2010 report: Development of Shorebird Distribution Maps for the North Slope of Alaska Using Geospatial Habitat Modeling: The First Step in Assessing Effects of Climate Change

Sarah T. Saalfeld
Manomet Center for Conservation Sciences, U.S. Fish and Wildlife Service, Migratory Bird Management

David T. Saalfeld
Manomet Center for Conservation Sciences, U.S. Fish and Wildlife Service, Migratory Bird Management

Richard B. Lanctot
U.S. Fish and Wildlife Service, Migratory Bird Management

and

Stephen Brown
Manomet Center for Conservation Sciences

A collaborative project with the
Arctic Landscape Conservation Cooperative

31 July 2011

Abstract

To determine the potential effects of climate change and development on Arctic-breeding shorebirds, we developed geospatial predictive models for nine species of breeding shorebirds throughout the Arctic Coastal Plain of Alaska (American Golden-Plover [*Pluvialis dominica*], Black-bellied Plover [*Pluvialis squatarola*], Dunlin [*Calidris alpina*], Long-billed Dowitcher [*Limnodromus scolopaceus*], Pectoral Sandpiper [*Calidris melanotos*], Red Phalarope [*Phalaropus fulicarius*], Red-necked Phalarope [*Phalaropus lobatus*], Semipalmated Sandpiper [*Calidris pusilla*], and Stilt Sandpiper [*Calidris himantopus*]). To develop these models, we assembled authoritative, spatially linked (GIS) databases on shorebird presence/absence, density, and species richness from 534 sites surveyed as part of the Program for Regional and International Shorebird Monitoring (PRISM) between 1998 and 2008. We identified and acquired spatially linked (GIS) databases representing priority physical and ecological variables that are biologically meaningful to shorebird presence/absence, density, and species richness. We developed statistical modeling approaches to determine associations between presence/absence, density, and species richness of shorebird species, and these physical and ecological variables. Currently, we are using the above products to develop species-specific predictive models and assess the predictive performance of the top-ranked models. Generation of these predictive maps will allow us to identify critical conservation areas across the Arctic Coastal Plain. Future work will focus upon comparing selection patterns of shorebird species, comparing predictability and accuracy of predictive models to assess differences in modeling performance based upon different response variables (e.g., presence/absence, density, species richness), and predicting changes in shorebird species distributions using currently developed climate change and development scenarios.

Citation: Saalfeld, S. T., D. T. Saalfeld, R. B. Lanctot, and S. Brown. 2011. 2010 report: Development of Shorebird Distribution Maps for the North Slope of Alaska Using Geospatial Habitat Modeling: The First Step in Assessing Effects of Climate Change. Unpublished report by the U.S. Fish and Wildlife Service and Manomet Center for Conservation Sciences to the Arctic Landscape Conservation Cooperative. U.S. Fish and Wildlife Service, Anchorage, AK.

Table of Contents

Abstract 1
Background 3
Goal and Objectives 4
Methods 5
PRISM Surveys 5
Spatially Linked (GIS) Database of General Shorebird Detections within Plots 7
Spatially Linked (GIS) Database of Shorebird Point Locations 8
Priority Physical and Ecological Variables 8
Identification and Acquisition of Priority Physical and Ecological Variables 8
Development of Additional Physical and Ecological Variables 12
Data Extraction and Review of Physical and Ecological Variables 13
Model Development and Statistical Analysis 13
Results and Discussion 13
Spatially Linked (GIS) Database of General Shorebird Detections within Plots 13
Spatially Linked (GIS) Database of Shorebird Point Locations 21
Priority Physical and Ecological Variables 22
Model Development and Statistical Analysis Results 23
Other Accomplishments 27
Relevance to Arctic LCC Conservation Goals: 27
Fund Expenditures 28
The Future 28
Acknowledgements 28
Literature Cited 29

Background

The Arctic Coastal Plain of Alaska (hereafter Coastal Plain) provides important habitat for millions of nesting and migrating shorebirds (Johnson and Herter 1989), with at least 29 species documented breeding within this region (King 1979). However, numerous shorebird species, including those that nest within the Coastal Plain have exhibited population declines in recent years (Brown et al. 2001; Morrison et al. 2006; Bart et al. 2007), with nearly a quarter of the world's shorebird species in danger of extinction (Piersma et al. 1997). Of the shorebird species that occur within the Coastal Plain, population declines have been documented for 11 species, 9 of which are considered species of high conservation concern or are highly imperiled on a global scale (U.S. Shorebird Conservation Plan 2004). Although many populations of shorebirds that breed on the Coastal Plain are in decline, declines have been attributed to factors occurring off the breeding grounds, mainly habitat loss and degradation in wintering and stop over locations (Brown et al. 2001). As much of the Coastal Plain remains undeveloped, threats to nesting and migrating shorebirds within this region have been limited (Brown et al. 2001). However, increased development within the Coastal Plain, as well as the effects of climate change could have serious negative impacts on currently declining shorebird populations in the near future.

More so than any other region, the Arctic has experienced the effects of climate change in recent years, with warming rates almost twice the global average (Arctic Climate Impact Assessment 2004). Additionally, current projection models for the Coastal Plain predict a 1.6°C increase in summer temperatures and 12% increase in summer precipitation by mid-century (i.e., 2051 to 2060; Martin et al. 2009). By mid-century, warmer temperatures are expected to lengthen the frost-free season by 18 days, primarily due to delayed onset of freezing in the fall (Martin et al. 2009). Sea levels are also projected to rise 0.18 – 0.59 m by the end of the 21st century (IPCC 2007). These climate-mediated changes are likely to have profound impacts on physical and ecological variables (e.g., surface water, vegetation community, insect community, etc.) affecting both shorebird habitats and populations on the Coastal Plain. For example, higher summer temperatures and a longer frost-free season are predicted to increase evapotranspiration rates, resulting in a 10 – 16% drier landscape by mid-century (Martin et al. 2009). Higher summer temperatures and a longer frost-free season are also predicted to accelerate ice wedge degradation and thermokarst pond development, leading to increased surface water (Shur et al. 2003). Vegetation communities will also likely be affected by climate-mediated changes, including the northward expansion of shrubs (Sturm et al. 2001; Arctic Climate Impact Assessment 2004). Additionally, sea level rise is predicted to increase erosion rates, sedimentation, flooding, and salinization of low-lying habitats (Jorgenson and Ely 2001; Martin et al. 2009). These changes in physical and ecological variables have the potential to dramatically shape shorebird habitats and ultimately population distributions.

Along with climate-mediated effects on shorebirds, increased human development could have a direct negative impact on shorebird populations and breeding habitat within the Coastal Plain in the near future. Along with new and expanding native villages; mineral, oil, and natural gas production in the Coastal Plain has expanded in recent years (Gilders and Cronin 2000; National Research Council 2003), and will likely continue to expand in the near future. Potential negative effects of development on shorebird species include the direct loss of habitat through the building of roads, drilling pads, pipelines, dumps, gravel pits, and other infrastructure (Meehan 1986). Along with direct habitat loss, numerous indirect effects of development have also been documented. For example, indirect effects of roads and drilling pads include increased levels of dust, altered hydrology, thawing of permafrost, and increased roadside snow accumulation (Auerbach et al. 1997; National Research Council 2003). Furthermore, development may enhance predator populations by

providing denning and nesting sites, perch sites, and supplemental food (e.g., human garbage; National Research Council 2003; Liebezeit et al. 2009). Therefore, indirect effects of development could have a profound effect on habitat quantity and quality for nesting shorebirds (Meehan 1986; Auerbach et al. 1997), likely making the negative impacts of development much greater than predicted simply due to direct habitat loss.

The first step to evaluating the potential impacts of climate-mediated changes and development on shorebird species within the Coastal Plain is to document the current distribution of shorebirds and determine habitat selection patterns of shorebirds within this region. Unfortunately, the contemporary distribution as well as habitat associations of shorebirds on the Coastal Plain is poorly known and only coarsely defined. For example, current distributions come from maps developed by The Nature Conservancy using U.S. Fish and Wildlife Service data acquired during waterfowl surveys or from a limited number of ground surveys representing only a small fraction of the entire Coastal Plain (Garner and Reynolds 1986; Johnson et al. 2007). Determining contemporary distributions and detailed, large-scale habitat selection patterns of shorebirds within the Coastal Plain will provide baseline estimates to assess the potential impacts of specific development and climate change scenarios. For example, contemporary distributions will allow the identification of important areas as indicated by greater species richness and/or presence or greater densities of imperiled or at risk shorebird species. Additionally, understanding current habitat selection patterns could allow us to predict shifts in the distribution of shorebird species based upon predicted climate-mediated changes within the Coastal Plain.

Goal and Objectives

To obtain a better understanding of how shorebirds will respond to climate-mediated changes and development in the Coastal Plain, we have begun to develop a series of spatially dependent habitat selection models that will predict the contemporary location, density, and species richness of shorebird species throughout the Coastal Plain. Specifically we:

- Assembled authoritative, spatially linked (GIS) databases on shorebird presence/absence, density, and species richness from 1998 – 2008 Program for Regional and International Shorebird Monitoring (PRISM) surveys.
- Identified priority physical and ecological variables that are biologically meaningful to shorebird presence/absence, density, and species richness.
- Acquired and assembled spatially linked (GIS) databases originating from ground or satellite-based data that depict physical and ecological variables meaningful to shorebird presence/absence, density, and species richness.
- Developed statistical modeling approaches to determine associations between presence/absence, density, and species richness of shorebird species, and physical and ecological variables to predict the contemporary geographic distribution, density, and species richness of shorebird species on the Coastal Plain.

Future goals and objectives include:

- Document the association between the presence/absence, density, and species richness of shorebird species and the spatially linked databases originating from ground or satellite-based data to document the geographic distribution of individual species, species density, and species richness on the Coastal Plain.

- Compare selection patterns of physical and ecological variables among shorebird species on the Coastal Plain.
- Determine the accuracy of predictive models for shorebird presence/absence, density, and species richness.
- Compare predictability and accuracy of predictive models for shorebird presence/absence, density, and species richness to assess differences in model performance based upon different response variables (e.g., presence/absence, density, species richness).
- Predict changes in shorebird species distributions using currently developed climate change and development scenarios.

Methods

PRISM Surveys

PRISM surveys were conducted at randomly and non-randomly selected plots located north of the Brooks Range, between Icy Cape in western Alaska and the Aichilik River near the Canadian Border during 9 years between 1998 and 2008 (surveys not conducted in 2003 and 2005; Figure 1). Over the 9 survey years, specific protocols and regional locations for plot selection varied. In 1998 – 2000, plots were accessed by fixed-winged aircraft or boats within the National Petroleum Reserve-Alaska (NPR-A), and therefore were restricted to within 10 km of accessible areas (e.g., rivers, airstrips, etc.). Prior to plot selection, habitat was stratified into wetland and upland habitat classifications using a land-cover classification derived from Landsat imagery (U.S. Department of the Interior 2002). Plots were then randomly selected, where plot boundaries followed natural borders between wetlands and uplands, resulting in variable plot sizes and shapes. For example, plots classified as wetland varied in size from 2 – 342 ha. However, upland plots were standardized to 9 ha square plots. Unsuitable nesting habitat (e.g., open water, mudflats, etc.) was excluded from all plots.

In 2001, random points were selected within the NPR-A. As helicopters were used to access plots in 2001 – 2008, plots were not restricted to accessible locations. Plots were expanded from the randomly selected point by moving outward in all directions, but remaining within the same habitat category (i.e., wetland or upland, defined using the same land-cover classification as described above; U.S. Department of the Interior 2002), until a plot size of 12 – 21 ha was obtained. If the random point fell within unsuitable habitat, another random point was selected. A second point was also selected within 1 – 3 km from the initial plot. The second plot was delineated similarly to the initial plot, expanding outwards from the point within suitable habitat. When possible, plots were selected so that one wetland and one upland plot were delineated within 1 – 3 km from one another.

In 2002, plot locations were randomly selected within the Arctic National Wildlife Refuge (ANWR) coastal plain and west to the NPR-A border without regard for habitat type. Procedures to select initial starting points and subsequent plot sites were similar to those outlined above for 2001. However, plots were standardized to 16 ha square plots. Because plots were selected without regard to habitat, a large portion of the plots occurred in upland habitat types, where shorebird abundance and species richness was low. Therefore, additional plots were non-randomly selected near the coast, where shorebird abundance was greater.

In 2004, plots locations were located within the ANWR coastal plain. Placement of plots was modified from 2002 to ensure that rarer habitat types, with potentially greater number of birds, were surveyed. Prior to plot selection, four habitat classifications (i.e., riparian, flooded, very wet,

and upland) were defined using composites of the 16 original landcover classifications developed for the ANWR coastal plain by Jorgenson et al. (1994). A grid of 16 ha cells was created over the ANWR coastal plain and the percentage of each habitat class was calculated within. To ensure plots were surveyed throughout the entire ANWR coastal plain, general areas were located by stratifying by latitude and longitude. Grid cells were then randomly selected as the starting plot within each of these general areas. Additionally, two more plots were randomly chosen within 3 – 5 km of the initial plot. All plots were standardized to 16 ha square plots. Final selections were modified to ensure more samples were allocated to habitat classifications with higher expected densities based upon Garner and Reynolds (1986).

In 2006, a portion of previously identified plots from 2001 surveys within the NPR-A were selected for sampling based upon preference for plots with greater abundance of Dunlin (*Calidris alpina*) and Pectoral Sandpipers (*Calidris melanotos*). A smaller number of randomly selected plots were also visited that were located in the northern portion of the NPR-A. If plots were sampled in both 2001 and 2006, only the 2006 survey was retained for further analyses, as surveys conducted later likely provide better estimates of current distributions.

In 2007 and 2008, plots were randomly located within the Teshekpuk Lake Special Area (TLSA) of the NPR-A. Plots were selected similar to 2004, where a grid of 16 ha cells was created over the TLSA. To ensure plots were surveyed throughout the entire region, the TLSA was divided into four geographic areas (NW, NE, SE, and SW) and a representative number of random grid cells were selected (based upon area). Each grid cell was classified to the predominant land cover type based upon a classification by Ducks Unlimited, Inc. (1998). Plots locations in both 2007 and 2008 were restricted so as not to be the same as those sampled in 2001, and plot locations in 2008 were restricted so as not to be the same as plots sampled in 2007.

Shorebirds were surveyed between 7 June and 1 July, using a single-visit, rapid area search technique. Surveyors systematically traversed each plot and recorded the presence of all shorebirds seen or heard within the plot boundary. On plot maps and survey sheets, surveyors recorded the location and number of pairs with nest, pairs with a probable nest, pairs, males, females, birds of unknown sex, and groups for each shorebird species. Time spent on plots was variable, especially in earlier years. In later years, time spent on 16-ha plots was standardized to 1.25 hours, resulting in a standardized search effort of 12.8 ha/hour.

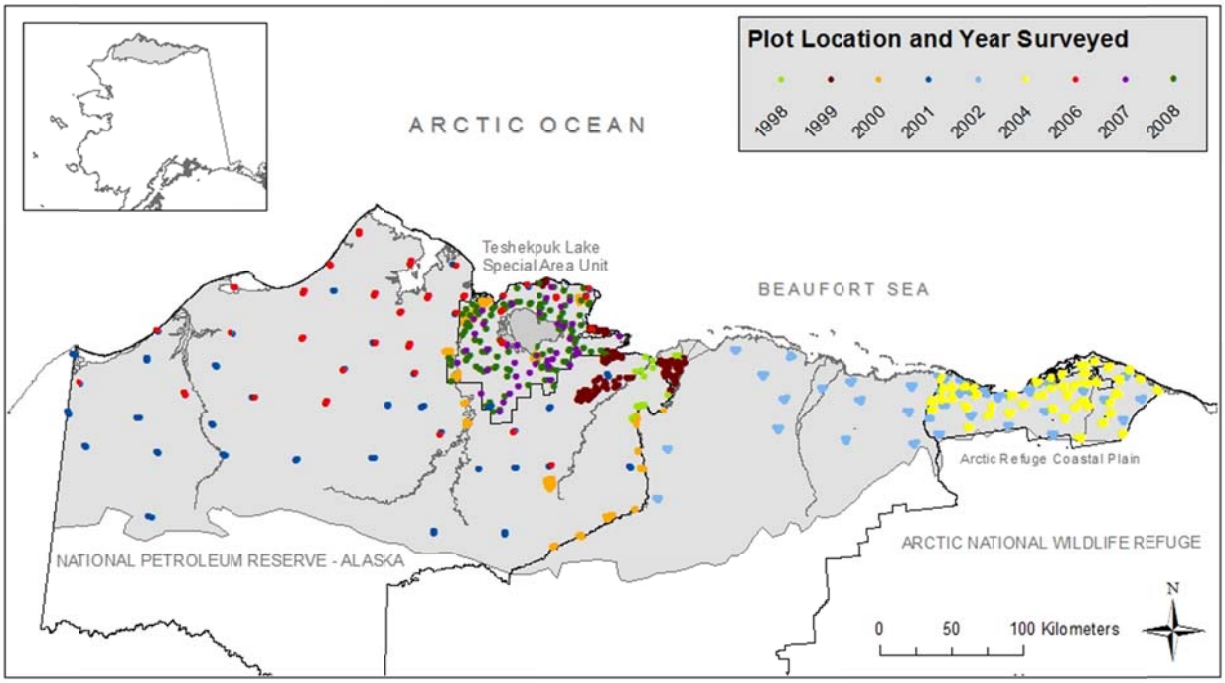

Figure 1. Location of the study area (shaded), major administrative boundaries, major rivers, and all plots surveyed between 1998 and 2008.

Spatially Linked (GIS) Database of General Shorebird Detections within Plots

Number of shorebird species detected within each plot was geospatially linked with the plot location. Plot locations were updated from the original shapefiles created prior to field surveys by incorporating any changes to plots that occurred in the field using ArcGIS 10 (ESRI, Redlands, CA). For each plot, plot locations were compared between original shapefiles overlaid on aerial photos in ArcGIS 10, plots overlaid on aerial photos on field data sheets, and any notes taken by surveyors while in the field (e.g., notes that plot was moved due to excessive water coverage). Any differences among these files were rectified in a new shapefile, where priority was given first to notes taken in the field, second to plots overlaid on aerial photos in the field (as surveyors often used land features in field to locate plot boundaries), and finally original GIS shapefiles. If consistency among these files was unable to be obtained, the plot was removed from the database. Plot size and shape were also updated based upon the above methods. In most of these instances plot size and shape were updated due to partial surveys in the field. If part of a plot was not surveyed, this portion of the plot was removed and area and search effort were updated based upon only the portion of the plot surveyed.

For each plot, the following attributes were recorded and included in authoritative, spatially linked databases:

- Plot ID
- Month of survey
- Day of survey
- Year of survey
- Plot area

- Plot perimeter
- Survey time
- Search effort (i.e., plot area/survey time)

Because of variability in plot selection and survey methods among years, as well as logistical constraints in the field that required plot size, plot location, and search effort to vary, plots were limited for analyzes based upon the following criteria, 1) plot size: 12 – 20 ha, 2) sampling effort: 9 – 22 ha/hour, 3) sampling time frame: 1 June – 1 July, and 4) elevation: 0 – 350 m. Elevations lower than 350 m were chosen, as the majority of shorebirds breed below this elevation (Johnson and Herter 1989).

For each plot that met the above criteria, the following metrics associated with shorebird detections were also recorded:

- Abundance (total number of individuals)
- Species richness (total number of shorebird species)
- Abundance of each shorebird species
- Presence/absence (1 or 0) of each shorebird species

An individual was considered detected within a plot if it was present on plot, flushed from plot, flew into plot, or performed a flight display over plot. An individual was not considered detected within a plot if it was present outside plot boundaries or flew over plot. Additionally, we removed species detected within only a few plots, with shorebird species detected within > 10% of plots retained for further analyses.

Spatially Linked (GIS) Database of Shorebird Point Locations

Along with plot locations, point locations were recorded for each shorebird detection between 2001 and 2008. Point locations were only obtained after 2000, as bird locations were not recorded in the field during 1998 – 2000 surveys. Point locations were obtained either from GPS coordinates taken in the field and written on survey sheets or from locations drawn on aerial photos or within plot boundaries while in the field. For locations drawn in the field, point locations were spatially linked through visual comparisons of marked field maps and aerial photos in ArcGIS 10. Placement of points was based upon distance from prominent land features (e.g., lakes, polygons, etc.) present on both field maps and aerial photos in ArcGIS 10, relative position to plot boundaries, and relative position to other shorebird observations. A point location was obtained for individuals present on plot, flushed from plot, flew into plot, or performed a flight display over plot. A point location was not obtained if an individual was present outside plot boundaries or flew over plot.

Priority Physical and Ecological Variables

Identification and Acquisition of Priority Physical and Ecological Variables

Prior to acquiring spatially linked coverages representing physical and ecological variables, principal investigators discussed potential biological factors that might influence the presence/absence, density, and species richness of shorebird species. A priority list was made based upon published literature and expert opinions, which included:

- Elevation
- Distance to coast
- Surface water
- Vegetation
- Normalized Difference Vegetation Index (NDVI)
- Temperature
- Precipitation
- Soil type
- Longitude
- Latitude
- Polygonization
- Snow melt

Following identification of priority variables, current available datasets for the Coastal Plain were identified by working with personnel of the Arctic LCC, U.S. Fish and Wildlife Service, University of Alaska Fairbanks, The Wilderness Society, The Nature Conservancy, U.S. Geological Survey, and The Audubon Society. From these contacts, datasets were obtained representing as many of the above priority variables as possible. Principle investigators, however, did not limit acquisition of datasets to the above priority list, but rather screened numerous other available datasets for potential use as predictor variables of shorebird presence/absence, density, and species richness. Principle investigators later refined variable selection in relation to biological relevance following a complete screening of available datasets. All datasets were screened based upon coverage, resolution, accuracy, and relevance to shorebirds in the Coastal Plain. Following this screening, 9 datasets were retained for further analyses (Table 1). These datasets had full coverage of the study area, good resolution and accuracy, and were biologically relevant to shorebirds on the Coastal Plain. All datasets were projected into the same coordinate system (i.e., NAD 1983 Albers), resampled to the same resolution (i.e., 10 m; this did not change the original resolution of the datasets, but rather, created smaller cell sizes for accurate extraction of variables to plots), and restricted to the same study area (i.e., Coastal Plain).

Table 1. Datasets representing priority physical and ecological variables describing shorebird presence/absence, density, and species richness on the Arctic Coastal Plain of Alaska.

Variable	Format	Resolution	Website	Citation
Monthly Air Temperature for each year from 1901 - 2009	Raster	2 km	http://www.snap.uaf.edu/downloads/alaska-climate-datasets	Scenarios Network for Alaska Planning, 1901-2009, CRU Historical Dataset - Air Temperature.
Total Monthly Precipitation for each year from 1901 - 2006	Raster	2 km	http://www.snap.uaf.edu/downloads/alaska-climate-datasets	Scenarios Network for Alaska Planning, 1901-2009, CRU Historical Dataset - Precipitation.
Soil Type	Polygon		http://soildatamart.nrcs.usda.gov/	Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database for [Alaska]. Available online at http://soildatamart.nrcs.usda.gov.
Elevation	Raster	2 arc second ~ 40 m	http://seamless.usgs.gov/	Gesch, D.B., 2007, The National Elevation Dataset, in Maune, D., ed., Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd Edition: Bethesda, Maryland, American Society for Photogrammetry and Remote Sensing, p. 99-118.
River and Stream Boundaries	Polyline		http://nhd.usgs.gov/data.html	Simley, J.D., Carswell, W.J., Jr. 2009, *The National Map*—Hydrography: U.S. Geological Survey Fact Sheet 2009-3054, 4 p.
Waterbody Boundaries	Polygon		http://nhd.usgs.gov/data.html	Simley, J.D., Carswell, W.J., Jr. 2009, *The National Map*—Hydrography: U.S. Geological Survey Fact Sheet 2009-3054, 4 p.

Table 1. Continued.

Variable	Format	Resolution	Website	Citation
Vegetation	Raster	30 m		Jorgenson, M. T. and M. Heiner. 2003. Ecosystems of Northern Alaska. Unpublished 1:2.5 million-scale map produced by ABR, Inc., Fairbanks, AK and The Nature Conservancy, Anchorage, AK.
Weekly NDVI for each year from 2000 - 2008	Raster	250 m	http://docs.gina.alaska.edu/ndvi/	Jenkerson, C. B. and G. L. Schmidt. 2009. eMODIS Alaska. ASPRS 2009 Annual Conference. Baltimore, MD.
Permafrost	Raster	2 km	http://www.nsidc.org	Kurkowski T. 2011. Scenarios Network for Alaska and Arctic Planning, University of Alaska.

Development of Additional Physical and Ecological Variables

Several additional variables related to the predicted variables of influence were created using the above datasets including:

- Mean monthly temperature by year
- Mean summer temperature by year
- Mean winter temperature by year
- Total monthly precipitation by year
- Total summer precipitation by year
- Total winter precipitation by year
- Slope
- Aspect
- Density of streams and rivers
- Density of water
- Density of waterbodies

Slope and aspect were derived from elevation using the spatial analyst tool in ArcGIS 10. Density estimates (i.e., density of streams and rivers, density of water, and density of waterbodies) were calculated using the spatial analyst tool in ArcGIS 10, where output cell size and search radius were held constant at 1 km and 10 km, respectively. Density of streams and rivers was derived using the line density function. As there is no tool to create a density surface from polygons, density of water was derived by first converting waterbody polygons from the USGS hydrography dataset (Simley and Carswell 2009) to a raster using a 15 m cell size. Each raster cell was then converted to a point, so that each point represented a 225 m^2 cell indicative of presence or absence of water. Density of points was derived using the spatial analyst tool in ArcGIS 10. Similarly, density of waterbodies was derived by first converting each waterbody polygon from the USGS hydrography dataset (Simley and Carswell 2009) to a point, where the point represented the centroid of each waterbody. Density of points was then derived using the spatial analyst tool in ArcGIS 10.

Along with creation of new variables, several databases were modified based upon significance to shorebirds. For example, NDVI was restricted to Julian dates 155 – 161 (i.e., 4 June – 10 June; dates representing initial annual green up) and was modified to remove nonvegetated areas represented by negative values, as well as waterbodies represented from the USGS hydrography dataset (Simley and Carswell 2009). Additionally, the following 9 composite vegetation classifications were derived from 18 original classifications for the study area in Jorgenson et al. (2003):

- Inland water (composite of coastal barren, coastal water, and lowland lake)
- Riverine (composite of riverine barrens and riverine waters)
- Riverine meadow (composite of riverine wet meadow, riverine moist meadow, and riverine low and tall scrub)
- Wet meadow (composite of coastal wet meadow and lowland wet meadow)
- Moist meadow (composite of coastal grass & DST and lowland moist meadow)
- Lowland mixed scrub
- Upland tussock tundra (composite of upland tussock tundra and upland shrubby tussock tundra)
- Upland scrub (composite of upland dwarf scrub tundra and upland low scrub)

- Upland moist meadow

Data Extraction and Review of Physical and Ecological Variables

Continuous and categorical variables were extracted to each plot using the Geospatial Modeling Environment (Beyer 2010). For continuous variables, mean values were extracted to each plot; while for categorical variables, percent composition was extracted to each plot. Additionally, distance to nearest waterbody, stream or river, and coastline, as well as latitude and longitude were extracted to the centroid of each plot using ArcGIS 10.

Following data extraction, the principle investigators refined variable selection by reviewing the relationship of physical and ecological variables to each other and shorebird presence/absence, density, and species richness. Variables were removed from further analyses if they (1) were highly correlated with other variables (e.g., temperature and precipitation), (2) lacked biological relevance (e.g., permafrost, slope, and aspect), (3) missing a significant number of years corresponding to data collection (e.g., precipitation), (4) had low resolution (e.g., soil type), or (5) were infrequently present in plots (e.g., density of rivers and streams, % riverine, % riverine meadow, and % upland moist meadow).

Model Development and Statistical Analysis

Statistical modeling techniques were developed based upon current information-theoretic modeling approaches to predict shorebird presence, density, and species richness, as well as assess and compare the accuracy of habitat selection models. *A priori* candidate models were developed based upon biologically relevant combinations, interactions, and polynomial terms for physical and ecological variables. A complete model set was developed containing all possible combinations of uncorrelated ($r > 2$), biologically relevant physical and ecological variables, interactions, and polynomial terms. Final models are discussed below in the Model Development and Statistical Analysis Results section.

Results and Discussion

Spatially Linked (GIS) Database of General Shorebird Detections within Plots

Excel and GIS files have been established for each surveyed plot that met the above restrictions (i.e., plot size: 12 – 20 ha, sampling effort: 9 – 22 ha/hour, sampling time frame: 1 June – 1 July, and elevation: 0 – 350 m). These data are available for incorporation into a geodatabase that is web-accessible. The following data were included in these files:

- Plot ID
- Month of survey
- Day of survey
- Year of survey
- Plot area
- Plot perimeter
- Survey time
- Search effort (i.e., plot area/survey time)

- Abundance (total number of individuals)
- Species richness (total number of shorebird species)
- Abundance of each shorebird species
- Presence/absence (1 or 0) of each shorebird species

Following plot restrictions, 534 plots remained for analyses, 24 in 1999, 2 in 2000, 53 in 2001, 113 in 2002, 135 in 2004, 49 in 2006, 40 in 2007, and 118 in 2008 (Figure 2). Within these plots, 6,547 shorebirds were detected, representing 21 shorebird species (Table 2). Of the 21 species detected, however, only 9 species (6,299 individuals) were present in ≥ 10% of plots. Pectoral Sandpipers were detected in the most plots (322 plots; Figure 3), followed by Semipalmated Sandpiper (*Calidris pusilla*; 302 plots; Figure 4), Red-necked Phalarope (*Phalaropus lobatus*; 230 plots; Figure 5), Red Phalarope (*Phalaropus fulicaria*; 214 plots; Figure 6), Dunlin (199 plots; Figure 7), Long-billed Dowitcher (*Limnodromus scolopaceus*; 194 plots; Figure 8), American Golden-Plover (*Pluvialis dominica*; 126 plots; Figure 9), Black-bellied Plover (*Pluvialis squatarola*; 106 plots; Figure 10), and Stilt Sandpiper (*Calidris himantopus*; 64 plots; Figure 11). See Table 2 for other species present in < 10% of plots.

Of the 9 most common species, Red Phalarope were observed the most with 1,228 individuals detected, followed by Pectoral Sandpiper (1,221 individuals), Semipalmated Sandpiper (1,147 individuals), Red-necked Phalarope (897 individuals), Dunlin (682 individuals), Long-billed Dowitcher (566 individuals), American Golden-Plover (246 individuals), Black-bellied Plover (211 individuals), and Stilt Sandpiper (101 individuals). Individual detections within a plot ranged from 0 – 81 individual shorebirds, with Long-billed Dowitchers having the highest count within a plot (47 individuals), followed by Pectoral Sandpipers (34 individuals), Red Phalaropes (29 individuals), Red-necked Phalaropes (27 individuals), Semipalmated Sandpipers and Dunlin (both with 17 individuals), and American Golden-Plovers, Black-bellied Plovers, and Stilt Sandpipers (each with 6 individuals). Distributions of these species across the Coastal Plain followed that described for each species in Johnson et al. (2007). However, by including detailed surveys within the TLSA (i.e., 2007 and 2008 surveys), distributions within this area were better delineated. Despite the general consistencies between these studies, future geospatial predictive models will allow us to better define species distributions throughout the Coastal Plain.

Shorebird species richness (i.e., number of shorebird species detected within a plot) varied from 0 – 10 species for all shorebird species, and 0 – 8 species for species present in > 10% of plots (Figure 12). The greatest shorebird species richness occurred within the north-west portion of the Coastal Plain in the NPR-A and TLSA. Shorebird species richness generally was lower within the eastern portion of the Coastal Plain and south into the Brooks Foothills (Figure 12).

Table 2. Shorebird species detected on 534 plots surveyed as part of the Program for Regional and International Shorebird Monitoring (PRISM) between 1999 and 2008.

Species	1999	2000	2001	2002	2004	2006	2007	2008
Black-bellied Plover (*Pluvialis squatarola*)	X	X	X	X	X	X	X	X
American Golden-Plover (*Pluvialis dominica*)	X		X	X	X	X	X	X
Semipalmated Plover (*Charadrius semipalmatus*)					X			
Lesser Yellowlegs (*Tringa flavipes*)						X		
Whimbrel (*Numenius phaeopus*)				X	X	X		
Bar-tailed Godwit (*Limosa lapponica*)	X	X	X	X		X		X
Ruddy Turnstone (*Arenaria interpres*)	X				X		X	X
Red Knot (*Calidris canutus*)						X		
Sanderling (*Calidris alba*)					X			
Semipalmated Sandpiper (*Calidris pusilla*)	X	X	X	X	X	X	X	X
Western Sandpiper (*Calidris mauri*)			X		X	X		
White-rumped Sandpiper (*Calidris fuscicollis*)			X		X			
Baird's Sandpiper (*Calidris bairdii*)				X	X	X	X	X
Pectoral Sandpiper (*Calidris melanotos*)	X	X	X	X	X	X	X	X
Dunlin (*Calidris alpina*)	X	X	X	X	X	X	X	X
Stilt Sandpiper (*Calidris himantopus*)	X	X	X	X	X	X	X	X
Buff-breasted Sandpiper (*Trygnites subruficollis*)				X	X	X	X	X
Long-billed Dowitcher (*Limnodromus scolopaceus*)	X	X	X	X	X	X	X	X
Wilson's Snipe (*Gallinago delicata*)				X				
Red-necked Phalarope (*Phalaropus lobatus*)	X	X	X	X	X	X	X	X
Red Phalarope (*Phalaropus fulicaria*)	X	X	X	X	X	X	X	X

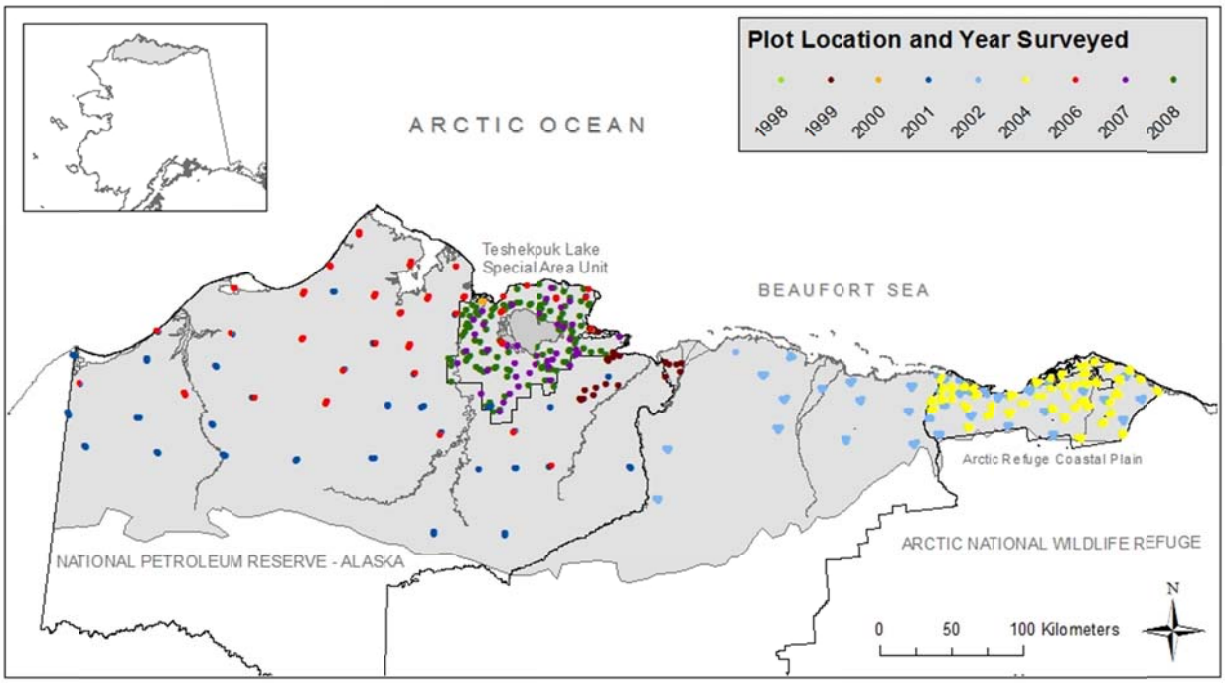

Figure 2. Location of the study area (shaded), major administrative boundaries, major rivers, and plots used in analyses (i.e., plots restricted by size, sampling effort, sampling time frame, and elevation) that were surveyed between 1998 and 2008.

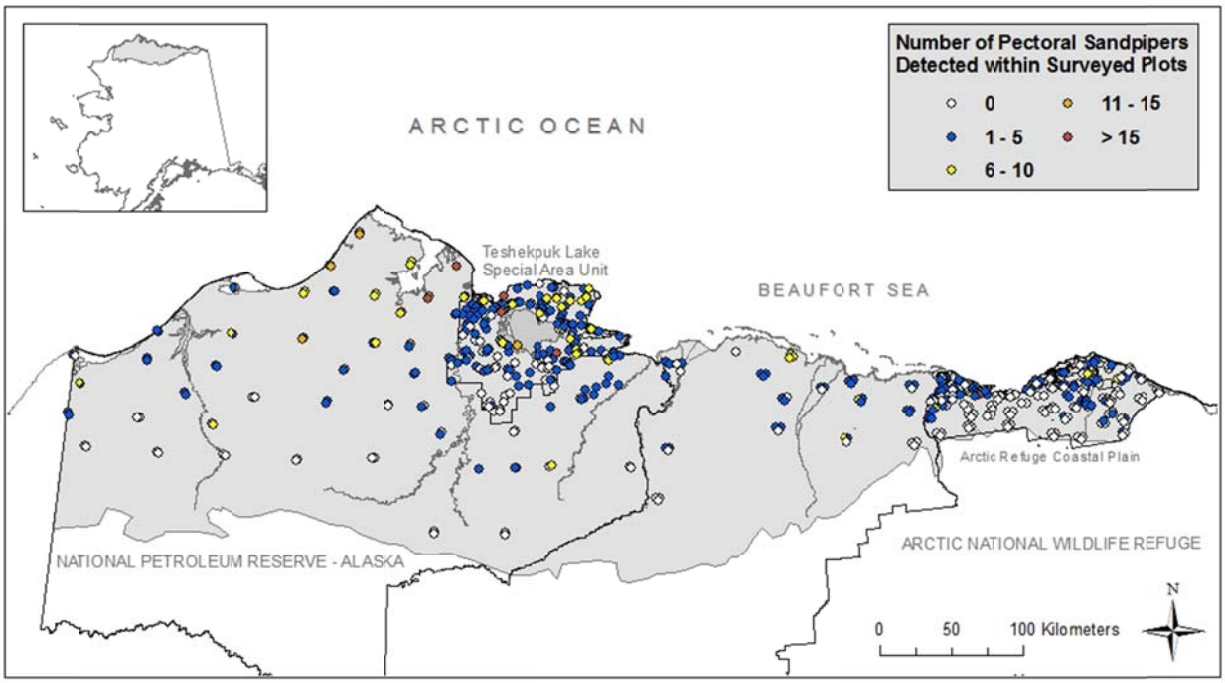

Figure 3. Location of the study area (shaded), major administrative boundaries, major rivers, and plots surveyed between 1998 and 2008 in relation to Pectoral Sandpiper (*Calidris melanotos*) counts.

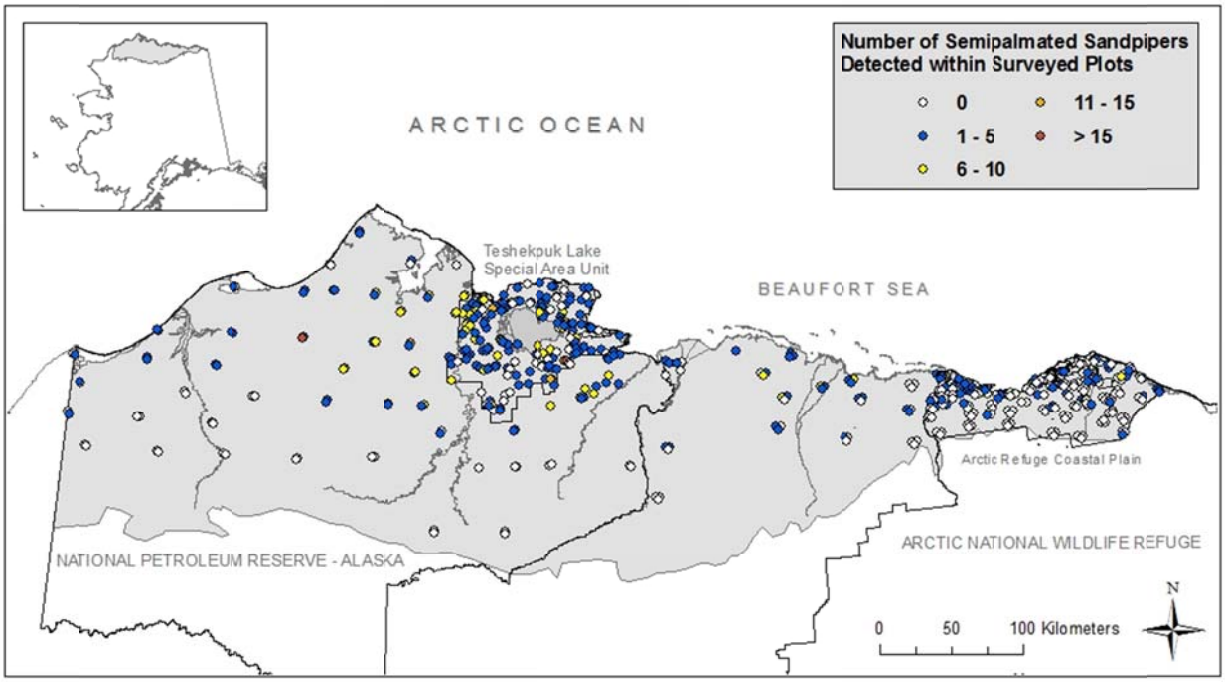

Figure 4. Location of the study area (shaded), major administrative boundaries, major rivers, and plots surveyed between 1998 and 2008 in relation to Semipalmated Sandpiper (*Calidris pusilla*) counts.

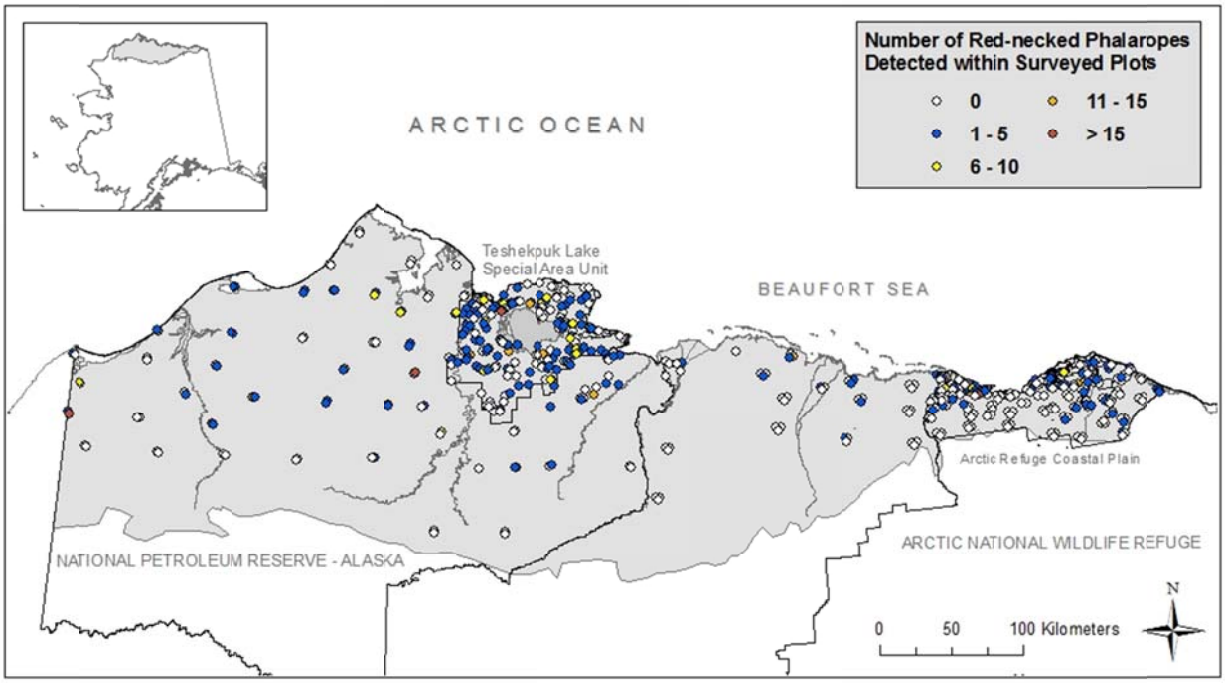

Figure 5. Location of the study area (shaded), major administrative boundaries, major rivers, and plots surveyed between 1998 and 2008 in relation to Red-necked Phalarope (*Phalaropus lobatus*) counts.

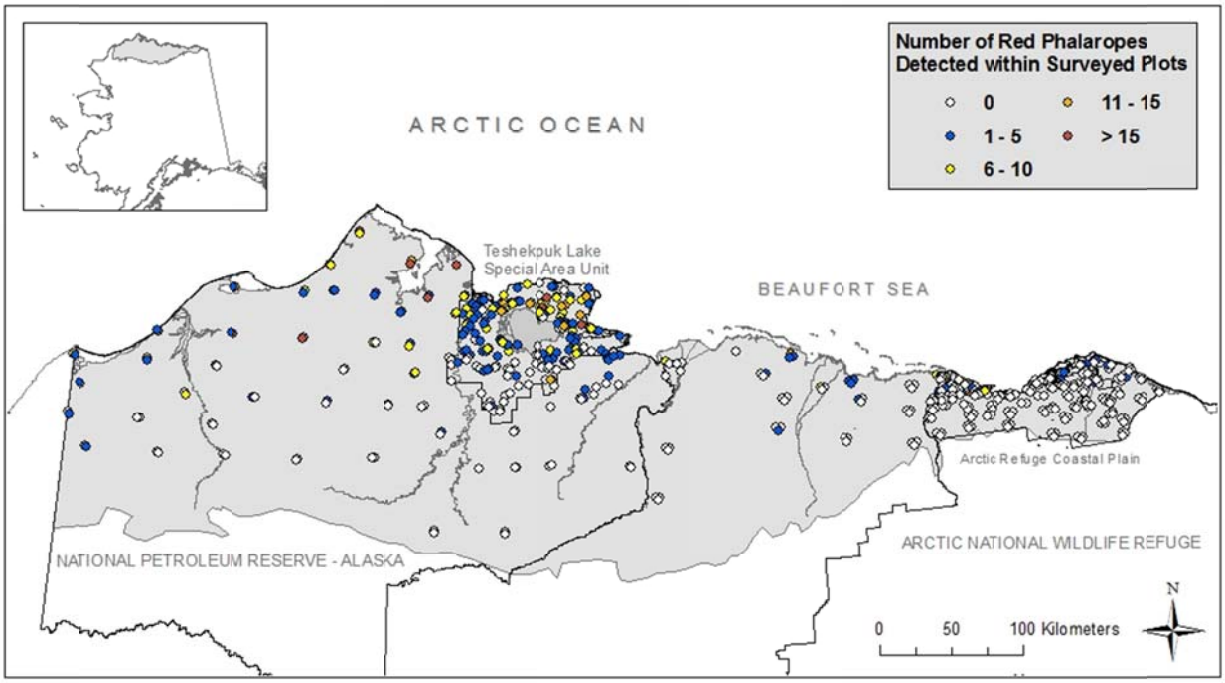

Figure 6. Location of the study area (shaded), major administrative boundaries, major rivers, and plots surveyed between 1998 and 2008 in relation Red Phalarope (*Phalaropus fulicaria*) counts.

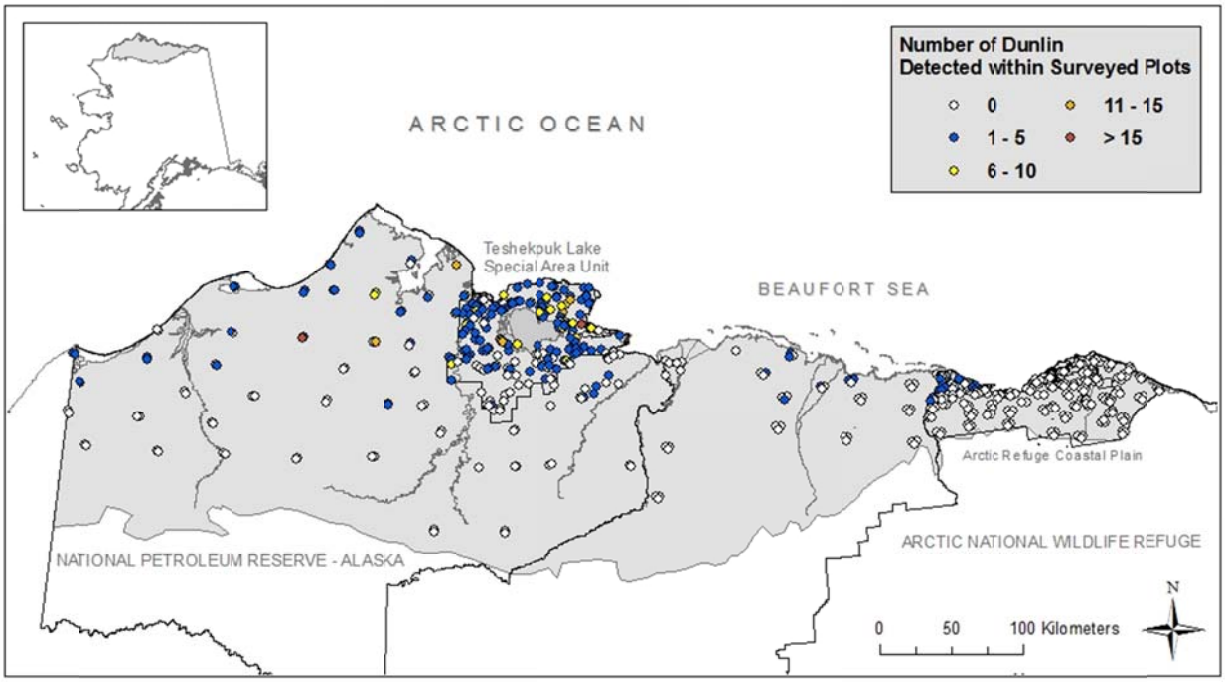

Figure 7. Location of the study area (shaded), major administrative boundaries, major rivers, and plots surveyed between 1998 and 2008 in relation to Dunlin (*Calidris alpina*) counts.

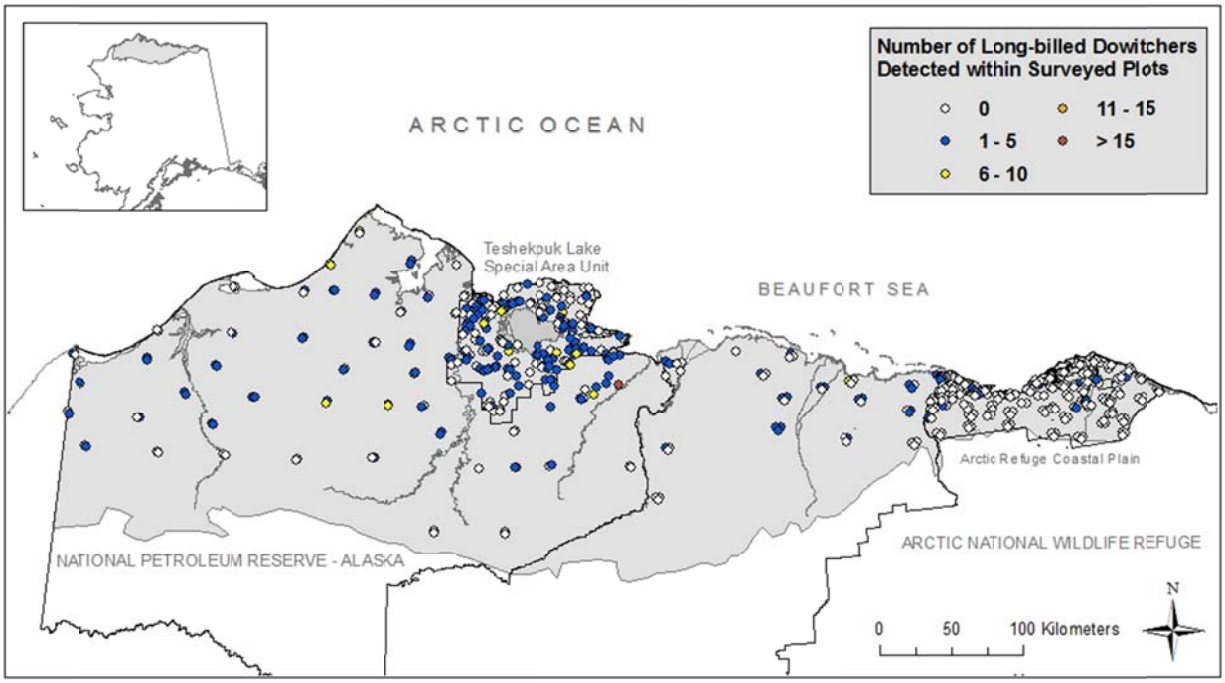

Figure 8. Location of the study area (shaded), major administrative boundaries, major rivers, and plots surveyed between 1998 and 2008 in relation to Long-billed Dowitcher (*Limnodromus scolopaceus*) counts.

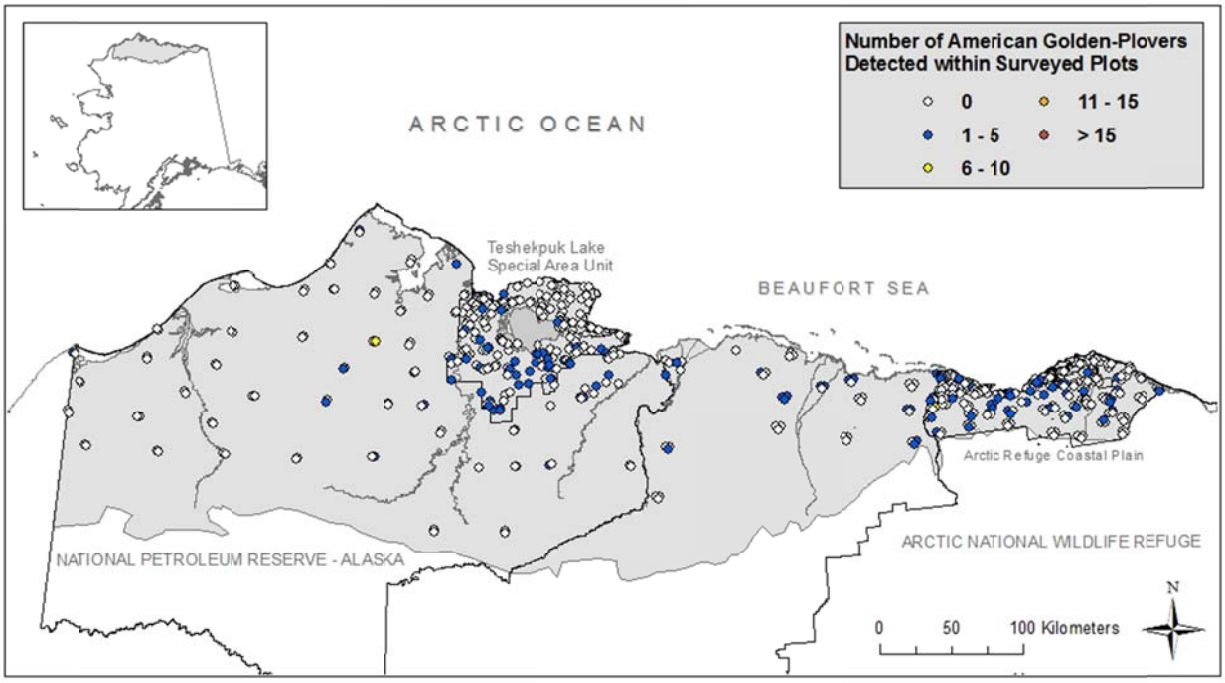

Figure 9. Location of the study area (shaded), major administrative boundaries, major rivers, and plots surveyed between 1998 and 2008 in relation to American Golden-Plover (*Pluvialis dominica*) counts.

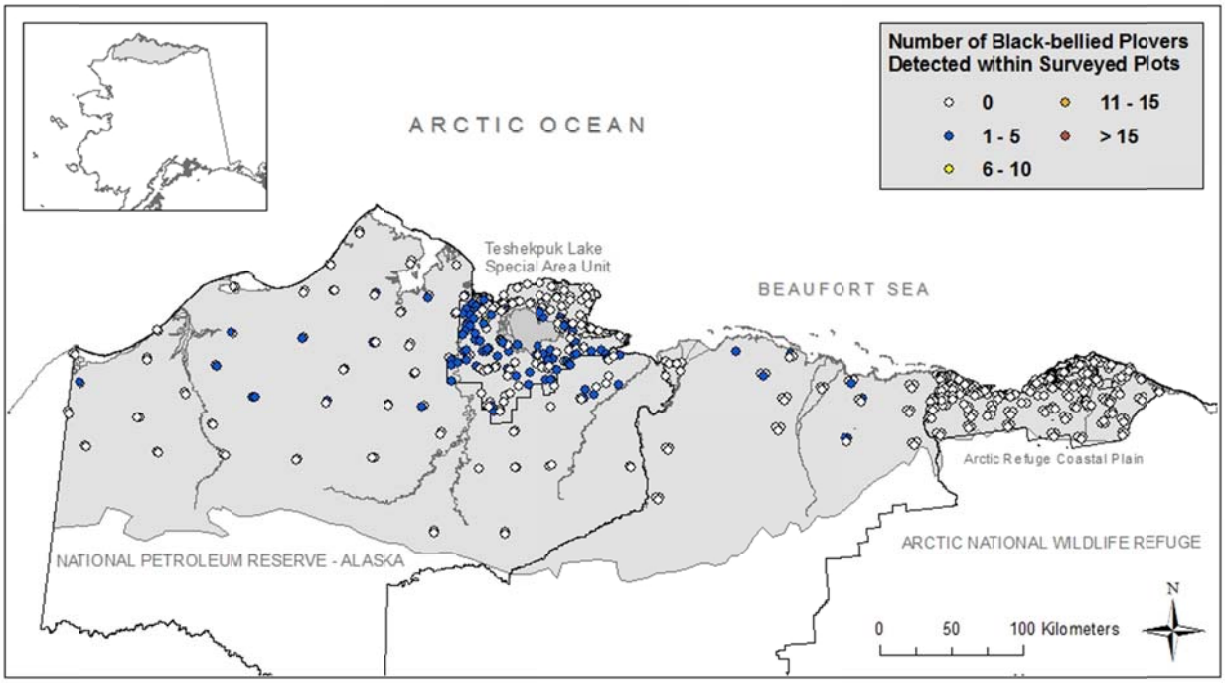

Figure 10. Location of the study area (shaded), major administrative boundaries, major rivers, and plots surveyed between 1998 and 2008 in relation to Black-bellied Plover (*Pluvialis squatarola*) counts.

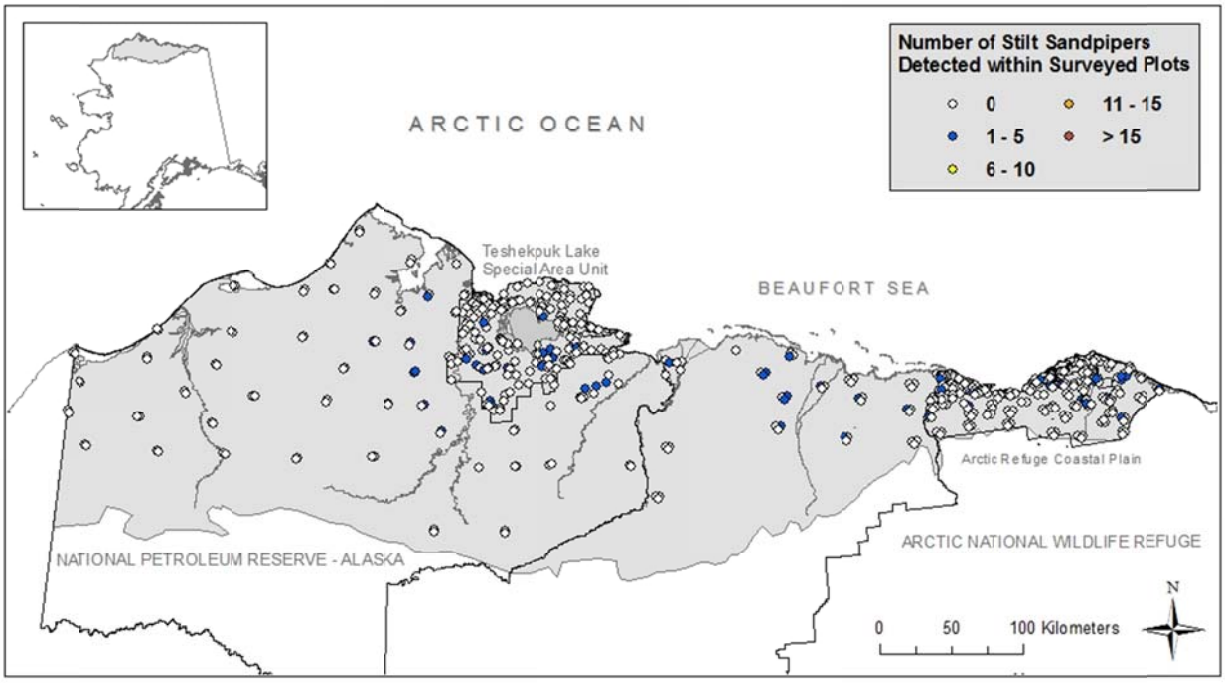

Figure 11. Location of the study area (shaded), major administrative boundaries, major rivers, and plots surveyed between 1998 and 2008 in relation to Stilt Sandpiper (*Calidris himantopus*) counts.

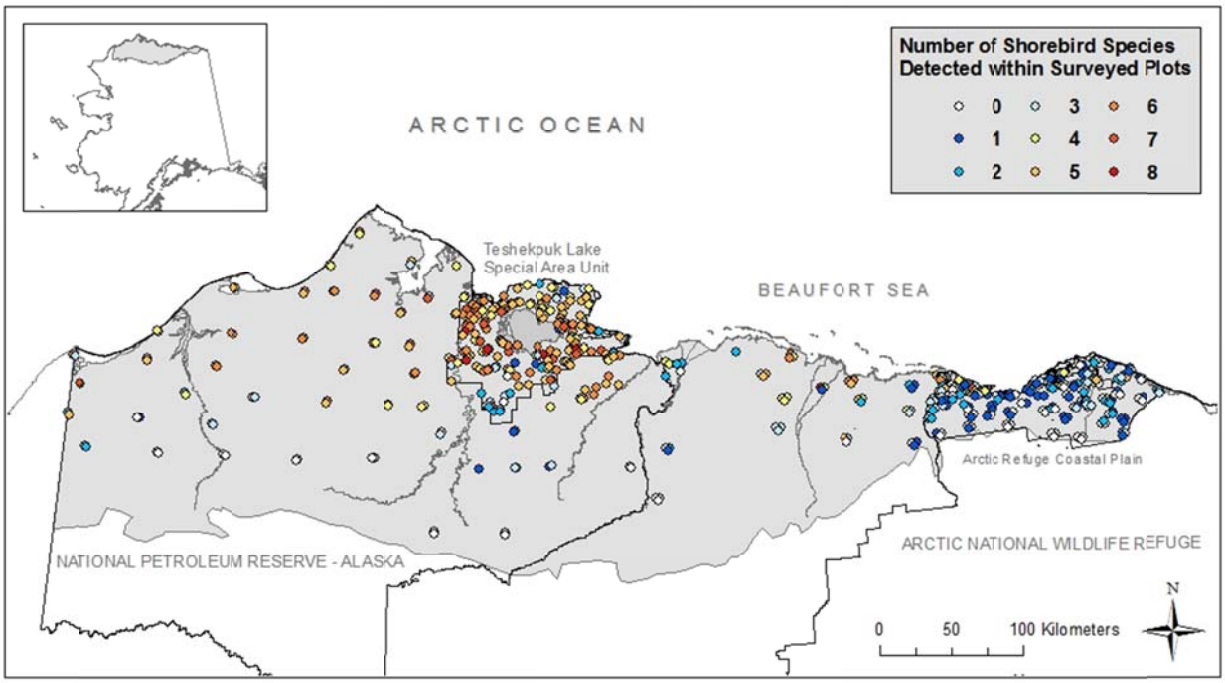

Figure 12. Location of the study area (shaded), major administrative boundaries, major rivers, and plots surveyed between 1998 and 2008 in relation to shorebird species richness.

Spatially Linked (GIS) Database of Shorebird Point Locations

Excel and GIS files have been established for individual shorebirds detected within surveyed plots that met the above restrictions (i.e., plot size: 12 – 20 ha, sampling effort: 9 – 22 ha/hour, sampling time frame: 1 June – 1 July, and elevation: 0 – 350 m). These data are available for incorporation into a geodatabase that is web-accessible. The following data were included in these files:

- Plot ID
- Month of survey
- Day of survey
- Year of survey
- Survey time
- Shorebird species
- Status (i.e., pair with nest, pair with a probable nest, pair, single male, single female, bird of unknown sex, and group)
- Number of individuals represented by status (e.g., pair with nest = 2 individuals)

From 2001 – 2008, 4,016 point locations were recorded for 21 shorebird species. During this process; however, several difficulties arose, including missing data as well as questionable accuracy of placing points based upon drawings in the field as well as for individuals in flight. Data were missing from a substantial number of plots including all plots from 1998 – 2000. Additionally, in some instances in later years, point locations for birds seen within plots were not recorded. This was

highly variable among plots and years. Because of the variability in recording point locations, as well as the small scale at which these data were recorded, these data will not be used in further analyses in this study. However, this database now exists and may be useful for future small-scale studies.

Priority Physical and Ecological Variables

After refining available spatially linked data sets representing physical and ecological variables for the Coastal Plain, 13 variables were identified as biologically relevant to shorebird presence/absence, density, and species richness. Additionally, 4 quadratic terms were identified as potentially important as well as 3 interactions (see Table 3 for a list of these variables and their hypothesized effects).

Table 3. Biologically relevant physical and ecological variables and their hypothesized effect on shorebird presence/absence, density, and species richness on the Arctic Coastal Plain of Alaska.

Included Variables	Hypothesized Effect
Elevation	Occupancy may increase or decrease linearly with elevation depending upon species
Elevation^2	Occupancy of some species may increase at intermediate elevations
Interaction between elevation and non-correlated variables	Selection of habitat variables may change based upon an elevational gradient
% water	Occupancy may increase or decrease linearly with percent surface water depending upon species
% water^2	Occupancy of some species may increase at intermediate amounts of surface water
% wet meadow	Occupancy may increase or decrease linearly with % wet meadow depending upon species; a factor of surface water and woody vegetation
% moist meadow	Occupancy may increase or decrease linearly with % wet meadow depending upon species; a factor of surface water and woody vegetation
% lowland mixed scrub	Occupancy may decrease linearly with greater woody vegetation
% upland tussock	Occupancy may increase or decrease linearly with % upland tussock depending upon species; a factor of elevation

Table 3. Continued.

Included Variables	Hypothesized Effect
% upland scrub	Occupancy may decrease as woody vegetation increases
NDVI (Yearly during week of julian date 155-161)	Occupancy may increase linearly with NDVI values, as greater NDVI values represent more plant production and is indicative of earlier snow melts
X	Occupancy varies across a longitudinal gradient
X^2	Occupancy of some species may increase at intermediate X values
Interaction between X and non-correlated variables	Selection of habitat variables may change based upon a longitudinal gradient
Y	Occupancy varies across a latitudinal gradient
Density of water	Occupancy may increase or decrease linearly with amount of water depending upon species
Density of waterbodies	Occupancy may increase or decrease linearly with number of waterbodies depending upon species
Distance to coast	Occupancy may increase linearly with distance to coast
Distance to $coast^2$	Occupancy of some species may increase at intermediate distances from coast
Interaction between distance to coast and non-correlated variables	Selection of habitat variables may change based upon distance to coast

Model Development and Statistical Analysis Results

Logistic or Poisson regression techniques will be used to create predictive models for species presence, density, and species richness for shorebirds on the Coastal Plain. Prior to analyses, a subset of plots will be withheld for accuracy assessments. For the remaining plots, Akaike's Information Criterion (AIC) will be used to rank models (a model will be considered plausible when $\Delta AIC < 2$; Burnham and Anderson 2002) from the candidate model set and calculate AIC weights. Parameter estimates, standard errors, and 95% confidence intervals will be determined using model averaging (i.e., sum of model weights for models that include a given parameter; Burnham and Anderson 2004) to create final model predictions.

Uncertainty in the model selection procedure will be assessed using 1,000 bootstrap samples (i.e., resampling the data with replacement). For each bootstrap sample, the same candidate model set will be evaluated and AIC will be computed for each model. The proportion of times each candidate model returns the lowest AIC when fit to the bootstrap sample will be recorded. This proportion provides a measure that any candidate model is found to be the best and provides some evidence of uncertainty in the model selection procedure (Gibson et al. 2004).

Accuracy of predictive models will be assessed from the subset of withheld plots. For presence/absence models, estimates of accuracy will be derived from two approaches: the proportion of plots accurately classified and the receiver operating characteristic (ROC) technique. In the first approach, a predicted presence/absence will be generated for each withheld plot by converting the probability of presence derived from logistic regression output by determining the threshold value (i.e., cutoff value, above which probability is indicative of presence and below which probability is indicative of absence) so that the overall value of the Cohen's κ-statistic is maximized (Collingham et al. 2000). Predicted presence/absence can then be compared to observed presence/absence to derive a proportion of plots accurately classified. The ROC technique is a threshold-independent method used to assess accuracy of the predictive models. A ROC curve is a plot of true positive cases (i.e., sensitivity) against corresponding false positive cases (i.e., 1-specificity) across a range of threshold values (Fielding and Bell 1997). The area under the ROC curve provides a measure of discrimination ability, and varies from 0.5 for a model with discrimination ability no better than random, to 1.0 for a model with perfect discrimination ability (Fielding and Bell 1997).

For density and species richness estimates, accuracy of predictive models will be assessed using correlation analysis between predicted values and observed values and standardized residuals of predicted values and observed values (Guisan and Zimmermann 2000).

From 13 variables, 4 quadratic terms, and 3 interactions, 112 *a priori* candidate models were developed based upon biologically relevant combinations, interactions, and polynomial terms for physical and ecological variables (Table 4). These models are now currently being tested using the approach described above.

Table 4. Candidate model set describing shorebird presence/absence, density, and species richness on the Arctic Coastal Plain of Alaska.

Model	No. of parameters
intercept	1
elevation	2
% water	2
% wet meadow	2
% moist meadow	2
% lowland mixed scrub	2
% upland tussock	2
% upland scrub	2
NDVI	2
X	2
Y	2
density of waterbodies	2

Table 4. Continued.

Model	No. of parameters
density of water	2
distance to coast	2
elevation + % lowland mixed scrub	3
% water + % moist meadow	3
% water + % lowland mixed scrub	3
% water + % moist meadow + % lowland mixed scrub	4
% wet meadow + % moist meadow	3
% wet meadow + NDVI	3
% wet meadow + X	3
% wet meadow + distance to coast	3
% wet meadow + % moist meadow + NDVI	4
% wet meadow + % moist meadow + X	4
% wet meadow + % moist meadow + distance to coast	4
% wet meadow + NDVI + X	4
% wet meadow + % moist meadow + NDVI + X	5
% moist meadow + % lowland mixed scrub	3
% moist meadow + % upland tussock	3
% moist meadow + NDVI	3
% moist meadow + X	3
% moist meadow + density of waterbodies	3
% moist meadow + density of water	3
% moist meadow + distance to coast	3
% moist meadow + % lowland mixed scrub + % upland tussock	4
% moist meadow + % lowland mixed scrub + NDVI	4
% moist meadow + % lowland mixed scrub + distance to coast	4
% moist meadow + % upland tussock + X	4
% moist meadow + NDVI + X	4
% moist meadow + NDVI + density of waterbodies	4
% moist meadow + NDVI + density of water	4
% moist meadow + density of water + distance to coast	4
% moist meadow + density of waterbodies + distance to coast	4
% lowland mixed scrub + % upland tussock	3
% lowland mixed scrub + % upland scrub	3
% lowland mixed scrub + NDVI	3
% lowland mixed scrub + Y	3
% lowland mixed scrub + distance to coast	3
% upland tussock + X	3
% upland scrub + X	3
NDVI + X	3

Table 4. Continued.

Model	No. of parameters
NDVI + density of waterbodies	3
NDVI + density of water	3
density of waterbodies + distance to coast	3
density of water + distance to coast	3
elevation^2	3
elevation * % lowland mixed scrub	4
X^2	3
X * % wet meadow	4
X * % moist meadow	4
X * % upland tussock	4
X * % upland scrub	4
X * NDVI	4
X * % wet meadow + % moist meadow	5
X * % wet meadow + NDVI	5
X * % wet meadow + % moist meadow + NDVI	6
X * % moist meadow + % wet meadow	5
X * % moist meadow + % upland tussock	5
X * % moist meadow + NDVI	5
X * % moist meadow + % wet meadow + NDVI	6
X * % upland tussock + % moist meadow	5
X * NDVI + % wet meadow	5
X * NDVI + % moist meadow	5
X * NDVI + % wet meadow + % moist meadow	6
distance to coast^2	3
distance to coast * % wet meadow	4
distance to coast * % moist meadow	4
distance to coast * % lowland mixed scrub	4
distance to coast * density of waterbodies	4
distance to coast * density of water	4
distance to coast * % wet meadow + % moist meadow	5
distance to coast * % moist meadow + % wet meadow	5
distance to coast * % moist meadow + % lowland mixed scrub	5
distance to coast * % moist meadow + density of waterbodies	5
distance to coast * % moist meadow + density of water	5
distance to coast * % lowland mixed scrub + % moist meadow	5
distance to coast * density of waterbodies + % moist meadow	5
distance to coast * density of water + % moist meadow	5
elevation^2 + % lowland mixed scrub	3
X^2 + % wet meadow	4

Table 4. Continued.

Model	No. of parameters
X^2 + % moist meadow	4
X^2 + % upland tussock	4
X^2 + % upland scrub	4
X^2 + NDVI	4
X^2 + % wet meadow + % moist meadow	5
X^2 + % wet meadow + NDVI	5
X^2 + % moist meadow + % upland tussock	5
X^2 + % moist meadow + NDVI	5
X^2 + % wet meadow + % moist meadow + NDVI	6
distance to coast^2 + % wet meadow	4
distance to coast^2 + % moist meadow	4
distance to coast^2 + % lowland mixed scrub	4
distance to coast^2 + density of waterbodies	4
distance to coast^2 + density of water	4
distance to coast^2 + % wet meadow + % moist meadow	5
distance to coast^2 + % moist meadow + % lowland mixed scrub	5
distance to coast^2 + % moist meadow + density of waterbodies	5
distance to coast^2 + % moist meadow + density of water	5
%water^2	3
%water^2 + % moist meadow	4
%water^2 + % lowland mixed scrub	4
%water^2 + % moist meadow + % lowland mixed scrub	5

Other Accomplishments

As of this writing, we have generated the following presentation from results associated with this project:

Saalfeld, S., R. Lanctot, S. Brown, J. Johnson, B. Andres, and J. Bart. 2011. Predicting shorebird habitat on the Arctic Coastal Plain of Alaska. Will be presented at the Western Hemisphere Shorebird Group Meeting, Vancouver British Columbia, August 11 – 15, 2011.

Relevance to Arctic LCC Conservation Goals:

This study meets several stated objectives within the Arctic Landscape Conservation Cooperative Development and Operations Plan (draft plan December 2009). Specifically, it:

- has a broad geographic scope that is focused on the Coastal Plain;

- addresses priority species and habitats on the Coastal Plain;
- will develop authoritative geospatial data sets that describe shorebird species abundance and distribution;
- strengthens the scientific basis of land management decisions by providing more detailed information on shorebird distribution useful for assessing potential impacts from development;
- will build science capacity, by combining available data collected by Migratory Bird Management Staff and many other organizations into one easily accessible GIS database that can become part of a library of mutually-compatible geospatial data sets;
- Will provide a modeling approach that can be implemented in other LCCs in the future.

Fund Expenditures

Funds were used to hire a post-doctoral researcher and technician that (1) assembled authoritative, spatially linked (GIS) databases on shorebird presence/absence, density, and species richness from 1998 – 2008 Program for Regional and International Shorebird Monitoring (PRISM) surveys, (2) identified, acquired, and assembled priority physical and ecological variables, and (3) developed statistical modeling approaches. Additionally, U.S. Fish and Wildlife Service, Migratory Bird Management Office provided funds for computer, computer software (i.e., ArcGIS 10 and SAS 9.2), as well as office space for post-doctoral researcher and technician.

The Future

The project has taken great strides during the past few months since a post-doctoral researcher was hired. We have assembled an authoritative, spatially linked (GIS) database on shorebird presence/absence, density, and species richness; identified and acquired spatially linked (GIS) databases representing priority physical and ecological variables; and developed statistical modeling approaches to determine associations between presence/absence, density, and species richness of shorebird species, and physical and ecological variables. We are currently in the process of running species-specific predictive models and assessing the predictive performance of the top-ranked models. As we move forward with analyses, we will continue to update our databases of physical and ecological variables as new datasets become available. We will be presenting preliminary findings from this study at the Western Hemisphere Shorebird Group Meeting in Vancouver, British Columbia in August 2011 (see above) and hope to obtain additional perspectives on our study approach from other shorebird biologists at that time. Within the next 6 month, we hope to (1) generate maps showing the predicted distribution of the most common shorebird species located on the Coastal Plain, (2) compare selection patterns of physical and ecological variables among shorebird species, (3) determine the accuracy of predictive models, and (4) compare predictability and accuracy of predictive models for shorebirds to assess differences in model performance based upon different response variables (e.g., presence/absence, density, species richness), positioning us to ultimately forecast how these distributions will change depending upon various climate change and development scenarios.

Acknowledgements

This report is based upon numerous field surveys conducted over a 10 year time span. This

study would not be possible without the time and effort provided by the surveyors who collected field data for the PRISM surveys. We thank them all for their countless hours of fieldwork that made this study possible. We especially thank J. Johnson, B. Andres, and J. Bart who either led or co-led various portions of the survey work described here. Besides the Arctic LCC funding, which necessitated this report, additional funding for this study was provided by the U.S. Fish and Wildlife Service and Manomet Center for Conservation Sciences.

Literature Cited

Arctic Climate Impact Assessment. 2004. Impacts of a warming Arctic. Cambridge: Cambridge University Press.

Auerbach, N. A., M. D. Walker and D. A. Walker. 1997. Effects of roadside disturbance on substrate and vegetation properties in Arctic tundra. Ecological Applications 7:218-235.

Bart, J., S. Brown, B. Harrington and R. I. G. Morrison. 2007. Survey trends of North American shorebirds: population declines or shifting distributions? Journal of Avian Biology 38:73-83.

Beyer, H. L. 2010. Geospatial Modeling Enviornment for ArcGIS. Available at <http://www.spatialecology.com/gme/>.

Brown, S., C. Hickey, B. Harrington and R. Gill. 2001. United States Shorebird Conservation Plan, 2nd ed. Manomet Center for Conservation Sciences, Manomet, Massachusetts.

Burnham, K. P. and D. R. Anderson. 2004. Multimodal inference: understanding AIC and BIC in model selection. Sociological Methods and Research 33:261-304.

Collingham, Y. C., R. A. Wadsworth, B. Huntley and P. E. Hulme. 2000. Predicting the spatial distribution of non-indigenous riparian weeds: issues of spatial scale and extent. Journal of Applied Ecology 37:13-27.

Ducks Unlimited, I. 1998. National Petroleum Reserve - Alaska earthcover inventory. Report prepared by Ducks Unlimited, Inc. for Bureau of Land Management (Alaska), Anchorage, AK.

Fielding, A. H. and J. F. Bell. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental Conservation 24:38-49.

Garner, G. W. and P. E. Reynolds. 1986. Arctic National Wildlife Refuge coastal plain resource assessment: final report baseline study of the fish, wildlife, and their habitats. U.S. Fish and Wildlife Service, Anchorage, AK.

Gibson, L. A., B. A. Wilson, D. M. Cahill and J. Hill. 2004. Spatial prediction of rufous bristlebird habitat in a coastal heathland: a GIS-based approach. Journal of Applied Ecology 41:213-223.

Gilders, M. A. and M. A. Cronin. 2000. North Slope oil field development. *in* J. C. Truett and S. R. Johnson, editors. The natural history of an Arctic oil field. Academic Press, San Diego, CA.

Guisan, A. and N. E. Zimmermann. 2000. Predictive habitat distribution models in ecology. Ecological Modelling 135:147-186.

IPCC. 2007. Climate Chage 2007: Synthesis Report. Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Geneva Switzerland: IPCC.

Johnson, J. A., R. B. Lanctot, B. A. Andres, J. R. Bart, S. C. Brown, S. J. Kendall and D. C. Payer. 2007. Distribution of breeding shorebirds on the Arctic Coastal Plain of Alaska. Arctic 60:277-293.

Johnson, S. R. and D. R. Herter. 1989. The birds of the Beaufort Sea. Anchorage: British Petroleum Exploration (Alaska), Inc.

Jorgenson, J. C., P. E. Joria, T. R. McCabe, B. R. Reitz, M. K. Raynolds, M. Emers and M. A. Wilms. 1994. Users guide for the land-cover map of the coastal plain of the Arctic National Wildlife Refuge. U.S. Fish and Wildlife Service, Fairbanks, AK.

Jorgenson, M. T. and M. Heiner. 2003. Ecosystems of northern Alaska. Unpublished 1:2.5 million-scale map produced by ABR, Inc., Fairbanks, AK and The Nature Conservancy, Anchorage, AK.

Jorgenson, T. and C. Ely. 2001. Topography and flooding of coastal ecosystems on the Yukon-Kuskokwim delta, Alaska: implications for sea-level rise. Journal of Coastal Research 17:124-136.

King, R. 1979. Results of aerial surveys of migratory birds on NPR-A in 1977 and 1978 Pages 187-226 *in* P. C. Lent, editor. Studies of selected wildlife and fish and their use of habitats on and adjacent for NPR-A 1977-1978. U.S. Department of the Interior, National Petroleum Reserve in Alaska, Anchorage, Field Study 3. Vol 1.

Liebezeit, J. R., S. J. Kendall, S. Brown, C. B. Johnson, P. Martin, T. L. McDonald, D. C. Payer, C. L. Rea, B. Streever, A. M. Wildman and S. Zack. 2009. Influence of human development and predators on nest survival of tundra birds, Arctic Coastal Plain, Alaska. Ecological Applications 19:1628-1644.

Martin, P. D., J. L. Jenkins, F. J. Adams, M. T. Jorgenson, A. C. Matz, D. C. Payer, P. E. Reynolds, A. C. Tidwell and J. R. Zelenak. 2009. Wildlife response to environmental Arctic change: predicting future habitats of Arctic Alaska. Report of the Wildlife Response to Enviornmental Arctic Change (WildREACH): Predicting Future Habitats of Arctic Alaska Workshop, 17-18 November 2008. Fairbanks, Alaska: U.S. Fish and Wildlife Service.

Meehan, R. H. 1986. Impact of oilfield development on shorebirds, Prudhoe Bay, Alaska. Ph.D., University of Colorado.

Morrison, R. I. G., B. J. McCaffery, R. E. Gill, S. K. Skagen, S. L. Jones, G. W. Page, C. L. Gratto-Trevor and B. A. Andres. 2006. Population estimates of North American shorebirds, 2006. Wader Study Group Bulletin 111:67-85.

National Research Council. 2003. Cumulative enviornmental effects of oil and gas activities on Alaska's North Slope. National Academics Press, Washington, D.C.

Piersma, T., P. Wierma and J. van Gils. 1997. The many unknowns about plovers and sandpipers of the world: introduction to a wealth of research opportunities highly relevant for shorebird conservation. Wader Study Group Bulletin 82:23-33.

Shur, Y., M. T. Jorgenson and E. R. Pullman. 2003. Widespread degradation of ice wedges on the Arctic coastal plain in northern Alaska in response to the recent warmer cllimate. American Geophysical Union, Fall Meeting 2003, Abstract C11A-05. Available at <http://adsabs.harvard.edu/abs/2003AGUFM.C11A..05S>.

Simley, J. D. and J. D. Carswell, Jr. 2009. The National Map - Hydrography: U.S. Geological Survey Fact Sheet 2009-3054.

Sturm, M., C. Racine and K. Tape. 2001. Increasing shrub abundance in the Arctic. Nature 411:546-547.

U.S. Department of the Interior. 2002. Waterfowl earth cover selection analysis within th National Petroleum Reserve, Alaska. Final Report, Bureau of Land Management, Alaska State Office, Anchorage, AK.

U.S. Shorebird Conservation Plan. 2004. High priority shorebirds - 2004. U.S. Department of Interior, Fish and Wildlife Service, Arlington, Virginia. http://www.fws.gov/shorebirdplan/downloads/ShorebirdPriorityPopulationsAug04.pdf. accessed 19 June 2006.