The Effects of Recreational Activities on Avian Occupancy and Breeding Success in Denali National Park and Preserve

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Abstract

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Tourism is increasing in tundra ecosystems across the world, yet its influence on bird communities and its interaction with other drivers of change are poorly known. To help fill this gap, we incorporate local knowledge with modern avian occupancy and breeding surveys in Denali National Park and Preserve. We measured occupancy rates of 13 bird species in relation to road proximity, traffic volume, and amount of hiking. We found that Lapland Longspur and Horned Lark occupancy rates were reduced by road disturbance while five other generalist shrub-tolerant species increased. Hiking disturbance negatively affected occupancy probabilities of five species, but positively affected occupancy of Fox Sparrow. We also interviewed eleven long-term employees and naturalists with local knowledge of the park. These interviews informed our occupancy and nest study as people mentioned declines in American Golden-Plover, Arctic Tern, Long-tailed Jaeger, and Northern Wheatear over the past five decades. Our occupancy study confirmed these reports as we did not detect a single Arctic Tern, few Northern Wheatears, and found both plovers and Jaegers to be sensitive to hiking disturbance. The effects of hiking and road disturbance on breeding success revealed lower hatching rates at a high

recreation area when we combined four shorebird species at two sites with dramatically different recreational activity. Shorebirds (American Golden-Plover, Wandering Tattler, Whimbrel, and Long-tailed Jaeger) nesting at the site with increased human access and hiking activity hatched eggs from 50% fewer territories than did those within the low recreation site. However, fledging of chicks by parents that successfully hatched eggs was high and similar at both sites. The knowledge gained from this study reveals a dramatically different park today than a few decades past. Park managers should seek to balance human recreation with the needs of sensitive tundra-breeding birds to further protect species of conservation concern. This may be done by siting new trails in shrub-lands or forest, limiting access to tundra hiking areas during the early breeding season, concentrating human presence on the landscape, improving some trails to reduce nearby social trails, educating tourists about nesting birds, and closing especially important nesting areas to the public.

Introduction to the Study

Few studies have investigated the effects of recreation in the high latitude arctic tundra ecosystem. Beginning in 2016 I set out to begin to understand these effects by drafting a two-year study plan with three main objectives. Objective one was to understand the historical distributions of avifauna near the park road using local knowledge of long-term employees and naturalists in the park. Objective two was to understand how birds occupy the tundra ecosystem in relation to recreational factors. Objective three was to understand how recreation affects breeding success at two sites with dramatically different recreational pressure. In chapter one I draw from both objective one and two to gain a broader picture of how recreation may have led to changes in occupancy probabilities over time and then comparing those with current measurements. In chapter two I mainly focus on objective three, breeding success.

Local knowledge is useful to provide context for current populations where ecological baselines may have shifted over time (Jardine 2019). I employed interview techniques with a snowball sampling approach to understand how the avifauna within Denali National Park have changed in both population size and occupancy. The data I gathered allows us to gain insight into ecological data otherwise unknown over the past 40 years. I combine this knowledge with historical literature dating back to the early twentieth from Adolf Murie (1924; 1946), Joseph Dixon (1927), and Charles Sheldon (1909). I found consensus among all eleven interviewees that the park has dramatically shifted in terms of recreational disturbance and avifauna distribution. A majority of participants voiced concerns about shifting ecological baselines that were not documented during their tenure at the park. My interview results pay homage to their dedicated observations and helps us interpret current distributions about historical observations. I combine

these interviews in chapter one with my occupancy study that was the first of its kind within the park to set a broad baseline of the tundra ecosystem.

The second objective of my study was to understand the current occupancy trends with recreational activities. I counted birds at 173 sites throughout the park with varying degrees of recreational pressure. I looked at the variables: road proximity, hiking, and traffic volume. I determined that all three variables affect tundra species but in different ways. Road proximity negatively affected the occupancy probability of two small tundra nesting passerines with decreased occupancy closer to the road. Five shrub dwelling species occupied areas close to the road. I also observed that greater amounts of hiking negatively affected occupancy of five species, while positively influencing one species. Traffic volume negatively affected the occupancy probability of one shrub species but positively affected two other shrubs species. My results indicate that recreational pressures do play a part in species occupancy in the tundra ecosystem.

Many birds that were less likely to occupy regions with greater recreational pressures also were described in local knowledge interviews from objective one. I deem these species to be of conservation concern for park managers. Species of conservation concern not only have dramatically declined in the past 40 years but also currently are being pressured by recreational activities within the park. I further investigate the drivers of species displacement in my third objective.

My third objective was to understand how breeding success is affected by recreational pressure. I looked at both hatching success from territories and fledging success of nests that hatched young. I broke this study up into two sites, one with high recreational use near the road and one far from the road with limited hiking opportunities. I found that the site with increased recreational pressure suffered from lower hatching success, but not fledging success. I compared

my variable of site with another variable (distance from the road) to measure the significance of road proximity. I found road proximity played an integral role in the site model but was overruled by other factors that site was able to take into account such as landscape features, hiking pressure, and proximity to an off-road closure. Recreation may lower nest success because of its frequent disturbance to ground-nesting birds that likely see humans as a possible source of nest predation. Furthermore, ground-nesting species may choose to breed farther from disturbance to avoid predators that use the road. The results of this study mirror my occupancy study and allow us to combine management implications.

My three objectives provide an opportunity to create a variety of solutions that take into account the unique landscape features of the tundra. Many species of conservation concern are negatively influenced by recreation; therefore, actions to protect them are warranted. I recommend park managers place new trails in shrub or forest landscapes, concentrate human presence on the landscape, limit disturbance in the early breeding season, close important nesting areas to the public, and educate tourists about ground-nesting birds. By combining these three objectives, I was able to increase our knowledge of the tundra ecosystem over a short time period. I included the community in my project to further its implications and recognition by current and future stakeholders within the park. I also have set a baseline for future studies to build upon to hopefully continue to protect the integrity of the tundra ecosystem.

CHAPTER 1:

The Effects of Recreational Activities on Avian Occupancy in a High Latitude Tundra Ecosystem

Avery Meeker

Abstract

Tourism is increasing in tundra ecosystems across the world, yet its influence on bird communities and its interaction with other drivers of change is poorly known. To help fill this gap, we interviewed 11 people with local knowledge of Denali National Park and Preserve, and estimated occupancy rates of 13 bird species in relation to road proximity, traffic volume, and hiking. Interviewees noted declines in American Golden-Plover, Arctic Tern, Long-tailed Jaeger, and Northern Wheatear over the past five decades. Our occupancy study confirmed these reports as we detected no Arctic Terns, few Northern Wheatears, and found both plovers and jaegers to be sensitive to hiking. We found that occupancy probability of tundra by Lapland Longspur and Horned Lark was reduced by road disturbance while that of five other generalist shrub-tolerant species increased. Hiking negatively affected occupancy probability of five species, but positively affected Fox Sparrow occupancy probability. Detection of species varied based on survey length, noise, start time and date. The knowledge gained from this study reveals a shifting ecological baseline in the park over the past few decades. Park managers should seek to balance human recreation with the needs of sensitive tundra-breeding birds to further protect species of conservation concern. This may be done by not siting new trails in tundra, limiting access to tundra hiking areas during the early breeding season, improving trails, educating tourists about tundra nesting birds, and closing especially important nesting areas to the public.

Introduction

Tundra ecosystems are currently undergoing rapid habitat change and increased human presence leading to unexpected consequences for multiple species (Mizel et al. 2016; Thompson et al. 2016). Studies routinely implicate climate change in high-latitude species turnover or population

declines, but few assess human disturbance and utilize long-term local knowledge in their findings. Meanwhile, tundra reserve management strategies have recently changed to increase recreational access, but with very little understanding of how species will adapt to these changes.

The number of recreational visits to natural areas worldwide is steadily growing and threatening protected area natural resources (Cordell 2010; Larson et al. 2016). Humans and their artifacts on the landscape affect organisms in many ways such as altering habitat and increasing predation rates, which lead to reduction or extirpation of species (Gutzwiller et al. 2008; Walker & Marzluff 2015). These changes along with ongoing habitat alteration due to climate change are expected have drastic effects on high latitude regions and the birds that breed within them (Thompson et al. 2016; Mizel et al. 2016; Mizel et al. 2017; Kubelka et al. 2018).

Permafrost loss, receding glaciers and increased colonization of woody species are changing tundra habitat (Jorgensen et al. 2001; Roland and Stehn 2013) and affecting many tundra birds (Sokolov et al. 2012; Mizel et al. 2016; Thompson et al. 2016). Increased shrub density and cover negatively affects tundra shorebirds, while many shrub tolerant passerines benefit from this increase (Thompson et al. 2016). These changes are thought to increase productivity of the tundra and overall density of birds, while challenging the survival of some species that require open lands. In Denali National Park and Preserve (hereafter Denali), many passerines typically restricted to lower elevation shrubs are now found at higher elevations where shrubs have recently colonized as permafrost has receded (Mizel et al. 2016). How these changes are mitigated or compounded by increasing recreation within tundra preserves is unknown.

Each year an average of 431,495 (NPS 2000-2018) tourists visit the northern slope of the Alaska Range and Denali National Park and Preserve. To accommodate tourists, the National Park Service (NPS) offers many recreational opportunities including maintained trails, educational bus trips, ranger-led discovery hikes, private inholding access, and backcountry

camping permits. While trails are in place for hiking, 48% of visitors report that they hike off of established trails while visiting the park (Hatcher and Fix 2010). In 2012 the Denali Park Road Vehicle Management plan was changed to dramatically increase the number of vehicles allowed on the park road (McKenny et al. 2013). These changes were meant to give managers more flexibility on daily roundtrip bus limits (160 vehicles per day) to increase park and vendor revenue and increase visitor access.

The effect of roads and recreation leads to both direct and indirect impacts on wildlife. Increased traffic volume in Denali has a negative effect on wildlife such as grizzly bears (*Ursus arctos)* and Dall sheep (*Ovis dalli)* increasing movement rates nears roads (Phillips et al. 2010). The effects of recreation on birds in Denali is currently unknown. Studies about the effects of recreation on birds reveal many potential contributors such as increases in energetic stresses (McGowan and Simons 2006), predation (Miller et al. 1998; Miller and Hobbs 2000), altered activity budgets (Steidl and Anthony 2000), displacement from preferred environments, and reduced productivity (Ruhlen et al. 2002).

Species abundance, breeding behavior, habitat use, migratory arrival time and historical distributions of birds have been particularly well studied throughout Denali (Dixon 1927; Murie 1946; McIntyre 2007; Mizel et al. 2016; Mizel et al. 2017). Previous studies and long-term monitoring projects have identified changes in avian abundance for a few species (McIntyre 2006, 2007; Schmidt et al. 2013; Mizel 2016). Three tundra species have likely decreased in abundance or shifted their breeding ranges since record-taking began in the early twentieth century (McIntyre 2007). Species are also shifting in elevation as the composition of vegetation changes throughout the park. Fourteen of seventeen shrub-tundra species are believed to have attitudinally shifted their breeding range from 1995 to 2013 (Mizel et al. 2016). Little is known about these avian populations prior to 1995 besides two BBS routes, causal observations and life

history exploration (Dixon 1927; Murie 1946). Currently the Fox Sparrow, *Passerella iliaca,* is increasing in abundance while Wilson's Warbler, *Cardellina pusilla,* has sharply decline up to 48% over fifteen years (Schmidt et al. 2013). One understudied subset of birds occupies the open tundra and includes migratory shorebirds, seabirds, and grassland songbirds.

Recent formal and informal reports made by long-term park visitors and employees identify some of these birds as possibly being at risk to human disturbance (McIntyre 2007). These reports suggest a possible shift in the ecological baseline within the park (Soga & Gaston 2018). To better understand the effect of recreation on birds within a shifted ecological system we established a two-year-long project focusing on two objectives 1) to understand the historical distributions of birds before our study period using local knowledge; 2) to measure current occupancy rates in relation to current recreational trends. We hypothesize that 1) species of conservation concern based on local knowledge will be negatively affected by recreational pressures (Jardine 2019); and 2) smaller generalist species will be less affected by recreation than larger specialists (Miller et al. 1998).

Methods

Local Knowledge Interviews

We identified individuals with local knowledge using a snowball sampling approach. Interviewees were selected to have greater than 20 years' continuous experience within the park, ability to identify park birds, and knowledge of different regions of the park (Table1). We found eleven individuals that fit these criteria and asked them a series of fourteen multipart questions regarding their experience and observations within the park (Appendix 1). We started interviews with open-ended, multiple choice and both general and specific questions pertaining to species

richness, abundance and nesting. Questions regarding species change and composition began broadly without introducing them to species of research interest in the tundra. We later asked questions about specific tundra species within the park. Of the thirteen, six interviewees currently or previously worked for the park and commercial bus companies, two are naturalists or guides within the park, and three have lived in the park for many years and currently or formerly operated private inholdings. A majority of interviews were recorded when possible for later interpretation. We protected identities of survey respondents for their personal privacy. We transcribed these interviews and condensed them for interpretation. This study was determined exempt from federal human subject regulations by the review committee at the University of Washington (IRB ID#: STUDY00002028).

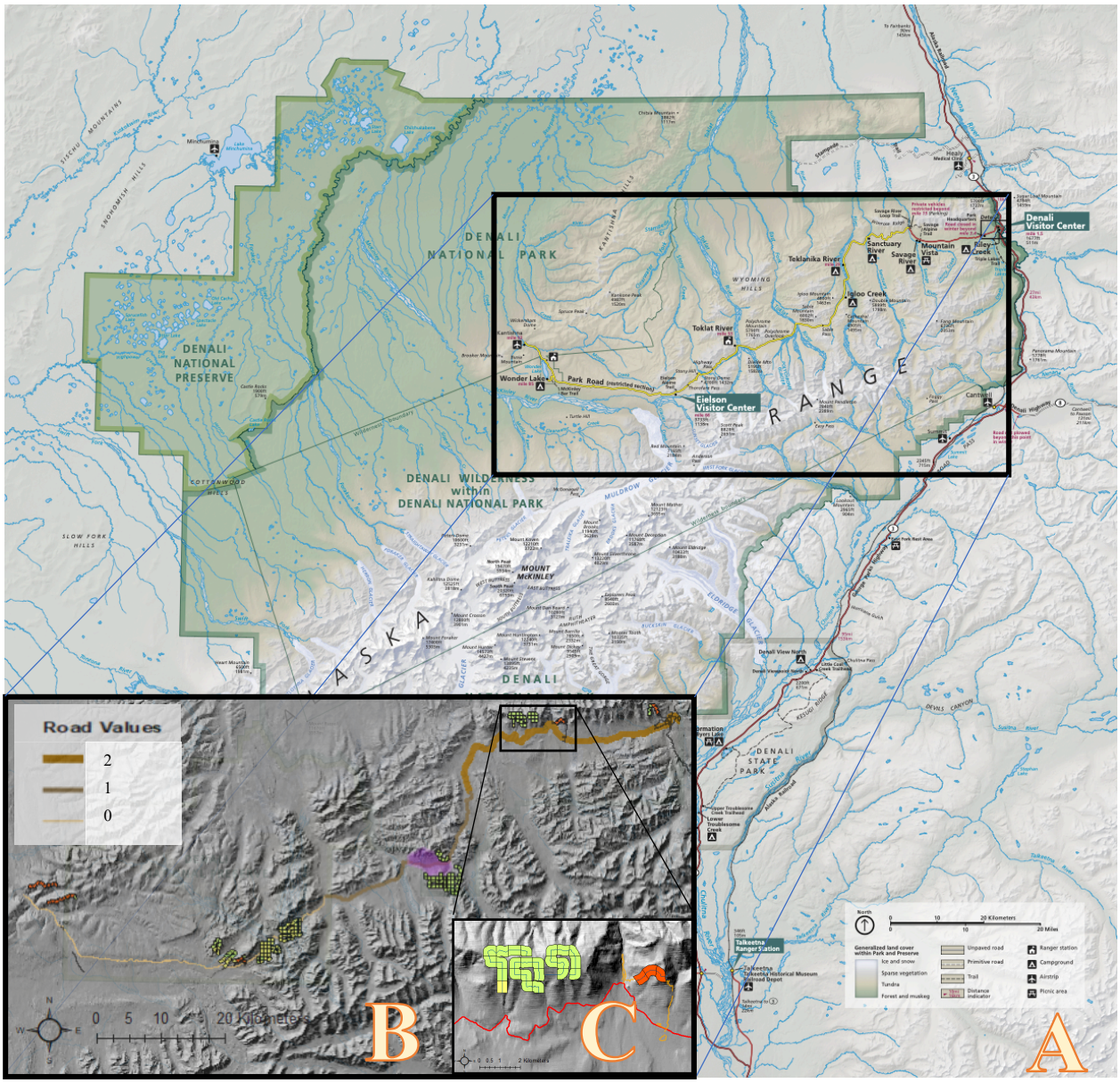
RELEVANCE	PARTICIPANTS	AVERAGE TIME IN PARK (YEARS)	LOCATION OF KNOWLEDGE
BUS DRIVER	4 (2M, 2F)	41	Road Corridor (East & West)
NATURALIST	2 (1M, 1F)	37	East to West
LANDOWNER	3 (1M, 2F)	37.67	West End (3)
EMPLOYEE	2 (2M)	30	Road Corridor (West)
TOTALS	11 (6M, 5F)	37.4	Entire road corridor

Table 1: Interviewee characteristics. Participants M = male, F = female. Time in the park is only relevant to spring and summer seasons. Locations of knowledge are relevant to the park road region of the park; road corridor represents majority observations solely from the road. East and west are in reference Toklat station (mile 53) and encompass all regions within 5 miles of the park road.

Study Area and Occupancy Surveys

Denali National Park and Preserve encompasses 6,070,029 acres of Alaskan interior (Figure 1A, NPS), which is accessible via a 144-km park road. Park records indicate that 166 species of birds have been observed within Denali, of which 119 (91 migrants, 28 residents) have been found to nest within the park's boundaries (NPS 2006; McIntyre 2007).

We distance-sampled 23 unlimited-width line transects to asses bird occupancy in mixed mountain tundra habitat above 3,000 feet in Denali (Figure 1B) between May 12th and June 30th, in 2017 and 2018 (Paton and Pogson 1996).Transects averaged 4.8 km in length and were selected at random to be within single day's hike from the park road or to include known hiking routes and trails. We broke line transects into one hundred seventy-three sites based upon comparable adequate habitat across transects and variation in recreational use. Each site was defined by taking 600m sections of each transect and creating a 250m buffer area on each side of the line (Figure 1C). Vegetation along each transect typically comprised sedges, dwarf birch, lichen and a variety of alpine flowers (Nouvet et al. 2008). Within the park we surveyed 1.6% (6644/420740 acres) of the tundra dwarf shrub vegetation which is classified below 8" in height (Stevens et al. 2001). We followed and modified the land-bird monitoring protocol for the Arctic Network in Alaska (Mizel 2017) to conduct surveys thirty minutes before sunrise until no longer than seven hours after sunrise. We followed a transect route by using preloaded maps on a Garmin76CSX GPS unit. Following each site survey, we collected weather conditions and noise data immediately.


DENALI NATIONAL PARK
DENALI NATIONAL PRESERVE
DENALI WILDERNESS within DENALI NATIONAL PARK
ALASKA RANGE
DENALI
MOUNT McKINLEY
Denali Visitor Center
Eielson Visitor Center
Wonder Lake
Park Road (restricted section)
Teklanika River
Sanctuary River
Savage River
Mountain Vista
Igloo Creek
Toklat River
Polley Creek
Cantwell
DENALI STATE PARK
Talkeetna Ranger Station
Road Values
2
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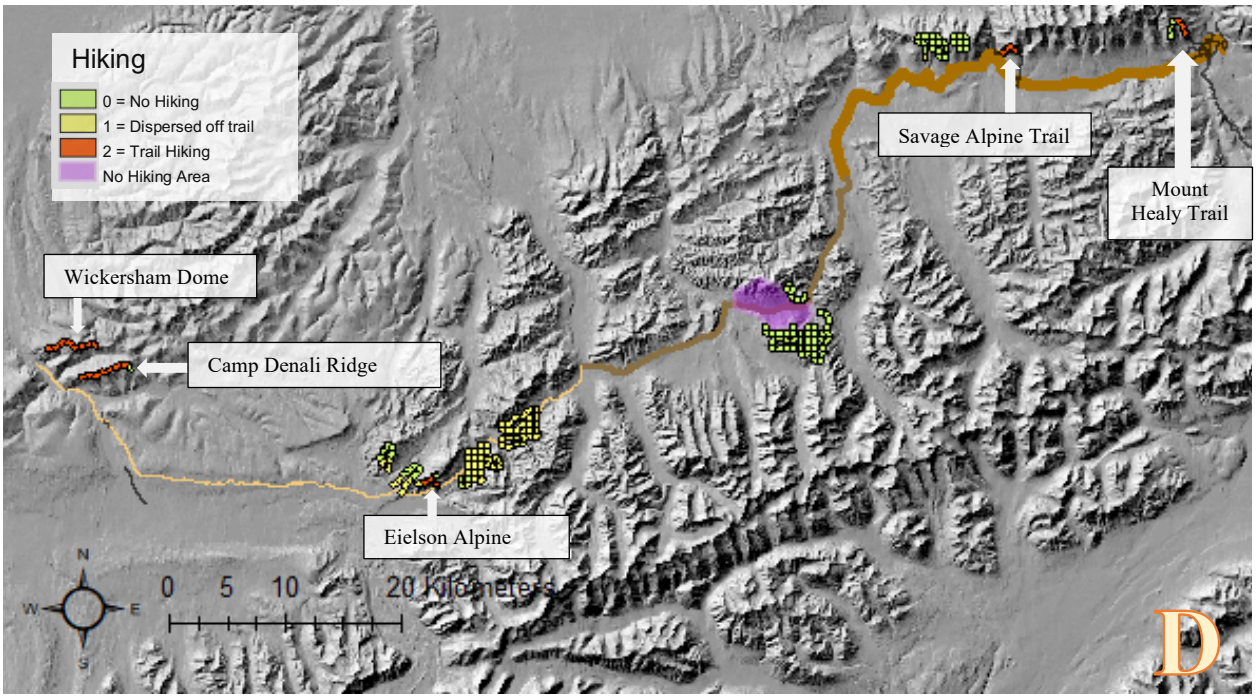


Figure 1: A) Denali National Park with study area. B) Road corridor with 173 sites (600x500m green squares). Road sections are coded by traffic volume (Table 2; 0=Low traffic volume, 1=medium volume, 2=high volume). C) Breakdown of Primrose (left, 3 routes) and Savage Alpine trail (right, 1 route) region. Blue lines represent routes through sites. Maintained Savage Alpine trail is orange. For color breakdown of sites see next panel. D) Sites by assigned hiking value: 1) (Green) No or limited Hiking, 2) (Yellow) Dispersed hiking off trail, 3) (Red) Trail Hiking. Purple area is a permanent wildlife closure off limits to any hiking off-road.

Modeling Occupancy and Detection

We modeled occupancy (ψ) and detection (p) of thirteen species that we observed occupying >10% of sites within a Bayesian framework using the package stocc (Johnson et al. 2013) in RStudio (R Core team 2015). We accounted for potential spatial autocorrection between sites by directly incorporating a spatial process into the occupancy component of the model with a spatially restricted regression approach (Johnson et al. 2013). All continuous covariates were standardized to have a mean of zero and standard deviation of one to improve model convergence.

We incorporated noise, date, survey length and time of day into detection models. Noise was considered subjectively by incorporating the intensity of the wind, the loudness of walking surface, and the degree of scolding by territorial birds (between 0-3). We considered date both linearly and with a squared term due to non-linear changes in peak detectability throughout the breeding season (Schmidt et al. 2013). We computed survey length in minutes (mean=26.33, SD=10.06). Thus, for observations Y_{ij} at site i on survey j, the detection component of the model followed a Bernoulli distribution using a probit link (Φ) such that:

$$Y_{ij} \sim Bernoulli(z_i * p_{ij})$$

$$\Phi^{-1}(p_{ij}) = \alpha_0 + \alpha_1 * Noise_{ij} + \alpha_2 * Date_{ij} + \alpha_3 * SurveyLength_{ij} + \alpha_4 * Time_{ij} + \alpha_5 * Date_{ij}^2$$

We examined a variety of occupancy covariates including distance from road, hiking, percent shrub vegetation, year and bus traffic volume. Year and shrub were considered control variables to account for differences in habitat and annual effects between sites. We measured distance from the center of each site to the Denali Park Road (distance to road). We scaled hiking from 0

– 2 using knowledge of established or maintained trails and general park use information (Stamberger et al. 2018). This produced a gradient of use from low hiking disturbance (score of 0), to medium dispersed hiking without trails (score of 1) and established or maintained hiking trails (score of 2). At routes with established or maintained trails we intentionally followed trail paths to limit disturbance and properly measure trail effects. Most visitor use is concentrated on trails compared to hiking cross country at higher elevations within the park (Stamberger et al. 2018). We calculated shrub vegetation from the 2008 Denali Landcover mapping project and combined open Spruce, stunted spruce, broadleaf, Alder, Willow, closed low birch, low shrub birch and low shrub sedge (Stevens et al. 2001). These categories represent vegetation taller than 8", which are currently expanding throughout the park road corridor (Roland & Stehn 2013). To improve model convergence and reduce parameters, we converted bus traffic volume categories to a numeric integer value between zero and two with higher values representing more buses (Table 2, Figure 1). Thus, occupancy at each site i, z_i, followed a Bernoulli distribution using a probit link (Φ) such that:

$$z_i \sim Bernoulli(\psi_i)$$

$$\Phi^{-1}(\psi_i) = \beta_0 + \beta_1 * RoadDist_i + \beta_2 * Hiking_i + \beta_3 * ClosedVeg_i + \beta_4 * Year_i + \beta_5 * Traffic_i + \eta_i + \epsilon_i$$

where $[\epsilon_i] = Normal(0, 1)$ and each η_i is a realization of a Gaussian spatial process (see Johnson et al. (2013) for details on the spatial process).

Bus Type	*Span*	*Bus days*	*Number of Buses*	*AVG. Buses Per day*	*Assigned value*
Tour	HQ-Teklanika	52	2464	47.38	2
Tour	Teklanika-Toklat	42	1804	42.95	1
Tour	Toklat-Kantishna	42	1540	36.67	0
Transit	HQ-Teklanika	47	1299	27.64	2
Transit	Teklanika-Toklat	41	923	22.51	1
Transit	Toklat-Kantishna	30	659	21.97	0
Combined	HQ-Teklanika	49.5	3763	76.02	2
Combined	Teklanika-Toklat	41.5	2727	65.71	1
Combined	Toklat-Kantishna	36	2199	61.08	0

Table 2: Bus volume along the Denali Park Road corridor between May 1st and June 30th, 2017. Only transit buses allow bus passengers to depart for hiking or camping purposes. HQ represents the park headquarters at kilometer 1; Teklanika is a rest stop and turnaround point at kilometer 48; Toklat is the most common turnaround point at kilometer 81; Kantishna represents the end of the park road at kilometer 144. Assigned values are based on relative combined traffic volume.

In our analysis, we spatially reconstructed the landscape with each bird detected in ArcGIS (v.10.6, ESRI). We sampled all birds detected within a buffer zone of 250m and discarded flyover detections. We ran full spatial occupancy models for 60,000 iterations with a burn-in rate of 10,000 and a thinning rate of four. We inspected all parameters for convergence visually and with Geweke diagnostics (Geweke 1991). When convergence was not acceptable, we altered our threshold values (1000-2000m), and Moran cut values (0.01-0.1), then compared the goodness of fit. Threshold values increase the size of our precision matrix to take into account a greater area. Moran cut values alter how much of the full ICAR model we subsample using the RSR process. When neither of these approaches worked, we dropped the road disturbance covariate which improved model convergence.

Results

Local Knowledge

A majority of those we interviewed reported substantial changes in the avifauna of Denali. Two-thirds of interviewees said they had noticed changes in species richness while one hundred percent of interviewees reported changes in species abundance. When asked to further specify these changes, a majority cited decreases in thirty-six different species, and stable or increasing numbers for thirty-seven species (Appendix II). Every respondent noticed decreases in the abundance of American Golden-Plovers and Long-tailed Jaegers since they started visiting the park (Figure 2). Some noticed increasing species such as Black-billed Magpie, *Pica hudsonia*, Mew Gull, *Larus canus*, and Greater White-fronted Goose, *Anser albifrons* with two, two and three respondents mentioning them respectively. Interviewees also occasionally mentioned stable

species, notably Horned Lark, *Eremophila alpestris,* (4 mentions), American Pipit, *Anthus rubescens,* (3) and Wandering Tattler, *Tringa incana* (3).

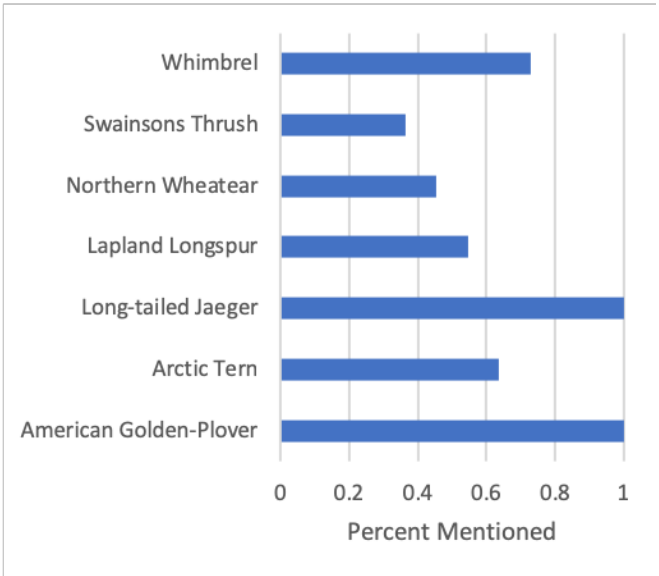


Figure 2: Species of conservation concern mentioned to be declining within Denali National Park and Preserve over the past 20-50 years.

Interviewees also identified the most commonly cited historical nesting locations for shorebird species of conservation concern within the park. The most common nesting places mentioned were: Little Stony Flats, the Plover Ponds (west end), Stony Dome, Primrose, and Highway Pass (Figure 3). Each of these areas saw changes in abundance or disappearance of shorebird species from the respondent's perspective. The species that appears most affected at these locations were American Golden-Plover, Long-tailed Jaeger, and Whimbrel, *Numenius phaeopus*.

In addition to changes in birdlife, interviewees noticed increases in recreation, disturbance, and general ecology. The most commonly cited recreational change in the park was the disturbance associated with the increase in bus traffic (all 11 mentioned). Other changes included notable increases in vegetation, phenology, warming, total visitation, east-end development, dust, and overflights. When queried directly about trails of concern for wildlife, interviewees identified Eielson Alpine trail (Figure 1D) as the most problematic, noting especially how the trail openly ends on the ridge creating a spillover effect of human use. Social trails were mentioned infrequently as being problematic for wildlife.

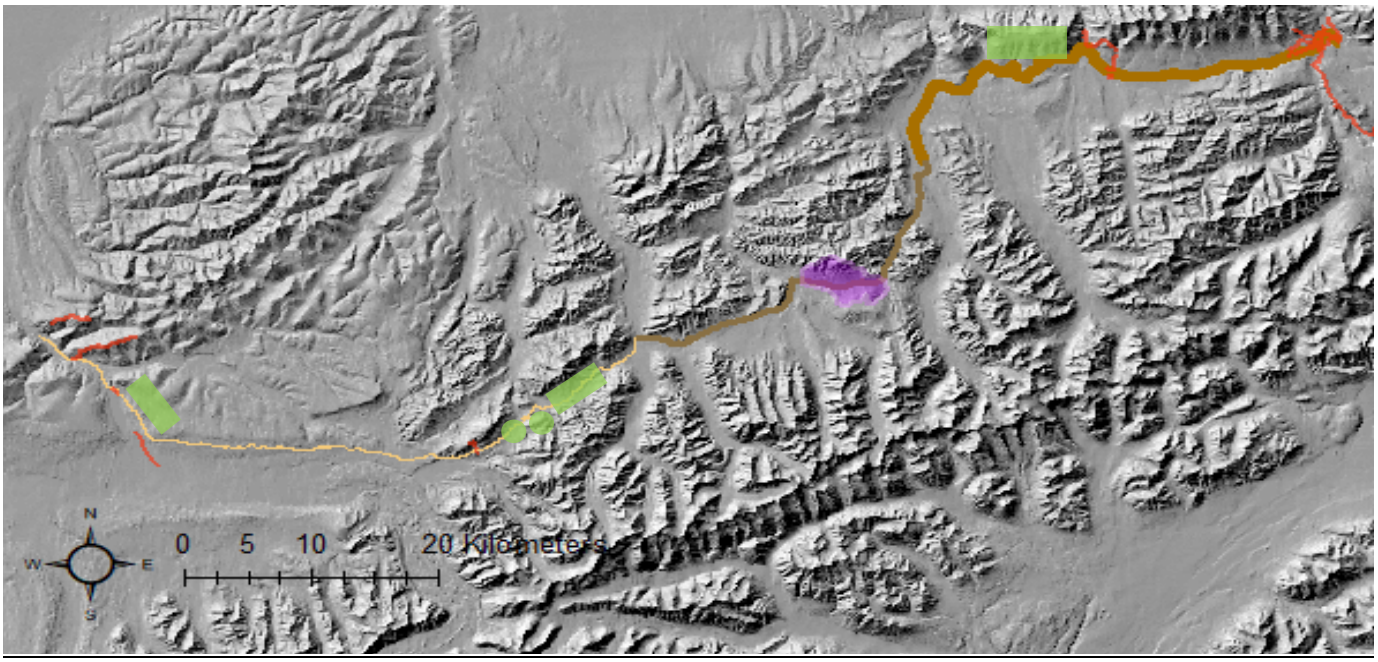


Figure 3: Historical nesting locations identified by local knowledge (green). Red lines represent trails and purple shading is the Sable Pass permanent wildlife closure.

Detection

We modeled the detection of thirteen bird species: ten songbirds (Passeriformes), two shorebirds (Charadriiformes) and one species of ptarmigan (Galliformes). Detection parameters outputs varied between species (Table 3). Increases in noise during surveys only reduced detection of two species, however, most surveys were quiet (average noise during surveys was 0.55 (SD=0.78) with 60% of all surveys recording a noise value of zero). We surveyed each site an average of 26.33 minutes (SD=10.06). Longer surveys lead to higher detection for nine species and surveys were typically shorter later in the season. Start time only significantly affected Lapland Longspur, *Calcarius lapponicus*, with lower detections later in the day. Date showed mixed responses, positively affecting Wilson's Warbler, and Golden-crowned Sparrow, *Zonotrichia altricapilla,* but negatively impacting three other species. Detection of Willow Ptarmigan, *Lagopus lagopus,* was most impacted by survey date, with a dramatic drop in detections after the second survey. Three species had peak detection in the middle of the season. Lapland longspur was the only species to exhibit a dip in mid-season detection rates.

Surveys of transects on established or maintained trails versus those not on trails revealed differences in average detection distances for two species (Figure 4). Horned Larks were detected on average closer to transects that ran along trails than to transects off trail, whereas White-crowned Sparrows, *Zonotrichia leucophrys,* were detected farther from transects along trails than from those off trails.

SPECIES	INTERCEPT	NOISE	SURVEY LENGTH	START TIME	DATE	(DATE)^2
AMERICAN GOLDEN-PLOVER	-0.41(0.83)	-0.06(0.13)	**0.25(0.12)**	0.05(2.56)	-0.21(0.12)	-0.09(0.10)
AMERICAN PIPIT	-0.30(0.34)	0.00(0.08)	**0.23(0.07)**	0.60(1.10)	**-0.17(0.06)**	0.09(0.06)
AMERICAN TREE SPARROW	1.39(0.44)	-0.24(0.12)	0.21(0.10)	-2.43(1.45)	-0.07(0.09)	-0.01(0.09)
FOX SPARROW	-0.50(0.45)	0.13(0.13)	**0.64(0.13)**	1.33(1.48)	0.06(0.10)	-0.12(0.09)
GOLDEN-CROWNED SPARROW	0.58(0.43)	-0.23(0.14)	**0.26(0.09)**	-1.83(1.4)	**0.30(0.10)**	**-0.21(0.09)**
HORNED LARK	-0.37(0.43)	0.05(0.08)	-0.02(0.07)	0.77(1.41)	**-0.17(0.07)**	-0.03(0.06)
LAPLAND LONGSPUR	-0.76(0.20)	0.05(0.15)	**0.36(0.18)**	**-0.45(0.16)**	-0.10(0.11)	**0.21(0.11)**
LONG-TAILED JAEGER	-0.49(0.78)	**-0.48(0.20)**	**0.34(0.11)**	-0.12(2.54)	0.06(0.13)	-0.04(0.12)
ORANGE-CROWNED WARBLER	-0.13(0.57)	0.07(0.15)	**0.38(0.13)**	0.12(1.88)	0.22(0.12)	-0.25(0.12)
SAVANNAH SPARROW	1.07(0.34)	-0.08(0.09)	-0.03(0.07)	-1.36(1.15)	0.01(0.07)	-0.02(0.07)
WHITE-CROWNED SPARROW	1.26(0.34)	-0.07(0.10)	**0.22(0.07)**	-2.16(1.14)	-0.05(0.07)	**-0.13(0.07)**
WILSON'S WARBLER	0.48(0.40)	-0.11(0.12)	**0.23(0.09)**	-0.90(1.37)	**0.41(0.09)**	**-0.39(0.09)**
WILLOW PTARMIGAN	0.10(0.42)	-0.18(0.13)	0.14(0.09)	-0.93(1.38)	**-0.69(0.09)**	-0.02(0.09)

Table 3: Posterior mean detection parameter estimates and standard deviations on the probit scale. Bold values represent 95% Bayesian confidence intervals that do not cross zero.

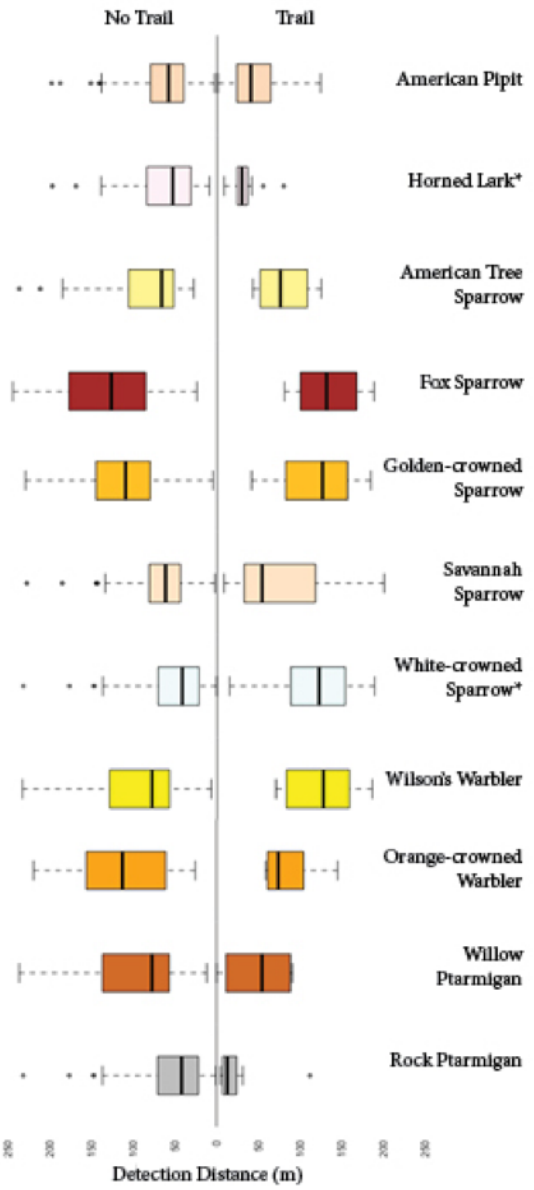
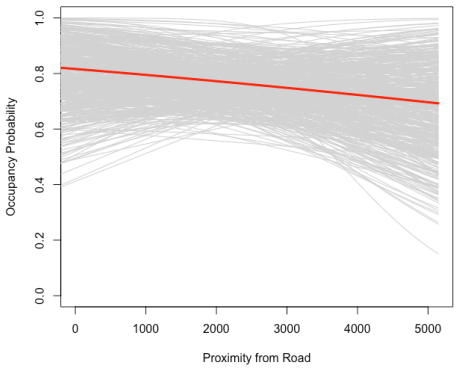


Figure 4: Mean detection distance of species along transects on established trails (n=24) versus off trail (n=149). Only species detected at both trail and off trail routes were included.
* represent significant differences in means using a one-way anova.

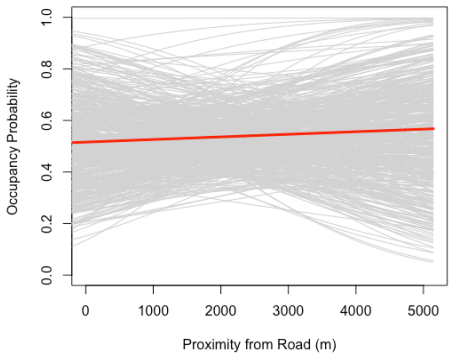
Occupancy

Distance from the road was a strong predictor of species occupancy probability (Figure 5, Table 4). Detections of five species increased as we sampled closer to the road, while detections of two species increased in sites farther from the road. The likelihood that Horned Larks and Lapland Longspurs occupied a site decreased with proximity to the Park Road whereas that of both warbler species, Willow Ptarmigan, and two sparrow species increased. Wilson's Warbler was the species most likely to occupy sites near the road. This species and the Fox Sparrow also were common in areas with greater bus traffic volume. American Tree-Sparrow*, Spizella arborea,* was the only species to exhibit reduced occupancy of sites with increased bus traffic.

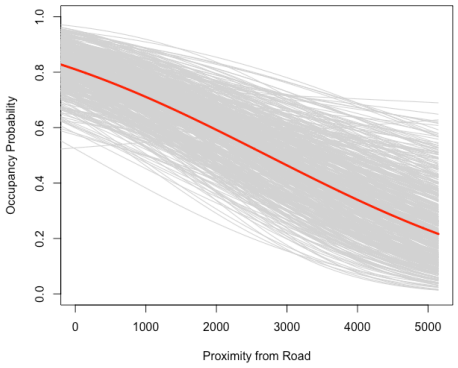
American Pipit



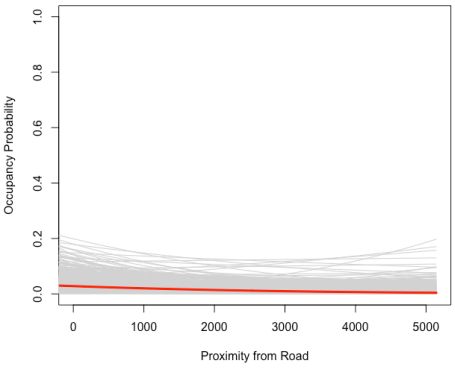
American Golden-Plover



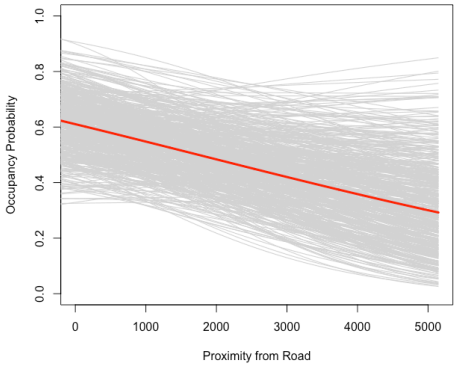
American Tree Sparrow



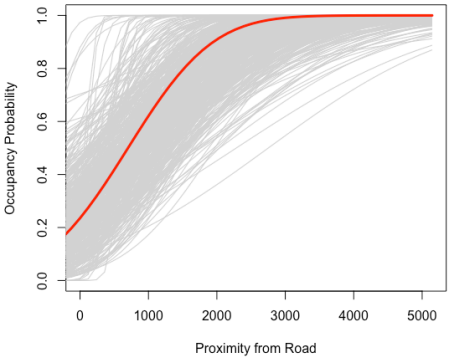
Fox Sparrow



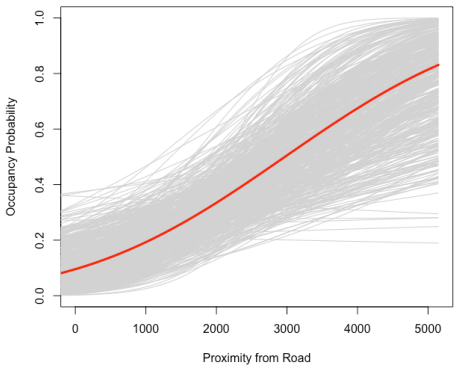
Golden-crowned Sparrow



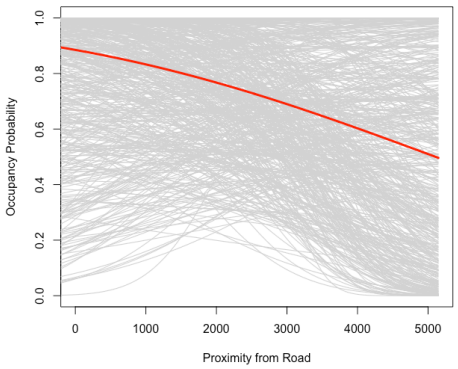
Horned Lark



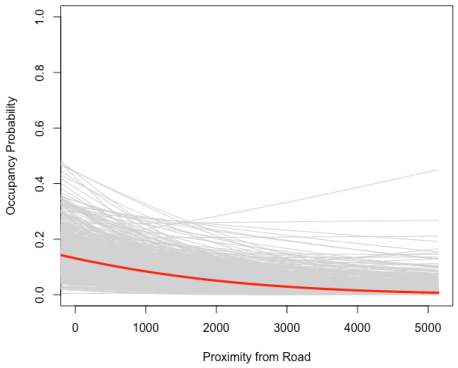
Lapland Longspur



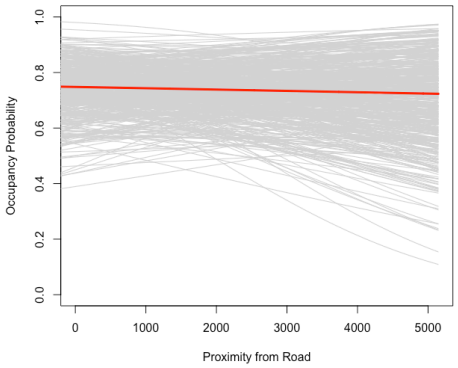
Long-tailed Jaeger



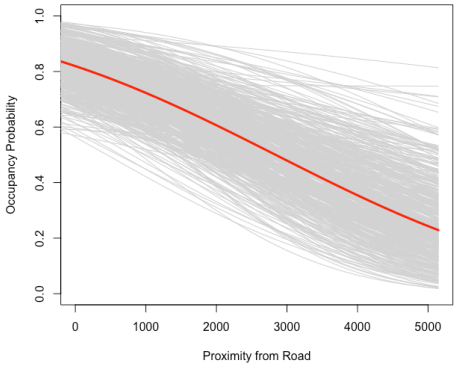
Orange-crowned Warbler



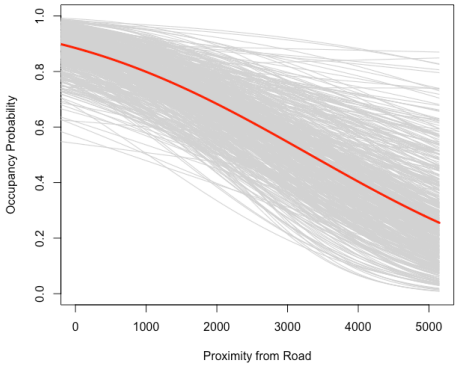
Savannah Sparrow



White-crowned Sparrow



Willow Ptarmigan



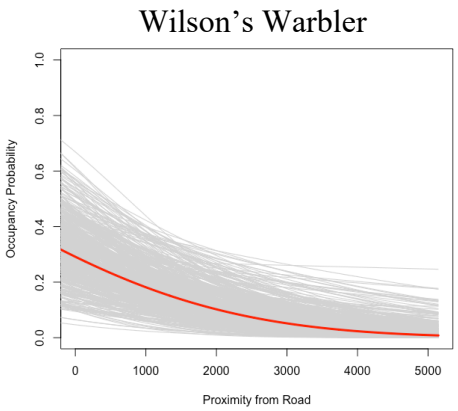


Figure 5: Occupancy probabilities in response to road proximity. Red lines represent posterior mean estimates and gray lines are 500 random samples pulled from the occupancy process.

SPECIES	INTERCEPT	ROAD DISTANCE[1]	HIKING[2]	CLOSED VEGETATION[3]	YEAR[4]	TRAFFIC VOLUME[5]
AMERICAN GOLDEN-PLOVER	0.33(1.71)	0.08(0.44)	**-1.49(1.32)**	0.30(0.34)	-0.43(0.40)	-
AMERICAN PIPIT	0.78(0.30)	-0.09(0.18)	0.47(0.45)	**-0.56(0.16)**	0.14(0.35)	-
AMERICAN TREE SPARROW	0.38(0.28)	**-0.39(0.13)**	**-0.40(0.19)**	**0.70(0.14)**	-0.04(0.28)	**-0.41(0.20)**
FOX SPARROW	-2.13(0.37)	-0.17(0.14)	**0.66(0.22)**	**0.35(0.14)**	**1.19(0.33)**	**0.93(0.25)**
GOLDEN-CROWNED SPARROW	0.03(0.28)	-0.19(0.13)	-0.03(0.19)	**0.26(0.13)**	-0.33(0.27)	-0.25(0.20)
HORNED LARK	0.88(1.23)	**1.23(1.03)**	0.56(0.43)	-0.26(0.44)	-0.29(0.62)	-0.22(0.71)
LAPLAND LONGSPUR	-0.62(0.27)	**0.53(0.23)**	**-0.62(0.27)**	-0.19(0.21)	-0.05(0.41)	-
LONG-TAILED JAEGER	0.83(0.95)	-0.28(0.61)	**-3.98(2.04)**	**3.0(1.24)**	**-2.57(1.09)**	-
ORANGE-CROWNED WARBLER	-1.53(0.35)	**-0.31(0.16)**	0.11(0.20)	0.14(0.15)	**0.79(0.34)**	0.28(0.21)
SAVANNAH SPARROW	0.65(0.27)	-0.02(0.13)	-0.03(0.18)	**0.67(0.15)**	0.22(0.27)	-0.08(0.17)
WHITE-CROWNED SPARROW	0.41(0.29)	**-0.39(0.14)**	0.29(0.20)	**0.47(0.14)**	0.26(0.29)	-0.04(0.19)
WILLOW PTARMIGAN	0.64(0.31)	**-0.43(0.16)**	**-0.70(0.22)**	**0.54(0.17)**	0.53(0.33)	-0.32(0.21)
WILSON'S WARBLER	-1.11(0.32)	**-0.43(0.15)**	0.29(0.21)	**0.35(0.15)**	**0.74(0.32)**	**0.54(0.22)**

Table 4: Posterior mean parameter estimates and standard deviations for occupancy covariates on the probit scale. Bold values represent 95% Bayesian credible intervals that do not cross zero.
[1] Positive values represent increased occupancy probability farther from the road.
[2] Positive values represent increased occupancy probability with increased hiking
[3] Positive values represent increased occupancy probability with taller shrub vegetation
[4] Positive values represent increased occupancy probability in 2018 from 2017.
[5] Positive values represent increased occupancy probability at areas with greater traffic volume.

Hiking also was a useful predictor of occupancy probability. Some form of hiking was measure in fifty percent of all sites. A majority of dispersed hiking was near the road because of access and convenience. Overall, hiking negatively affected occupancy probability of five species, notably Lapland Longspur, Long-tailed Jaeger and American Golden-Plover. These three species were rarely detected on trails and were rare at dispersed hiking sites. Fox Sparrow was the only species whose occupancy probability was significantly positively related to the intensity of hiking.

Survey year and shrub cover explained some of the variation in the occupancy probability of many species. Closed/shrub vegetation was a useful predictor variable, with the occupancy probability of nine of thirteen species significantly affected by shrub cover. All species of sparrow occupied sites with more shrub, whereas American Pipit was the only species to be negatively associated with shrubby sites. We also found a positive year effect in 2018 for four of thirteen species. Long-tailed Jaeger was the only species to show an adverse year affect from 2017 to 2018.

Discussion

Recreation has far-reaching impacts on the conservation of multiple species including those in the tundra ecosystem. We find that on the tundra of one of the world's largest national parks, recreation is problematic for several bird species. People regularly visiting, living, and working in the park noticed these declines over the past four decades, establishing a shifted baseline of birdlife in the park (Soga and Gaston 2018). By expanding upon local knowledge with modern occupancy surveys, we suggest that this baseline will continue to erode for sensitive tundra-obligate nesters, such as American Golden-Plover, Long-tailed Jaeger, and Lapland Longspur,

which rely on open vistas for nest placement that enable mate recruitment, predator detection and avoidance (Murie 1946; Drury 1961; Keyel et al. 2013).

Integrating modern surveys with historical insights enhanced our ability to understand ecological change. Local knowledge suggested that many species declined or were extirpated in the several decades prior to our study. Furthermore, original writings by Adolf Murie (1946) in the early part of the 20th century suggest even earlier ecological changes (McIntyre 2007). Our modern study suggests that Arctic Tern, *Sterna paradisaea,* Northern Wheatear, *Oenanthe oenanthe,* and Whimbrel are extinct or nearly so within the park road corridor. Without incorporating local knowledge, we would not understand the current altered state of the park's environment (Jardine 2019).

We determined that recreational pressures including the park road affect current species occupancy in the tundra ecosystem. The park road attracted more species than it repelled, but those repelled were of greater conservation concern. Species that were negatively affected by the road likely avoid its constant disturbance and the presence of both people and vehicles along the road corridor. We found that both Lapland Longspur and Horned Lark had lower occupancy probability near the road. This is at odds with previous studies that have found Horned Larks nesting in close proximity to roads in lower latitudes (Cannings & Threlfall 1981). BBS data collected within the park since 1982 also reveals decreases in Lapland Longspurs along the road corridor and consistently low Horned Lark detections (Pardieck et al. 2018). Our study suggests Horned Larks in the tundra ecosystem may react differently than they do at lower latitudes. We may have observed these difference because of increased predator pressure along the road leading to lower nesting success (Goullaud et al. 2018). The road itself is the most constant source of disturbance on the landscape, with frequent bus use every day between mid-May to mid-September. Road disturbance could translate into problems for wildlife in many ways

because people, animals, and predators all use the roadway for travel and to search for food. The downstream effects of the park road likely ripple across the landscape depending on surrounding habitat and frequency of use. Many species of sparrows, warblers and ptarmigan also had higher occupancy probabilities near the road in this study. These species may exploit edge created by the road, while others might discount its presence and experience higher predation rates (Miller et al. 1998; Walker and Marzluff 2015).

Bus traffic volume had mixed effects on three tundra species, none of conservation concern. Traffic volume is dramatically different along sections of the park road and is expected to continue to increase in future years. Bus travel peaks in late June for the remainder of the summer and was fairly constant in both years of our study. However; the amount of buses and vehicles on the landscape has steadily increased over the past few years, increasing the presence of vehicles on the landscape and in tundra areas where a majority of wildlife stops occur (McKenny et al. 2013). The openness of the tundra means sound travels far and buses are visible from a long distance. Species that reacted positively to traffic volume may not be affected by constant visual and noise disturbances. Some species may have already abandoned areas near the road due to increases in bus traffic that our study was unable to document.

Many species' occupancy probability was negatively affected by hiking. Trail hiking within the park and across the country has grown dramatically over the past twenty years and likely has altered significant habitat (Cordell 2010). Before trails, Denali was considered one of the greatest trail-less wildernesses in the world. The recent expansion of maintained trails has led to frequent access to regions that used to be limited to off-trail hiking. Five species were negatively affected by hiking including three species of conservation concern: American Golden-Plover, Lapland Longspur and Long-tailed Jaeger. These species were extremely rare at routes with a trail and sparse in sites with dispersed hiking compared to historical descriptions (Murie

1946). In the grassland ecosystem species have been recorded nesting in lower densities near trails (Miller et al. 1998). Tundra species negatively affected by hiking likely experience similar issues as grassland species and avoid regions of high human activity because they forage and nest on the ground (Murie 1946; Thompson et al. 2015; Meeker 2019). Fox Sparrow was the only species where occupancy probability was positively influenced by hiking, showing that they may benefit from the extirpation of other species that cannot tolerate disturbance at both trail and trail-less regions of the park.

Sampling from a trail also had an effect on detection distance compared to trail-less survey routes for two species. We detected Horned Lark's closer to trails than non-trail routes, and White-crowned Sparrows farther from trail routes. This suggests while Horned Larks may be deterred by the road, they are more tolerant of trail disturbance. These results are similar to grassland studies and forest studies that have found increasing species abundance away from trails (Miller et al. 1998). This may be due to alterations in habitat surrounding tundra trails where shrub is limited and larks have access to small open patches of dirt for bathing (Cannings & Threlfall 1981).

Controlling for year and vegetation proved important in understanding species occupancy probabilities on the landscape. The effects of the year were prevalent in four species with both warbler species and Fox Sparrow increasing between 2017 and 2018. Previous studies in the park have found Wilson's Warblers decreasing in abundance between 1995-2009 by 48%, our data, while extremely limited, suggest this trend may be continuing (Schmidt et al. 2013). Long-tailed Jaeger was the sole species to respond negatively in the second year of our study, which could be due to changes in snow cover or nesting preference between years (Maher 1970). Shrubby vegetation was associated with increased occupancy by a majority of species. This suggest that many species will increasingly occupy the tundra as more shrub vegetation

colonizes high latitudes while some tundra obligate species decline (Thompson et al. 2016). In our study the species most at risk of being affected by shrubby vegetation colonization is the American Pipit.

Our results indicate that increasing visitation and climate-driven changes in shrub cover reset the baseline bird diversity and abundance within a large protected area. Recent recreation in a variety of forms is continuing to affect species occupancy of high elevation tundra. Understanding these effects within the US National Park we studied is essential for managers facing the dual mandate of the National Park Service, which is to conserve species while providing recreational opportunities for visitors (Organic Act 1916). Park managers seeking to balance human recreation with the needs of sensitive tundra-breeding birds should consider locating new trails in shrub-lands or forest, improving current trails to reduce nearby habitat disturbance, limiting and concentrating access to tundra hiking areas during the early breeding season, educating tourists about ground nesting tundra birds, and closing especially important nesting areas to the public. Limiting bus and hiking and road disturbance during the critical early breeding months could dramatically protect species currently believed to be declining throughout the park. Concentrating humans and vehicles on the landscape during the breeding season would reduce frequent disruption to many species on the tundra landscape and increase quiet times for hikers and wildlife. Respondents we interviewed also suggested a variety of possible solutions to help protect species from future issues. Suggestions include limiting bus traffic (6), increasing alpine tundra education (2) and embracing and teaching the trail-less philosophy (2).

Acknowledgements:

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Appendix 1:

INTERVIEW QUESTIONS for long-term residents and visitors to Denali:

1. What is your relationship with Denali NP?
2. What time periods have you visited Denali National Park and approximately how many times have you visited during those periods?

- ☐ <1960 # of visits: _____
- ☐ 1960 - 1970 # of visits: _____
- ☐ 1970 - 1980 # of visits: _____
- ☐ 1980 - 1990 # of visits: _____
- ☐ 1990 - 2000 # of visits: _____
- ☐ 2000 - 2010 # of visits: _____
- ☐ 2010 - Present # of visits: _____

3. Can you estimate how many times you've visited the park in each of these months?

May: _____

June: _____

July: _____

4. In general, what are the most apparent changes you've noticed in the park over this period?
5. In the park corridor have you noticed changes with birds regarding:
   a. Overall number of species? Yes or No
   b. Nesting behavior? Yes or No
   c. Abundance in the park corridor? Yes or No
6. (If you answered yes to any part of question 5) Please describe the changes you have seen, give the time period in which you noticed them and highlight on our map where they may have occurred.
7. Which specific birds have you noticed changes in abundance in Denali NP?
   I. Stable: _____

_____

   II. Increased: _____

_____

III. Decreased: _____

_____

8. Which specific high elevation birds have you noticed changes in abundance in Denali NP?

I. Stable: _____

_____

II. Increased: _____

_____

III. Decreased: _____

_____

9. We are focusing some of our efforts on understudied species within the park. Two of these species are the Surfbird and the American Golden-Plover, do you have any unique or specific observations about these birds?

10. Have you ever observed Surfbird or American Golden-Plover breeding within the park corridor? Location: _____

11. How do you think birds are reacting to:

i. Park road?	Positive	No change	Negative
ii. Maintained trails?	Positive	No change	Negative
iii. Social trails?	Positive	No change	Negative

12. How do you feel about trails in Denali and do you think they have effects on the local birds in the area? Do any specific trails stand out to you as good or bad for birds?

13. Would you like to see the park take more action to protect the birds of Denali National Park in future?

14. Is there anything else regarding the state of birds in Denali that you would like to share with me?

Appendix II: Survey responses for species listed as increasing, stable or decreasing populations. Numeric values represent multiple mentions by different people.

Population Perception	Species List
Increasing	GWFG (3), MEGU (2), BBMA (2), shrub-dwellers/sparrows (2) PEFA, AMRO, GCSP, WIPT, SPGR, BRCR, RBNU, Gulls, TRSW, FOSP, LISP, HARLANS, NOHA, SEOW
Stable	HOLA(4), AMPI(3), WATA(3), OCWA(2), GOEA, NOHA, NOWH, NOSH, ARWA, SWTH, COLO, BBMA, CORA, Scaup, Mallard, Pintail, Hawk-owl, Ptarmigan, Redpoll, Crossbill, Grosbeak, GCRF, MEGU
Decreasing	AMGP(11), LTJA(11), WHIM(8), LALO(6), ARTE(7), NOWH(5), SWTH(4), SAPH(2), BOGU(3), SURF(2), NOPH(2), UPSA, CLSW, WCSP, LTDU, RTLO, SNBU, SAVS, SEOW, VATH, SEPL, CATH, GCTH, BASA, TOSO, RUBL, GYLE, BOGU, HADU, NOSH, RNPH, WIWA, HETH, GWFG, Scoter, MYWA

CHAPTER 2

The Effects of Recreation on Breeding Shorebirds (Charadriiformes) in Denali National Park and Preserve

Avery Meeker

Abstract

*Recreation worldwide is rapidly increasing, with little understanding of its impacts on breeding by shorebird species. We studied the effects of hiking and road disturbance on breeding success of four shorebird species at two sites with dramatically different recreational activity within Denali National Park and Preserve over two years. The low recreation site contained 17 shorebird territories an average of 3184m from the road and was located adjacent to a permanent wildlife closure, which limited recreational use of the area. The high recreation site contained 14 territories an average of 590m from the road in an area of frequent hiking activity. Shorebirds (*American Golden-Plover*, Pluvialis dominica,* Wandering Tattler*, Tringa incana,* Whimbrel*, Numenius phaeopus and* Long-tailed Jaeger*, Stercorarius longicaudus) nesting at the site with increased human access and hiking activity hatched eggs from 50% fewer territories than did those within the low recreation site. However, fledging of chicks by parents that successfully hatched eggs was high and similar at both sites. Our findings suggest that dispersed hiking and frequent road disturbance across the high latitude tundra can negatively affect breeding shorebirds during the nesting phase, but not after hatching, when precocial young are highly mobile.*

Introduction

The order Charadriiformes, collectively 'shorebirds,' including American Golden-Plover *Pluvialis dominica*, Wandering Tattler *Tringa incana*, Whimbrel *Numenius phaeopus* and Long-tailed Jaeger *Stercorarius longicaudus,* is experiencing population declines worldwide due to rapid habitat alteration on both breeding and nonbreeding grounds (Studds et al., 2017; Kubelka et al., 2018). These effects are mostly attributed to increased woody vegetation cover and predation from changes such as reduced arvicoline (formerly microtene) rodent populations, and climate change (Studds et al., 2017, Thompson et al., 2017, Kubelka et al., 2018; Wieser et al., 2018). In addition to these effects, recreation, which is also increasing in high latitude tundra areas, may affect shorebird behavior and breeding success (Reed & Merenlender, 2008, Cordell, 2010). Activities such as hiking, both on and off-trail, and road disturbance from motorized and unmotorized vehicles negatively affect many avian populations including shorebirds (Miller et al., 1998; McGowan & Simons, 2006; Larson et al., 2016) These recreational activities affect birds by increasing energetic stress, predation (Miller et al., 1998; Miller and Hobbs, 2000; McGowan and Simons, 2006), altering activity budgets (Steidl and Anthony, 2000), and reducing overall productivity (Ruhlen et al., 2002). Recreational activity is not detrimental to all avian species, such as those with generalist diets (Deluca and King, 2014). However, specialists, including many shorebird species, may not tolerate recreation because of its rapid habitat alteration and disruption of sensitive breeding and foraging behaviors (Miller et al., 1998; Wolf et al., 2013).

Few formal studies have investigated avian responses to changes that are occurring at high latitudes. As snow-free periods lengthen, the time appropriate for egg laying also grows, which is thought to account for an observed increase in the likelihood of clutch completion in

some arctic-breeding shorebirds (Weiser et al., 2018). However, warmer conditions may also lead to increased nest predation, which has been consistently found across all clades of shorebirds (Kubelka et al., 2018). How these changes interact with human recreation, which is limited to a few summer months of intense use each year in the arctic, is unknown.

Denali National Park and Preserve in interior Alaska (hereafter 'Denali') has seen consistent increases in recreational visits over the past 40 years (NPS 2019). The park manages visitors by placing limits on public vehicle access to a majority of the park road and advocates a trail-less wilderness. This makes Denali ideal for understanding the environmental effects of dispersed, non-consumptive recreational activities. Recent formal and informal reports made by long-term park visitors within Denali identify several shorebirds, notably Artic Tern, Whimbrel, Long-tailed Jaeger, and American Golden-Plover, as possibly being at risk to human disturbance (McIntyre, 2007; Meeker and Marzluff, 2019). Denali's avifauna has been well documented since the early part of the 20th century, and researchers have explored a variety of topics (Schmidt et al., 2018, Williams pers. com.), but little effort has been made to understand breeding shorebirds or effects of recreation on birds in general.

To begin to understand the effect of recreation on high latitude shorebirds we studied four species of Charadriiformes. Our objectives were to track success at breeding territories at two sites, one with high recreational pressure from hiking and road disturbances and one low recreation site far from the road with little hiking and adjacent to a permanent wildlife closure. We followed territories from establishment through pairing, nesting, hatching, and fledging of young. We tested the hypothesis that territories near high recreational disturbance (in our study those closer to the road and in frequent hiking areas) will have low success at hatching eggs and fledging young.

Methods

Study Site

We studied shorebirds at two alpine tundra sites in interior Alaska within Denali (63.720916 N, -148.965947 W). Each site was accessible from the 144km park road corridor within a single day's hike: Sable Pass, and the Highway-Thorofare valley (Figure 1). Recreation use at these two sites is quite different but consistent across years. Both are in areas where driving is limited to only park-approved vehicles. Sable Pass is found near kilometer 60 of the park road and is shielded from road disturbance because of its location adjacent to a permanent wildlife closure. The closure limits off-road hiking to the area which makes accessing the non-closed region of the valley almost inaccessible to the public. Both Highway and Thorofare passes are common off-road hiking areas within the park and see constant use throughout the shorebird breeding season (Figure 1). Hiking is concentrated in this tundra region because of its accessibility to well-known day hiking and camping locations, and because of the open tundra landscape, which is preferred by most hikers (Stamberger et al., 2018). The National Park service conducts hikes in this area through interpretive hikes and by a private inholding lodge named Camp Denali.

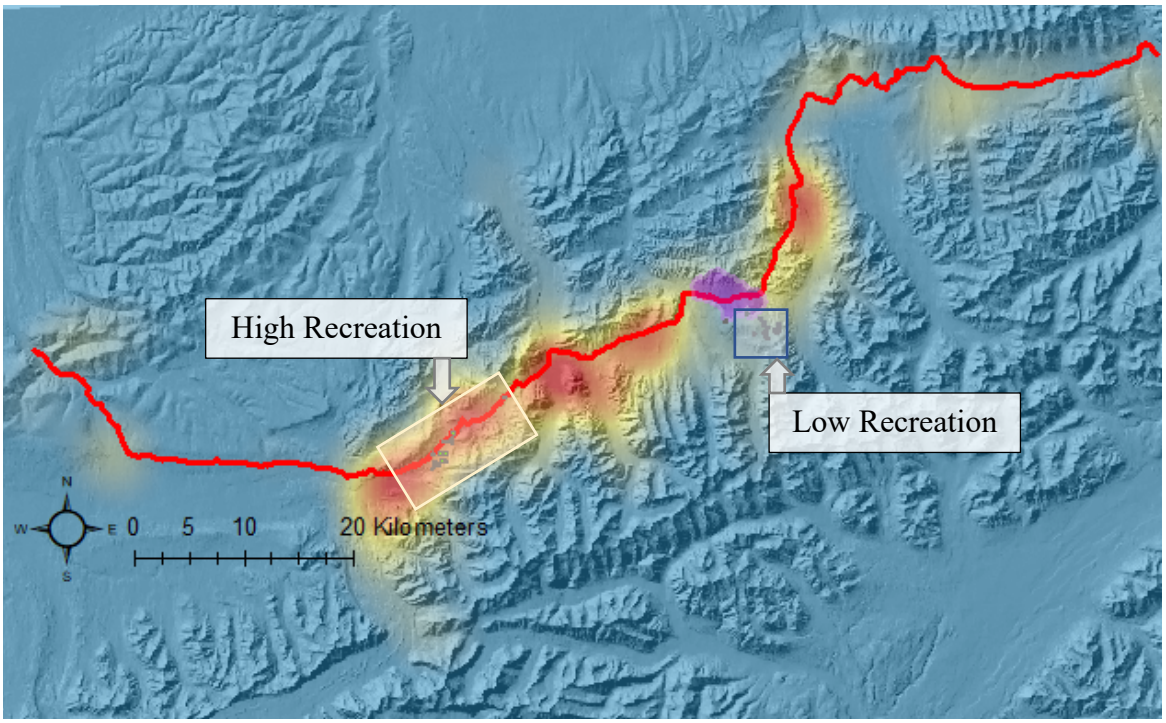

Figure 1: Density of hiking use along the Denali Park road corridor (Red high use, blue low use) adapted from Stamberger et al. (2018). High Recreations site: Sable Pass Valley; Low Recreation site: Highway-Thorofare Valley. Purple region represents the permanent wildlife closure where no hiking or day use occurs off the road.

Vegetation within Denali ranges from stunted black and white spruce forest to sparse, open tundra or rock where many charadriid species breed each summer (Stevens et al., 2001). Vegetation in Sable Pass is a mix of stunted to tall willow, dwarf birch, and open tussock tundra. The Highway-Thorofare valley is a long and narrow east to west valley between kilometer 86 and 104 of the park road. Highway pass makes up a majority of the Highway-Thorofare valley with its gentle sloping grassy tundra to the north and small, steep rolling hills into the Alaska Range to the south. Thorofare pass is slightly narrower and is bound by the tall Thorofare Ridge to its north and steep, rocky Gravel Mountain to its south.

Field Methods

We monitored breeding territories for multiple co-occurring species at both sites during the 2017 and 2018 breeding seasons. We visited territories five to fifteen times to monitor territory establishment, pairing, egg laying, nest success, chick survival, and first flight (Vickery et al., 1992). We plotted each territory on digital maps uploaded to the application Avenza Maps (3.2) using territory mapping techniques originally presented by Kendeigh (1944). We updated these maps during each visit to provide locations of nests, chicks, adults, possible predators and territory boundaries (Kendeigh, 1944). In post-processing, we uploaded data into ArcGIS (V. 10.6, ESRI), calculated proximity to the park road and created a vegetation buffer around each territory center or nest. Vegetation was derived from the 2008 Denali Landcover mapping project by drawing a 150m radius circle around each nest and combining the amount of low shrub-birch and low shrub-sedge (Stevens et al., 2001). These vegetation classes are taller than 20cm and are currently colonizing higher elevations at high latitudes (Mizel et al., 2016; Thompson et al., 2016).

Each species we monitored has precocial young that leave the nest within a few hours or days after hatching (Maher, 1970). We attempted to follow all pairs after hatching to document age first flight, which we considered 'fledging' but were unable to follow every territory to first flight or fail. To reduce observation time bias (Mayfield, 1975), we did not include territories found late in the season, and we found all active territories during territory establishment or early nesting. We limited nest disturbance by not interacting with nests or recently hatched chicks. Instead, we monitored territories for more extended periods from a distance to determine breeding stages and gauge success or failure (Vickery et al., 1992).

Data and Models:

To test hypotheses concerning the influence of site on territory nest and fledging success, we fit binomial generalized linear models in RStudio (V.1.1.463; R Core Team 2015). We collapsed all species into one group because of a limited sample size. We include covariates for vegetation and year to control for their possible effects. We standardized distance from road ("road") and vegetation ("shrub") to mean 0 and standard deviation equal to 1. We compared all models using Akaike's information criteria correction for small sample sizes (AICc) in the R package AICcmodavg (V 2.1-1, Mazerolle, 2016). We ranked candidate models based on our hypothesis and provide the outputs for the best fitting model (ΔAIC). Every nest within the Highway-Thorofare valley had known hiking and consistent road traffic in both 2017 and 2018 seasons (Stamberger et al., 2018). In our study, site and a territory's distance from the road are highly correlated because all Sable Pass territories were far from the road. We analyzed site and distance from the road in separate models but acknowledge they are linked variables that should be considered similarly in model interpretation (site includes differences in road proximity as well as other landscape aspects we did not directly measure). We were unable to add an

interaction effect between site or road proximity and year because of complete nesting failure in the Thorofare Valley during the 2018 season. We modeled hatching and fledging success separately to measure different stages of breeding. We excluded American Golden-Plover from fledging analyses because their hatchlings quickly moved far off territories within a few days of hatching. We also removed year in fledging success models because all nests failed in one year.

We compared shrub and road proximity variables using linear discriminant analysis using the MASS pack in RStudio (Venables and Ripley, 2002). We investigated the spread of the data to ensure consistency of sites across species, year, and vegetation.

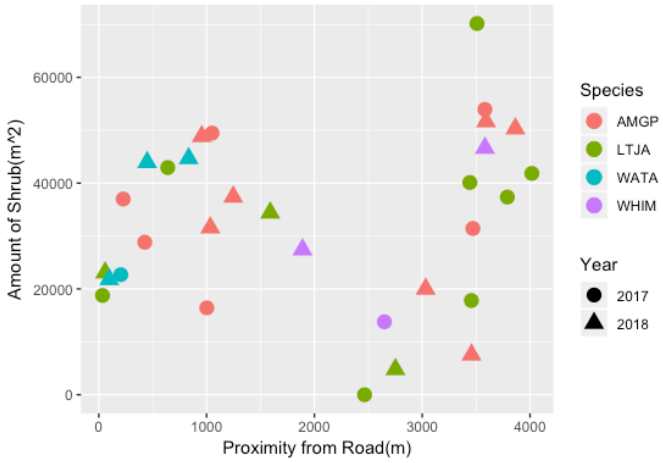

Figure 2: Calculated distance from road and amount of shrub for each species' central territory location. Amount of shrub is derived from a 150m radius circle drawn around each nest (size=70,685m^2).

Results

Shorebird territories at the Highway-Thorofare Valley (high recreation) site were on average 590m (SD=426, n=14) from the road, whereas Sable Pass territories were an average of 3184m (SD=690, n=17). Wandering Tattler's were the only species to exclusively defend territories in the high recreation corridor, with all territories situated within 850m of the road in both years. In contrast, Whimbrels only nested far from the road in Sable Pass, also in both years. The majority of Long-tailed Jaegers (72%) nested at Sable Pass, whereas American Golden-Plovers were equally likely to nest at Sable Pass (46%) or within the Highway-Thorofare Valley (54%). Differences in the amount of shrub around each territory showed little variation between species and site (Figure 2, Table 1).

Species	*Recrea-tion*	*Terri-tories*	*Pairs*	*Nests*	*Hatching Success[1]*	*Fledging Success[2]*	*Road Proximity(m)*	*Shrub (m^2)*
American Golden-Plover	High	7	4	4	0.29	NA[4]	3499.4	35811
	Low	6	6	6	1[3]	NA[4]	848.9	35648.3
Long-tailed Jaeger	High	3	3	3	0.67	0.5	3127.4	30811.6
	Low	8	8	8	0.88	0.86	244.6	28261.3
Wandering Tattler	High	4	4	1	0.25	1	396	32278.7
	Low	0	0	0	-	-	-	-
Whimbrel	High	0	0	0	-	-	-	-
	Low	3	3	2	0.67	1	2706.9	29287.7
Totals	**High**	**14**	**11**	**8**	**0.36**	**0.8**	**3184.5**	**32307.2**
	Low	**17**	**17**	**16**	**0.86**	**0.88**	**590**	**33388.4**

Table 1: Territory nest success and nest fledging success by species for the 2017 and 2018 breeding season at Sable Pass and Highway-Thorofare Valley in Denali National Park. Nest success is calculated by the total amount of territories divided by the number of successful nests. Fledging success is the total amount of successful nests divided by the total amount that fledged.
[1] Hatching success is the portion of territories where pairs were observed tending nestlings.
[2] Fledging success is the portion of hatched nests that successfully fledged chicks to first flight.
[3] Three nests excluded because of inconclusive evidence of hatching.
[4] We were unable to follow these pairs after hatching.

Response	*Models*	*K*	*AICc*	*Delta_AICc*	*AICcWt*	*Cum.Wt*
Hatching Success	Site + Year	3	29.93	0.00	0.43	0.43
	Road + Year	3	31.73	1.80	0.17	0.60
	Site + Shrub + Year	4	31.78	1.86	0.17	0.77
	Road + Shrub + Year	4	32.78	2.85	0.10	0.87
	Site	2	34.21	4.28	0.05	0.92
	Road	2	34.90	4.98	0.04	0.96
Fledging Success[1]	Null	1	12.88	0.00	0.52	0.52
	Shrub	2	15.32	2.45	0.15	0.68
	Site	2	15.35	2.47	0.15	0.83
	Road	2	15.92	3.04	0.11	0.94
	Site + Shrub	3	18.36	5.48	0.03	0.98
	Road + Shrub	3	19.09	6.21	0.02	1.00

Table 2: Top six binomial GLM models for hatching and fledging success. K is the number of parameters, Delta AICc represents change in value from the top model, AICcWt describes the relative likelihood of a model and Cum. Wt is the cumulative sum of AICcWt's above each model.
[1]American Golden-Plover nests are not included in Fledging success

	Hatching Success			Fledging Success		
	Estimate	Std. Error	p val.	Estimate	Std. Error	p val.
(Intercept)	3.35	1.27	**0.01**	1.5	0.78	0.05
High Recreation Site	-2.88	1.24	**0.02**			
Year - 2018	-2.68	1.21	**0.03**			

Table 3: Parameter estimates on the logit scale (I'm assuming, but you'll have to verify), standard errors, and p-values from top AICc models for successful territory nesting and fledging (first flight). Site compares the high recreation site (Sable Pass) to the low recreation site (Highway-Thorofare Valley). A negative site estimate represents lower success at the high recreation site Year is the change in success from 2017 to 2018 breeding season.

Hatching success was significantly lower at the high recreation site than at the low recreation site (Table 3). A majority of the failed territories in the high recreation site contained a male that either never attracted a mate (American Golden-Plovers) or if he did, the pair never nested (Wandering Tattlers). The few Long-tailed Jaeger's at the high recreation site (n=3), accounted for a majority of the species' territory failure. Considering all the shorebird territories within 500m (n=6) of the road at the high recreation site, only 28% of successfully hatched eggs.

Year also played an important role in hatching success for many shorebird species (Table 3). In 2018 every territory at the high recreation site failed. At the low recreation site birds nested in relatively the same density, occupied similar territories, and bred successfully in both years. In 2017, a single pair of Wandering Tattlers nested at the high recreation site and raised 2 of 4 chicks to first flight. At the same site in 2018, we located 3 pairs of tattlers, but none produced nests and no chicks were located later in the season. Also, in 2018 at the high recreation site we only found a single Long-tailed Jaeger nest, but it failed within days after laying a single egg. The parents abandoned the site for the remainder of the season after failure. At the high recreation site in 2018 American-Golden Plovers lost two nests (one confirmed predation) and one male that defended a territory failed to attract a mate. In 2017 two plover nests were successful, while two failed to attract a mate.

We observed that hatching times varied across the two years of our study. Long-tailed Jaeger's nested ten days earlier in 2018 than all Long-tailed Jaegers in 2017. American Golden-Plover hatching ranged from 9-15 days later in 2018 than in 2017 at the low recreation site. At the high recreation site, plover's only nested a few days later the second year.

We suspect predation and lack of food resources accounted for most nest and fledging failures. One American Golden-Plover nest was found partially preyed upon within a few days of expected hatching on July 2nd, 2018. Two of the eggs were missing, and the remaining two eggs

were partially warm with adults nearby. One of the remaining eggs was partially eaten, containing a dead, fully developed chick. A few days later on July 7th, both eggs remained in the same position and adults had abandoned the valley. At this site we witnessed adults fending off Arctic ground Squirrels, *Spermophilus parryii*, which are known egg predators. The fact that Jaegers never fledged more than a single young while hatching two eggs is indicative of food stress in this species which mostly preys upon cyclical small mammals populations (Maher, 1970).

Fledging success was unrelated to site, year, or distance from road (Table 2). Only 18% of nests that hatched did not fledge young, a majority of which were nests of Long-tailed Jaegers. Two failed Jaeger fledging attempts occurred in 2017 and two more occurred in 2018 (both at the low recreation site). We were unable to include the two failures in 2018 because their fate may have been compromised by trapping and tagging for another scientific study.

Discussion

Concern over the conservation of shorebirds worldwide is currently focused on stopover sites and migration routes (Studds et al., 2017). While these areas are important for all shorebirds, without proper protections on the breeding grounds, especially in otherwise reserved areas, we may continue to see dramatic reductions in these charismatic species. Our study shows that recreation at important breeding sites may be accelerate population declines by reducing shorebird nesting success. This adds to the list of current drivers of population loss such as climate change, increased woody vegetation and predation (Thompson et al., 2016; Studds et al., 2017; Kubelka et al., 2018). With respect to nesting success, we suggest that shorebirds in the arctic tundra ecosystem are most sensitive to recreation during the nest initiation and incubation

(hatching) phases of the breeding season (May 28th – June 30th). As such, managers tasked with conserving biodiversity and providing recreational opportunities for humans should consider ways to broaden recreational pursuits during the late summer and autumn, while curtailing them during the spring and early summer.

Overall recreation may have many direct and indirect effects on territory success for breeding shorebirds along the Denali road corridor. Those effects appear stronger for American Golden-Plover which was the only species with difficulty attracting a mate within an established territory. Long-tailed Jaeger's appeared to be resilient to road disturbance, but other indirect recreational effects from the road such as increased predation may reduce overall success. Previous studies show predation to typically be the most reliable driver of breeding success, especially at high latitudes (Kubelka et al., 2018). Predators may be attracted to areas with increased recreation due to increased food subsidies (Walker & Marzluff, 2015). Within Denali, the most likely food subsidy is road killed Arctic Ground Squirrels.

We also found that while site is a better predictor for success in a high recreation area; road proximity also is a good indicator (Appendix I). The effect of site may be driven in part by road disturbance, but also by proximity to a permanent closure, various landscape features, and food availability (Maher, 1970). Distance to road may be more predictive of nesting success in future studies that investigate numerous sites of variable distance from the road.

Recreation drivers, along with climate and vegetation changes may have already caused local extirpation of some species in Denali National Park such as the Arctic Tern (Meeker 2019). The effects of recreation within Denali may displace American Golden-Plover's, Long-tailed Jaeger's and other shorebird species that the park has interest in protecting for conservation and visitor enjoyment.

To limit recreations impact on nest and fledging success park managers should consider annual weather and nesting stages of tundra birds. While limiting the overall number of vehicles and people on the landscape would help, concentrating their presence on the landscape may be more effective at reducing disturbance. This management action would reduce the frequency of disturbance to tundra nesting birds that rely on the visual openness of the tundra to establish a safe nesting territory (Keyel et al., 2013). While we cannot manage for year affects, we may use them to predict management decisions during seasons of high snow when the nesting season is restricted to a smaller window of time (Wieser et al., 2018). Limiting or concentrating recreation in high snow years may give birds greater flexibility in establishing themselves into productive territories.

In our study the most likely driver of our year effect was complete nest failure in 2018 within the Highway-Thorofare valley during a high snow year. Specifically, three nests failed, three pairs never produced nests and one male failed to attract a mate. The most noticeable difference between the years was an increase predator presence near the park road and slow snow melt. Otherwise, we did not observe any specific recreational losses to any nests during this study. We also monitored behavior of Long-tailed Jaeger nests at the low recreation site in 2018 but were unable to assess them at the high recreation site because of a lack of nests.

Based on the limited number of pairs we were able to locate nesting within 5km of the Denali park road corridor it is difficult to extrapolate this data to a broad scale. We suggest further studies continue to track nesting success at high recreation sites to better understand disturbance trends and temporal fluctuations due to food availability. Also, in the future monitoring nesting behavior may provide better evidence for drivers of hatching and fledging success.

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Appendix I: Hatching success of competitive road distance model. Positive road distance estimate represents increased hatching success away from the road.

	Hatching Success			
	Estimate	Std. Error	z val.	p val.
(Intercept)	1.93	0.85	2.27	**0.02**
Road distance	-1.34	0.64	2.09	**0.04**
Year	-2.28	1.05	-2.17	**0.03**