Wandering Tattler (*Tringa incana*)	0	0		
	Total	107	344		

Table 2.5. Cumulative AIC_c weights for covariates (i) analyzed for detection probability (p) for Lesser Yellowlegs, Wilson's Snipe, all lowland shorebirds, and all upland shorebirds. I used Akaike's Information Criterion (with a small sample size correction) for model selection and cumulative variable weights (w_i) to identify most important covariates. Bolded numbers indicate covariates retained for abundance estimation model (cumulative AIC_c $w_i \geq 0.50$).

Covariate	**Lesser Yellowlegs** Cumulative AIC_c w_i	**Wilson's Snipe** Cumulative AIC_c w_i	**All Lowland Shorebirds** Cumulative AIC_c w_i	**All Upland Shorebirds** Cumulative AIC_c w_i
Elevation	0.023	0.361	**0.691**	0.000
Distance to wetland	0.263	**0.680**	**0.758**	0.165
Habitat	0.035	0.139	**0.565**	0.075
Percent scrub canopy	0.014	0.049	0.301	0.207
Percent water on plot	**0.620**	0.039	0.275	0.133

Table 2.6. Model selection results for Lesser Yellowlegs models of detection probability (p) and abundance (N). I relied upon Akaike's Information Criterion (with a small sample size correction) for model selection and used cumulative variable weights (w_i) and ΔAIC_c to identify most important covariates. Bolded model is top model from which abundance estimates (N) were derived. Because global model set is so small, all models are presented.

Model	AIC_c	Δ AIC_c	AIC_c Weights	Model Likelihood	Num. Parameters	Deviance
p (percent water on plot) **N (plot)**	**49.105**	**0.000**	**0.620**	**1.000**	**3**	**42.894**
p (distance to wetland) N (plot)	50.819	1.714	0.263	0.424	3	44.608
p (.) N (plot)	54.501	5.397	0.042	0.067	2	50.397
p (habitat) N (plot)	54.810	5.705	0.036	0.058	4	46.456
p (elevation) N (plot)	55.617	6.512	0.024	0.039	3	49.406
p (percent scrub canopy) N (plot)	56.589	7.484	0.015	0.024	3	50.379

Table 2.7. Goodness of fit tests for all models.

Model	**Median ĉ Value**
All Lowland Shorebirds	1.0
All Upland Shorebirds	< 1.0
Lesser Yellowlegs	< 1.0
Wilson's Snipe	1.0

Table 2.8. Average detection estimates (p) with pooled strata.

Group	Detection (p)	Standard Error
Lesser Yellowlegs	0.752	0.132
Wilson's Snipe	0.868	0.045
All Lowland Shorebirds	0.883	0.033
All Upland Shorebirds	0.938	0.064

Table 2.9. Lesser Yellowlegs abundance estimates for 2016 and 2017 on military lands in interior Alaska.

Year and Strata	Average Number per Plot	Average Density (per ha)	Total Abundance
2017			
Tanana Flats Training Area River	0.905 (SE = 0.085)	0.057 (SE = 0.005)	510 (SE = 329)
Tanana Flats Training Area Lowland	1.015 (SE = 0.059)	0.063 (SE = 0.004)	11,864 (SE = 6,098)
Donnelly Training Area East	0.107 (SE = 0.011)	0.007 (SE = 0.001)	104 (SE = 71)
Donnelly Training Area West	0.000 (SE = 0.004)	0.000 (SE = 0.000)	0 (SE = 0)
Total			12,478 (SE = 6,494)
2016			
Tanana Flats Training Area River	0.471 (SE = 0.100)	0.029 (SE = 0.006)	265 (SE = 56)
Tanana Flats Training Area Lowland	0.385 (SE = 0.059)	0.024 (SE = 0.004)	4,494 (SE = 689)
Donnelly Training Area East	0.667 (SE = 0.136)	0.042 (SE = 0.008)	646 (SE = 132)
Donnelly Training Area West	0.034 (SE = 0.006)	0.002 (SE = 0.000)	343 (SE = 59)
Total			5,748 (SE = 936)

Table 2.10. The variation in Lesser Yellowlegs abundance (σ^2) explained by each habitat covariate and corresponding standard errors (SE) are presented from variance components analysis in Program MARK. Beta (β) estimates explain relationships between abundance and habitat covariates. Upper and lower 95% confidence limits (CL) presented. Variance explained by percent water on plot and elevation is negative and designated with a "*".

Habitat Covariate	**σ^2**	**Lower 95% CL**	**Upper 95% CL**	**β**	**SE**	**Percent Variance Explained**
Intercept Model	3.823	2.095	8.867	3.137	0.513	--
Distance to Wetland	3.045	1.644	7.280	-0.003	0.001	20.371
Percent Scrub Canopy	3.470	1.884	8.214	-0.032	0.019	9.249
Habitat	3.573	1.866	8.960			6.554
Forest				0.767	1.802	
Scrub				-1.406	1.460	
Percent Water on Plot	3.930	2.144	9.266	0.049	0.067	*
Elevation	4.001	2.165	9.532	-0.002	0.004	*

Table 2.11. Model selection results for Wilson’s Snipe models of detection probability (p) and abundance (N). I relied upon Akaike’s Information Criterion (with a small sample size correction) for model selection and used cumulative variable weights (w_i) and ΔAIC_c to identify most important covariates. Bolded model is top model from which abundance estimates (N) were derived.

Model	**AIC_c**	**ΔAIC_c**	**AIC_c Weights**	**Model Likelihood**	**Num. Parameters**	**Deviance**
p (distance to wetland) **N (plot)**	**4326.597**	**0.000**	**0.208**	**1.000**	**4**	**4318.404**
p (distance to wetland + elevation) N (plot)	4327.247	0.649	0.151	0.723	5	4316.955
p (distance to wetland) N (plot)	4328.521	1.923	0.080	0.382	3	4322.405
p (habitat + distance to wetland + percent scrub canopy) N (plot)	4328.644	2.047	0.075	0.359	5	4318.353
p (habitat + distance to wetland + percent water on plot) N (plot)	4328.691	2.093	0.073	0.351	5	4318.399
p (habitat + distance to wetland + percent scrub canopy + distance to wetland) N (plot)	4329.215	2.618	0.056	0.270	6	4316.806
p (distance to wetland + elevation) N (plot)	4329.229	2.632	0.056	0.268	4	4321.036
p (habitat + distance to wetland + elevation + percent water on plot) N (plot)	4329.258	2.661	0.055	0.264	6	4316.848
p (habitat)	4329.622	3.025	0.046	0.220	3	4323.507

N (plot)						
p (percent scrub canopy + distance to wetland) N (plot)	4330.268	3.671	0.033	0.160	4	4322.075
p (percent water on plot + distance to wetland) N (plot)	4330.596	3.999	0.028	0.135	4	4322.403
p (percent scrub canopy + elevation + distance to wetland) N (plot)	4331.041	4.444	0.023	0.108	5	4320.750
p (percent water on plot + elevation + distance to wetland) N (plot)	4331.237	4.640	0.020	0.098	5	4320.946

Table 2.12. Wilson’s Snipe abundance estimates for 2016 and 2017 on military lands in interior Alaska.

Year and Strata	Average Number per Plot	Average Density (per ha)	Total Abundance
2017			
Tanana Flats Training Area River	1.845 (SE = 0.085)	0.115 (SE = 0.005)	1,040 (SE = 79)
Tanana Flats Training Area Lowland	1.494 (SE = 0.059)	0.093 (SE = 0.004)	17,456 (SE = 5,319)
Donnelly Training Area East	0.353 (SE = 0.011)	0.022 (SE = 0.001)	342 (SE = 276)
Donnelly Training Area West	0.221 (SE = 0.004)	0.014 (SE = 0.004)	2,198 (SE = 504)
Total			21,036 (SE = 6,178)
2016			
Tanana Flats Training Area River	1.336 (SE = 0.128)	0.083 (SE = 0.008)	753 (SE = 160)
Tanana Flats Training Area Lowland	0.318 (SE = 0.068)	0.020 (SE = 0.004)	3,710 (SE = 1,419)
Donnelly Training Area East	0.000 (SE = 0.000)	0.000 (SE = 0.000)	0 (SE = 0)
Donnelly Training Area West	0.143 (SE = 0.018)	0.009 (SE = 0.001)	1,418 (SE = 910)
Total			5,881 (SE = 2,489)

Table 2.13. The variation in Wilson's Snipe abundance (σ^2) explained by each habitat covariate and corresponding standard errors (SE) are presented from variance components analysis in Program MARK. Beta (β) estimates explain relationships between abundance and habitat covariates. Upper and lower 95% confidence limits (CL) presented. Variance explained by distance to wetland is negative and designated with a "*".

Habitat Covariate	**σ^2**	**Lower 95% CL**	**Upper 95% CL**	**β**	**SE**	**Percent Variance Explained**
Intercept Model	5.310	4.707	11.858	2.704	0.384	--
Percent Water on Plot	5.100	3.312	8.717	0.033	0.021	3.960
Percent Scrub Canopy	5.248	3.395	9.021	-0.016	0.013	1.171
Habitat	5.306	3.423	9.177			0.086
Forest				1.393	1.034	
Scrub				1.129	0.960	
Elevation	5.193	3.368	8.903	-0.002	0.001	2.208
Distance to Wetland	5.421	3.521	9.272	0.006	0.012	*

Table 2.14. Model selection results for all lowland shorebird models of detection probability (p) and abundance (N). I relied upon Akaike's Information Criterion (with a small sample size correction) for model selection and used cumulative variable weights (w_i) and ΔAIC_c to identify most important covariates. Bolded model is top model from which abundance estimates (N) were derived. All models with Δ $AIC_c < 5$ presented.

Model	AIC_c	ΔAIC_c	AIC_c Weights	Model Likelihood	Num. Parameters	Deviance
p (elevation + habitat + distance to wetland) **N (plot)**	**144.237**	**0.000**	**0.163**	**1.000**	**6**	**132.012**
p (elevation + distance to wetland) N (plot)	144.937	0.699	0.115	0.704	4	136.830
p (elevation + habitat + distance to wetland + percent scrub habitat) N (plot)	145.868	1.631	0.072	0.442	7	131.567
p (elevation + habitat + percent water on plot + distance to wetland) N (plot)	146.146	1.908	0.063	0.385	7	131.845
p (habitat + distance to wetland) N (plot)	146.236	1.998	0.060	0.368	5	136.076
p (elevation + percent scrub canopy + distance to wetland) N (plot)	146.497	2.259	0.052	0.323	5	136.336
p (distance to wetland) N (plot)	146.740	2.502	0.046	0.286	3	140.676
p (elevation + percent water on plot + distance to wetland)	146.925	2.687	0.042	0.260	5	136.764

N (plot)						
p (elevation + habitat) N (plot)	147.310	3.076	0.035	0.214	5	137.153
p (elevation) N (plot)	147.499	3.262	0.032	0.195	3	141.436
p (habitat) N (plot)	147.644	3.406	0.029	0.182	4	139.537
p (elevation + habitat + percent scrub canopy + percent water on plot + distance to wetland) N (plot)	147.863	3.626	0.026	0.163	8	131.475
p (.) N (plot)	148.174	3.936	0.022	0.139	2	144.142
p (habitat + percent scrub canopy + distance to wetland) N (plot)	148.218	3.980	0.022	0.136	6	135.997
p (habitat + percent water on plot + distance to wetland) N (plot)	148.293	4.055	0.021	0.131	6	136.068
p (percent scrub canopy + distance to wetland) N (plot)	148.501	4.263	0.019	0.118	4	140.394
p (elevation + percent scrub canopy + percent water on plot + distance to wetland) N (plot)	148.543	4.305	0.019	0.116	6	136.318

p (percent water on plot + distance to wetland) N (plot)	148.713	4.475	0.017	0.106	4	140.606
p (elevation + percent scrub canopy) N (plot)	149.001	4.763	0.015	0.092	4	140.895
p (elevation + habitat + percent scrub canopy) N (plot)	149.015	4.778	0.015	0.091	6	136.790

Table 2.15. Lowland shorebird abundance estimates for 2016 and 2017 on military lands in interior Alaska.

Year and Strata	Average Number per Plot	Average Density (per ha)	Total Abundance
2017			
Tanana Flats Training Area River	3.369 (SE = 0.184)	0.211 (SE = 0.011)	1,900 (SE = 135)
Tanana Flats Training Area Lowland	3.097 (SE = 0.106)	0.194 (SE = 0.007)	36,192 (SE = 13,005)
Donnelly Training Area East	0.526 (SE = 0.034)	0.033 (SE = 0.002)	510 (SE = 112)
Donnelly Training Area West	0.366 (SE = 0.024)	0.023 (SE = 0.002)	3,637 (SE = 179)
Total			42,239 (SE= 13,431)
2016			
Tanana Flats Training Area River	2.375 (SE = 0.204)	0.148 (SE = 0.013)	1,339 (SE = 104)
Tanana Flats Training Area Lowland	0.700 (SE = 0.080)	0.044 (SE = 0.005)	8,183 (SE = 1,117)
Donnelly Training Area East	0.719 (SE = 0.146)	0.045 (SE = 0.009)	697 (SE = 74)
Donnelly Training Area West	0.209 (SE = 0.019)	0.013 (SE = 0.001)	2,079 (SE = 559)
Total			12,298 (SE = 1,854)

Table 2.16. The variation in all lowland shorebird abundance (σ^2) explained by each habitat covariate and corresponding standard errors (SE) are presented from variance components analysis in Program MARK. Beta (β) estimates explain relationships between abundance and habitat covariates. Upper and lower 95% confidence limits (CL) presented. Variance explained by distance to wetland and habitat is negative and designated with a “*”.

Habitat Covariate	**σ^2**	**Lower 95% CL**	**Upper 95% CL**	**β**	**SE**	**Percent Variance Explained**
Intercept Model	9.615	6.560	15.252	3.966	0.462	--
Elevation	9.097	6.243	14.361	-0.003	0.001	5.388
Percent Scrub Canopy	9.161	6.291	14.453	-0.030	0.016	4.724
Percent Water on Plot	9.605	6.600	15.147	0.024	0.021	0.100
Distance to Wetland	9.750	6.691	15.398	-0.003	0.003	*
Habitat	9.888	6.768	15.681			*
Forest				1.014	1.290	
Scrub				1.184	1.200	

Table 2.17. Upland shorebird abundance estimates for 2016 and 2017 on military lands in interior Alaska.

Year and Strata	Average Number per Plot	Average Density (per ha)	Total Abundance
2017			
Tanana Flats Training Area River	0.000 (SE = 0.000)	0.000 (SE = 0.000)	0 (SE = 0)
Tanana Flats Training Area Lowland	0.061 (SE = 0.007)	0.004 (SE = 0.000)	712 (SE = 183)
Donnelly Training Area East	0.146 (SE = 0.011)	0.009 (SE = 0.001)	142 (SE = 24)
Donnelly Training Area West	0.269 (SE = 0.019)	0.017 (SE = 0.001)	2,669 (SE = 287)
Total			3,523 (SE = 494)
2016			
Tanana Flats Training Area River	0.176 (SE = 0.031)	0.011 (SE = 0.002)	100 (SE = 17)
Tanana Flats Training Area Lowland	0.000 (SE = 0.000)	0.000 (SE = 0.000)	0 (SE = 0)
Donnelly Training Area East	0.000 (SE = 0.010)	0.000 (SE = 0.001)	0 (SE = 0)
Donnelly Training Area West	0.172 (SE = 0.025)	0.011 (SE = 0.002)	1,713 (SE = 248)
Total			1,813 (SE = 265)

Table 2.18. The variation in all upland shorebird abundance (σ^2) explained by each habitat covariate and corresponding standard errors (SE) are presented from variance components analysis in Program MARK. Beta (β) estimates explain relationships between abundance and habitat covariates. Upper and lower 95% confidence limits (CL) presented. Variance explained by percent scrub canopy cover, percent water on plot, and habitat is negative and designated with a "*".

Habitat Covariate	**σ^2**	**Lower 95% CL**	**Upper 95% CL**	**β**	**SE**	**Percent Variance Explained**
Intercept Model	1.119	0.522	3.759	1.702	0.336	--
Elevation	0.973	0.438	3.602	0.002	0.001	13.008
Distance to Wetland	1.064	0.478	3.940	0.001	0.001	4.947
Percent Scrub Canopy	1.131	0.561	4.606	-0.004	0.014	*
Percent Water on Plot	1.131	0.561	4.606	-0.004	0.014	*
Habitat	1.131	0.561	4.606	-0.004	0.014	*
Forest				-0.998	0.923	
Scrub				-0.248	0.754	

Table 2.19. Lowland shorebird density and plot size calculations.

Strata	Average Density (per ha)	Extrapolated Plot Level Abundance 500 by 500 m plot	Extrapolated Plot Level Abundance 600 by 600 m plot	Extrapolated Plot Level Abundance 700 by 700 m plot
Tanana Flats Training Area River	0.211 (SE = 0.011)	5.275 (SE = 0.275)	7.596 (SE = 0.396)	10.339 (SE = 0.539)
Tanana Flats Training Area Lowland	0.194 (SE = 0.007)	4.850 (SE = 0.175)	6.984 (SE = 0.252)	9.506 (SE = 0.343)
Donnelly Training Area East	0.033 (SE = 0.002)	0.825 (SE = 0.050)	1.188 (SE = 0.721)	1.617 (SE = 0.098)
Donnelly Training Area West	0.023 (SE = 0.002)	0.575 (SE = 0.050)	0.828 (SE = 0.720	1.127 (SE = 0.098)

Table 2.20. Sample size calculations using data from 2017 surveys. Listed are number of plots required to achieve desired coefficient of variation (CV).

CV	400 by 400 m plots
0.30	160
0.25	230
0.20	360
0.15	640
0.10	1,441

Figures

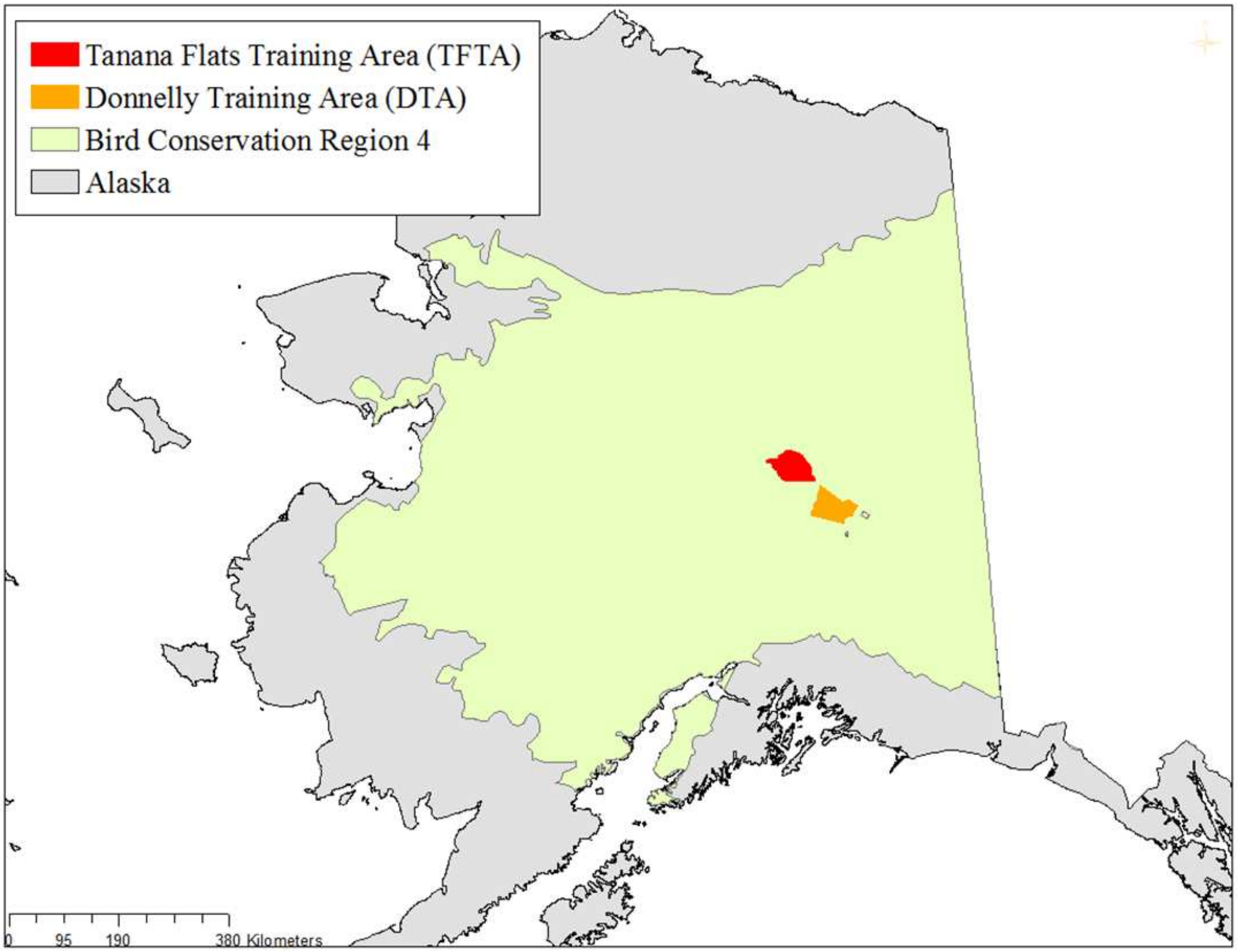

Figure 2.1. Study area within Alaska and Bird Conservation Region 4.

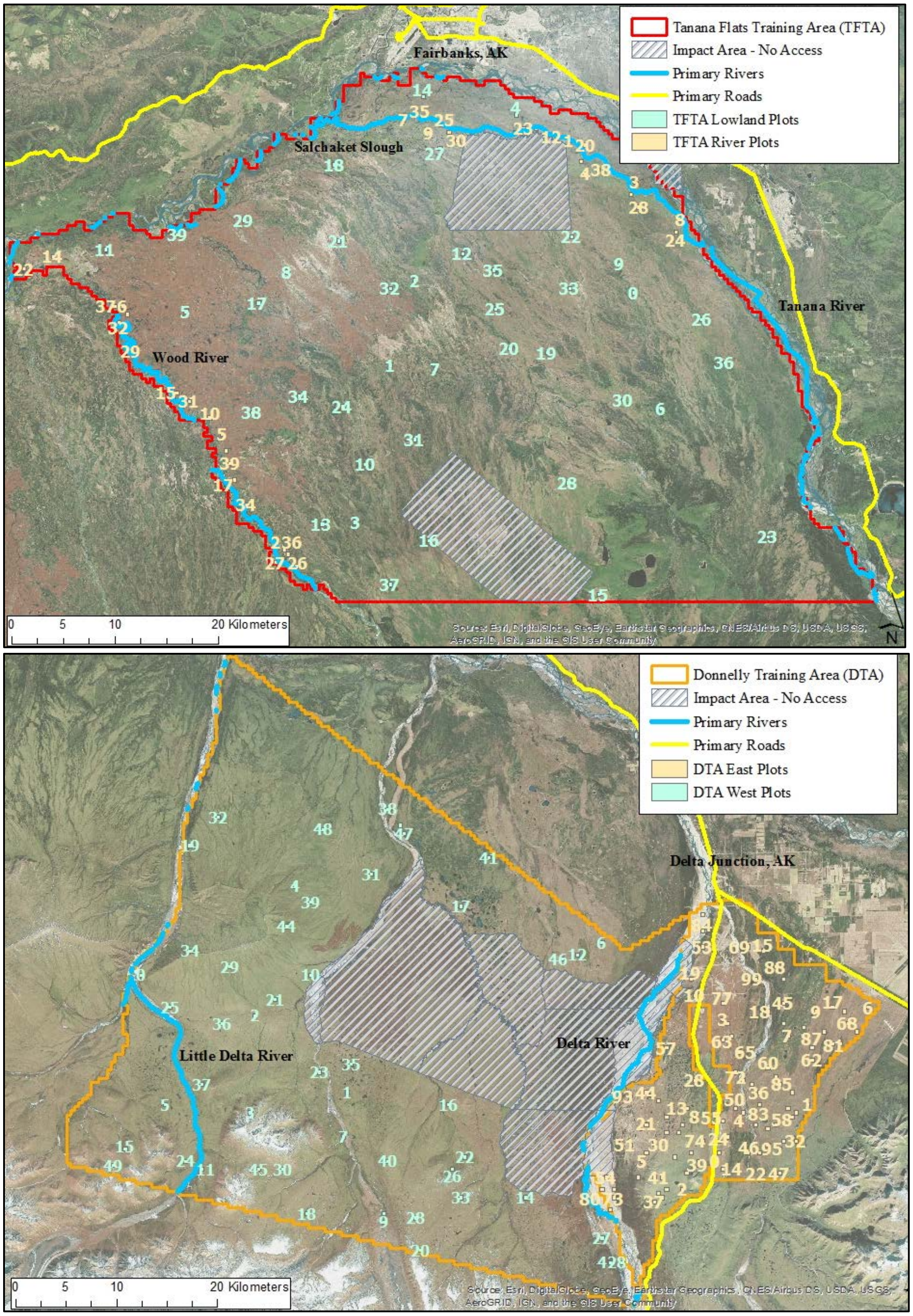

Figure 2.2. Tanana Flats Training Area (TFTA) Lowlands, TFTA River, Donnelly Training Area (DTA) East, and DTA West strata spatially balanced plots. Plots were visited in ascending order beginning with the lowest number. Using the spatially balanced sampling tool, I randomly chose 400 by 400 m plots separately within each of the four strata, shown as different colored plots in map.

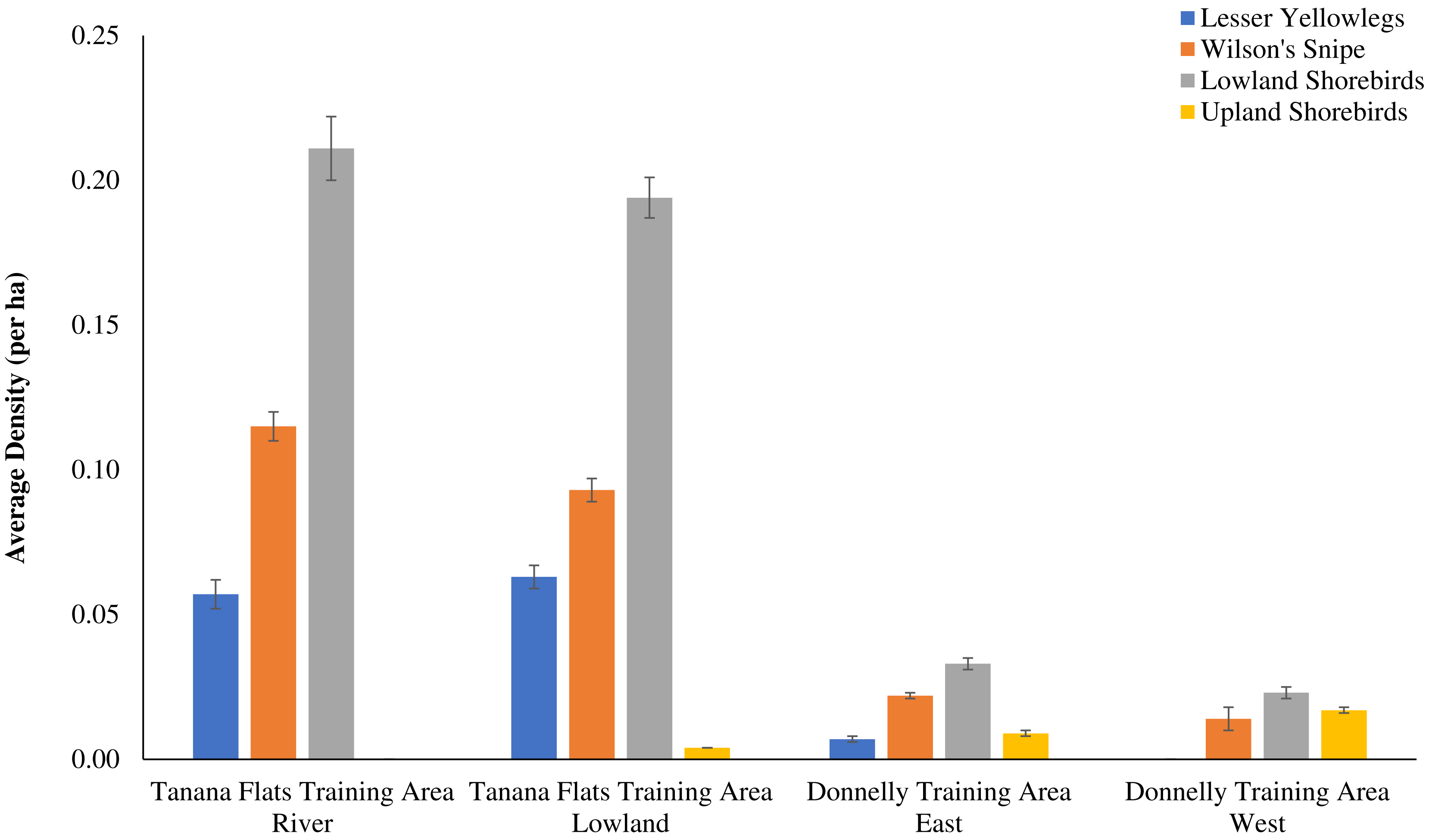

Figure 2.3. Estimated shorebird density by strata. Highest densities of birds occurred on Tanana Flats Training Area Lowland and River strata. Lowest densities of birds were on Donnelly Training Area East and West strata.

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Appendix 1a Table 1.1. Plot vegetation data codes, and descriptions, collected during plot surveys.

Covariate	**Description**
Radius:	50m from center of plot
Plot_Num	Shorebird Plot Number
Date	In Month, Day, Year format (MMDDYYYY)
Time	Time, 24 hour
Observers	Initials of all observers
Photo N, E, S, W	Photo taken with iPad of habitat in each cardinal direction
Viereck (IV level)	Fourth level Viereck, dominant habitat type within 50m radius plot
Percent_Plot	Percent of plot the Viereck code represents (out of 100% of entire 400 m by 400 m plot)
Percent water on plot	Percent of the entire plot which has open water (defined as > 5 m in diameter)
Open_Water	Percent open water within 50m radius
Tree_Canopy	Percent tree canopy within 50m radius
Scrub_Canopy	Percent scrub canopy within 50m radius
Bare_Ground	Percent bare ground within 50m radius
Geomorph	Geomorphology: Wet, Mesic, Dry
Elevation	In meters, taken from GIS or elevation given on iPad
Slope_Deg	Slope in degrees from center point. Use compass.
Aspect	Direction slope is angled N,E,S,W
Special Features	Note any other interesting features within survey area
CoverClass_1	Most dominant 3rd level Viereck in entire plot
Pct_Cov_1	Percent of most dominant cover class (CoverClass_1) for entire plot
CoverClass_2	Second most dominant III level Viereck in entire plot
Pct_Cov_2	Percent of second dominant cover class (CoverClass_2) for entire plot
CoverClass_3	Third most dominant III level Viereck in entire plot
Pct_Cov_3	Percent of third dominant cover class (CoverClass_3) for entire plot
Notes	Any additional comments

Appendix 1a Table 1.2. Distribution of plots sampled in 2017 and sizes of the 4 strata on military lands in interior Alaska that formed the sampling frame to estimate shorebird use.

Stratum	**Stratum Area (hectares)**	**Area Sampled (hectares)**	**Total Quadrats in Training Area**	**Quadrats Sampled 2017**
Tanana Flats Training Area River	9,023	320	563	20
Tanana Flats Training Area Lowlands	186,947	528	11,684	33
Donnelly Training Area East	15,503	768	968	48
Donnelly Training Area West	158,947	656	9,934	41

Appendix 2a Table 2.1. Plot vegetation data codes, and descriptions, collected during plot surveys.

Covariate	**Description**
Radius:	50m from center of plot
Plot_Num	Shorebird Plot Number
Date	In Month, Day, Year format (MMDDYYYY)
Time	Time, 24 hour
Observers	Initials of all observers
Photo N, E, S, W	Photo taken with iPad of habitat in each cardinal direction
Viereck (IV level)	Fourth level Viereck, dominant habitat type within 50m radius plot
Percent_Plot	Percent of plot the Viereck code represents (out of 100% of entire 400 m by 400 m plot)
Percent water on plot	Percent of the entire plot which has open water (defined as > 5 m in diameter)
Open_Water	Percent open water within 50m radius
Tree_Canopy	Percent tree canopy within 50m radius
Scrub_Canopy	Percent scrub canopy within 50m radius
Bare_Ground	Percent bare ground within 50m radius
Geomorph	Geomorphology: Wet, Mesic, Dry
Elevation	In meters, taken from GIS or elevation given on iPad
Slope_Deg	Slope in degrees from center point. Use compass.
Aspect	Direction slope is angled N,E,S,W
Special Features	Note any other interesting features within survey area
CoverClass_1	Most dominant 3rd level Viereck in entire plot
Pct_Cov_1	Percent of most dominant cover class (CoverClass_1) for entire plot
CoverClass_2	Second most dominant III level Viereck in entire plot
Pct_Cov_2	Percent of second dominant cover class (CoverClass_2) for entire plot
CoverClass_3	Third most dominant III level Viereck in entire plot
Pct_Cov_3	Percent of third dominant cover class (CoverClass_3) for entire plot
Notes	Any additional comments

Appendix 2a Table 2.2. Plot-level abundance estimates generated under the highest-ranking model for detection probability for Lesser Yellowlegs. Derived abundances are shrinkage estimates. There were an additional 123 plots with zero birds.

Plot	Derived Abundance	Standard Error
Tanana Flats Training Area River Plot 2	2.690	1.765
Tanana Flats Training Area River Plot 13	1.001	0.033
Tanana Flats Training Area River Plot 18	1.003	0.061
Tanana Flats Training Area River Plot 22	4.002	0.065
Tanana Flats Training Area River Plot 30	4.002	0.065
Tanana Flats Training Area River Plot 32	3.594	1.959
Tanana Flats Training Area Lowland Plot 0	4.501	1.587
Tanana Flats Training Area Lowland Plot 1	3.810	1.961
Tanana Flats Training Area Lowland Plot 3	1.003	0.061
Tanana Flats Training Area Lowland Plot 5	4.019	0.230
Tanana Flats Training Area Lowland Plot 7	6.999	0.308
Tanana Flats Training Area Lowland Plot 12	1.003	0.061
Tanana Flats Training Area Lowland Plot 13	1.001	0.033
Tanana Flats Training Area Lowland Plot 14	1.003	0.061
Tanana Flats Training Area Lowland Plot 24	6.005	0.152
Tanana Flats Training Area Lowland Plot 27	5.163	1.272
Tanana Flats Training Area Lowland Plot 34	6.002	0.080
Donnelly Training Area East Plot 21	2.129	0.513
Donnelly Training Area East Plot 38	3.007	0.107

Appendix 2a Table 2.3. Plot-level abundance estimates generated under the highest-ranking model for detection probability for Wilson's Snipe. Derived abundances are shrinkage estimates. There were an additional 102 plots with zero birds.

Plot	Derived Abundance	Standard Error
Tanana Flats Training Area River Plot 1	1.008	0.099
Tanana Flats Training Area River Plot 2	4.022	0.202
Tanana Flats Training Area River Plot 9	7.019	0.274
Tanana Flats Training Area River Plot 10	5.023	0.228
Tanana Flats Training Area River Plot 11	1.008	0.099
Tanana Flats Training Area River Plot 13	3.060	0.286
Tanana Flats Training Area River Plot 16	1.000	0.000
Tanana Flats Training Area River Plot 19	1.008	0.099
Tanana Flats Training Area River Plot 22	1.000	0.000
Tanana Flats Training Area River Plot 30	5.000	0.000
Tanana Flats Training Area River Plot 32	4.070	0.333
Tanana Flats Training Area Lowlands Plot 0	3.019	0.174
Tanana Flats Training Area Lowlands Plot 1	4.643	4.098
Tanana Flats Training Area Lowlands Plot 2	1.000	0.000
Tanana Flats Training Area Lowlands Plot 4	4.288	1.881
Tanana Flats Training Area Lowlands Plot 5	4.022	0.202
Tanana Flats Training Area Lowlands Plot 7	3.060	0.286
Tanana Flats Training Area Lowlands Plot 8	10.029	0.586
Tanana Flats Training Area Lowlands Plot 9	1.025	0.163
Tanana Flats Training Area Lowlands Plot 10	2.045	0.232
Tanana Flats Training Area Lowlands Plot 11	1.000	0.000
Tanana Flats Training Area Lowlands Plot 12	2.045	0.232
Tanana Flats Training Area Lowlands Plot 20	1.000	0.000
Tanana Flats Training Area Lowlands Plot 21	6.022	0.251
Tanana Flats Training Area Lowlands Plot 24	4.070	0.333
Tanana Flats Training Area Lowlands Plot 29	1.025	0.163
Tanana Flats Training Area Lowlands Plot 30	1.008	0.099
Donnelly Training Area East Plot 5	1.032	0.190
Donnelly Training Area East Plot 21	2.045	0.232
Donnelly Training Area East Plot 24	9.048	0.542
Donnelly Training Area East Plot 27	2.080	2.873
Donnelly Training Area East Plot 38	1.025	0.163
Donnelly Training Area East Plot 89	1.008	0.099
Donnelly Training Area West Plot 11	2.000	0.000
Donnelly Training Area West Plot 24	1.000	0.000
Donnelly Training Area West Plot 28	3.000	0.000
Donnelly Training Area West Plot 30	1.025	0.163
Donnelly Training Area West Plot 45	1.025	0.163
Donnelly Training Area West Plot 46	1.025	0.163

Appendix 2a Table 2.4. Plot-level abundance estimates generated under the highest-ranking model for detection probability for all lowland shorebirds. Derived abundances are shrinkage estimates. There were an additional 92 plots with zero birds.

Plot	Derived Abundance	Standard Error
Tanana Flats Training Area River Plot 1	2.017	0.151
Tanana Flats Training Area River Plot 2	5.029	0.221
Tanana Flats Training Area River Plot 7	2.019	0.162
Tanana Flats Training Area River Plot 9	7.041	0.311
Tanana Flats Training Area River Plot 10	5.034	0.247
Tanana Flats Training Area River Plot 11	3.020	0.165
Tanana Flats Training Area River Plot 13	7.187	0.616
Tanana Flats Training Area River Plot 16	3.004	0.063
Tanana Flats Training Area River Plot 18	1.049	0.245
Tanana Flats Training Area River Plot 19	1.010	0.113
Tanana Flats Training Area River Plot 22	5.006	0.083
Tanana Flats Training Area River Plot 30	10.009	0.118
Tanana Flats Training Area River Plot 32	9.222	0.824
Tanana Flats Training Area Lowlands Plot 0	8.037	0.301
Tanana Flats Training Area Lowlands Plot 1	7.387	3.875
Tanana Flats Training Area Lowlands Plot 2	1.002	0.039
Tanana Flats Training Area Lowlands Plot 3	2.908	2.860
Tanana Flats Training Area Lowlands Plot 4	4.947	2.033
Tanana Flats Training Area Lowlands Plot 5	8.042	0.333
Tanana Flats Training Area Lowlands Plot 7	10.197	0.793
Tanana Flats Training Area Lowlands Plot 8	11.201	0.926
Tanana Flats Training Area Lowlands Plot 9	1.043	0.224
Tanana Flats Training Area Lowlands Plot 10	2.076	0.308
Tanana Flats Training Area Lowlands Plot 11	1.002	0.040
Tanana Flats Training Area Lowlands Plot 12	3.121	0.413
Tanana Flats Training Area Lowlands Plot 13	4.716	27.368
Tanana Flats Training Area Lowlands Plot 14	3.850	5.596
Tanana Flats Training Area Lowlands Plot 19	1.041	0.217
Tanana Flats Training Area Lowlands Plot 20	1.001	0.035
Tanana Flats Training Area Lowlands Plot 21	6.039	0.283
Tanana Flats Training Area Lowlands Plot 24	10.191	0.763
Tanana Flats Training Area Lowlands Plot 27	5.175	0.549
Tanana Flats Training Area Lowlands Plot 29	1.050	0.246
Tanana Flats Training Area Lowlands Plot 30	1.008	0.098
Tanana Flats Training Area Lowlands Plot 34	6.178	0.571
Donnelly Training Area East Plot 5	1.004	0.054
Donnelly Training Area East Plot 21	6.031	0.178
Donnelly Training Area East Plot 23	2.045	0.259
Donnelly Training Area East Plot 24	9.031	0.189
Donnelly Training Area East Plot 27	1.136	0.474
Donnelly Training Area East Plot 38	4.016	0.117

Donnelly Training Area East Plot 57	1.002	0.043
Donnelly Training Area East Plot 89	1.001	0.028
Donnelly Training Area West Plot 7	4.001	0.033
Donnelly Training Area West Plot 11	4.000	0.007
Donnelly Training Area West Plot 24	1.000	0.003
Donnelly Training Area West Plot 28	3.000	0.003
Donnelly Training Area West Plot 30	1.000	0.007
Donnelly Training Area West Plot 45	1.000	0.009
Donnelly Training Area West Plot 46	1.011	0.100

Appendix 2a Table 2.5. Plot-level abundance estimates generated under the highest-ranking model for detection probability for all upland shorebirds. Derived abundances are shrinkage estimates. There were an additional 132 plots with zero birds.

Plot	Derived Abundance	Standard Error
Tanana Flats Training Area Lowlands Plot 0	1.005	0.063
Tanana Flats Training Area Lowlands Plot 15	1.005	0.064
Donnelly Training Area East Plot 41	3.004	0.111
Donnelly Training Area East Plot 49	1.005	0.064
Donnelly Training Area East Plot 58	2.006	0.090
Donnelly Training Area East Plot 89	1.005	0.064
Donnelly Training Area West Plot 2	1.005	0.064
Donnelly Training Area West Plot 3	1.005	0.064
Donnelly Training Area West Plot 28	3.998	0.130
Donnelly Training Area West Plot 33	2.006	0.090