

Gallivanting Goslings: Post-Hatch Movement Ecology and Behavior of Emperor Geese (*Anser
canagicus*) on the Yukon – Kuskokwim Delta, Alaska

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CHAPTER I: INTRODUCTION

Global surface temperatures have risen faster since 1970 than any other 50-year period over the last 2000 years, with the global temperature increasing by 1.09°C from 2011-2020 (IPCC, 2023). Warming impacts on ecosystems are nearing irreversibility, with the Arctic being the most impacted region as it is warming at a rate four times faster than the rest of the planet (Duffey et al., 2023; IPCC, 2023). This warming trend is expected to continue and be amplified by a melting polar ice cap (Duffey et al., 2023). Climate change is likely to have significant effects on habitats in Arctic and sub-Arctic regions, with increased intensity of weather events, sea level rise and high rates of permafrost degradation altering the landscape (IPCC, 2023). This change in habitat can affect distribution, abundance, extinction risk and trophic interactions of species dependent on the Arctic (Macias-Fauria & Post, 2018). In particular, selection of resources and movements have been shown to affect individual fitness, which is linked to population dynamics, making it imperative to examine how a species uses its' environment to understand adaptation (or lack thereof) to a rapidly changing high latitude ecosystem (Oro et al., 2004).

Geese (family *Anatidae*) breed primarily in Arctic and sub-Arctic regions and thus may be susceptible to effects of climate change (Owen, 1980). Geese are long lived (~20 years) organisms with slow paced life histories, with greater age structure complexity and high parental investment in offspring (Owen, 1980). Generally, population dynamics of slow paced species are driven by changes in adult annual survival; however, in times of environmental stochasticity, populations may be driven by changes in other vital rates (demographic buffering hypothesis; Hilde et al., 2020). Because of this, reproductive rates may be an important driver of changes in goose populations (Koons et al., 2014; Hilde et al., 2020). Here, we examine the brood rearing ecology of Emperor Geese, to learn about this sensitive time period that is directly related to

lifetime survival and fitness, and could influence population dynamics (Schmutz, 1993; Richman et al., 2015).

The emperor goose (*Anser canagicus*) is a medium sized (1580-2630g) marine goose that is endemic to the Bering Sea region (Eisenhauer & Kirkpatrick, 1977). The species primarily breeds on the Yukon-Kuskokwim Delta (80-90%; hereafter YKD) with smaller populations breeding on the Seward Peninsula and eastern Russia (Eisenhauer & Kirkpatrick, 1977; Lewis et al., 2021). Non-breeding and failed breeding individuals travel to the northeastern lagoons of the Chukotka Peninsula, Russia and St. Lawrence Island, Alaska to complete their molt (Hupp et al., 2007). During the winter months, the species resides in rocky intertidal shores from Kodiak Island, to the Alaskan Peninsula, and along the Aleutian Chain (Eisenhauer & Kirkpatrick, 1977; Hupp et al., 2008; Uher-Koch et al., 2021). The species is unique among geese in that they feed on sedges and algae during the summer months, and switch to primarily feeding on marine invertebrates throughout the winter (Eisenhauer & Kirkpatrick, 1977). They also serve as a culturally significant subsistence species for Alaskan Native peoples across their range (Mengak, Naves, & Schamber, 2022).

Emperor goose populations have been variable through time. From the 1960s to 1980s, the population decreased by >50% (Pacific Flyway Council, 2016). This decline from over 100,000 birds in 1982 to less than 45,000 in 1986 prompted a closure of both subsistence and sport hunting, which remained in place until the population rebounded to a 3-year average of 80,000 birds in 2015. The hunting season resumed in 2017 and the population continues to remain above threshold for harvest (Pacific Flyway Council, 2016). The previous decline in the 1980s was attributed to low annual survival of adults, but an information gap on this species also exists during their first 3 years of life before reaching breeding age (Petersen, 1992). As of 2023,

the survey of emperor goose breeding pairs was estimated to be ~24,400 birds (USFWS, 2023). This estimate is just above the closure threshold of 23,000 birds that would limit hunting of the species (Pacific Flyway Council, 2016; USFWS, 2023). While emperor geese continue to have slow growing populations, understanding more about their breeding ecology is important for future conservation implications.

Throughout their annual life cycle, emperor geese remain at high latitudes, making them susceptible to the effects of climate change (Hupp et al., 2008; IPCC, 2023). Audubon has the species listed at high vulnerability status, with the species losing 94% of their breeding range with a global surface temperature increase of 2°C (Audubon, 2024). Furthermore, the ecotypes of their primary breeding ground (YKD) has been altered by 16.2% from 1948-2018 with permafrost degradation being the main process affecting the area (Jorgenson et al., 2018). One such change is that important brood-rearing areas such as grazing lawns of *Carex* sedge have also declining since 1991, with the nutrients in these lawns being critical to gosling development (Lohman et al., 2019). Gosling growth rate has been linked to recruitment, as larger goslings are better equipped to cope with the stress of migration (Schmutz, 1993). Goslings grow at faster rates while consuming forage high in nitrogen (indicative of protein) which is present in grazing lawns (Richman et al., 2015). Anecdotally, emperor goose goslings have slower development and appear much less vigorous than similar species during banding drives and brood rearing, however the cause of this observation is unknown (Daniels *pers comm*, 2022; Sedingner *pers comm*; 2023). Knowing that the habitats available to broods are changing and that recruitment is linked to high quality available resources, brood movement and habitat selection may be a factor effecting their population dynamics.

Until 2023, research on emperor goose breeding ecology has been limited for over 20 years (Petersen, 1993; Schmutz, 1993; Schmutz, 2001, Thompson et al., 2023). Given the changes in global temperatures and habitat type and quantity in their primary breeding grounds, the present affords us a unique opportunity to observe the plasticity of the species after a period of warming and during a time of inconsistent ‘greening’ of the Arctic (Aubry et al., 2013).

I used 13 backpack style GPS satellite transmitters in a pilot study of the technology from 2022 - 2023 to examine how nesting females use space on the YKD to raise broods. Firstly, I analyzed the distance traveled from nesting site, area used, and resources selected for brood rearing to identify potential stressors on goslings and habitat importance for the species (Chapter II). Secondly, I conducted an observational study of goslings on varying habitats to identify primary behaviors exhibited during the development process, and to identify potential variables that may be affecting their growth (Chapter III). These two studies serve as an exploratory manuscript to examine in detail emperor goose movements and behavior during the brood rearing period around the study site of Kigigak Island. This work expands on former brood rearing studies conducted by Schmutz (2001, 2001, 1993) at Manokinak River Camp, and uses modern technologies in a climatically altered landscape.

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CHAPTER II: EXAMINING DISPERSAL DISTANCE, HOME RANGE AREA AND RESOURCE SELECTION OF BROOD REARING EMPEROR GEESE

Abstract

The emperor goose (*Anser canagicus*) is a marine species of goose endemic to the Bering Sea region that has been close to or below objectives since the 1960s and are a culturally important species to indigenous communities along their range. Most research on emperor goose breeding ecology was conducted over 20 years ago on the Yukon Kuskokwim Delta in western Alaska, the region where 90% of the species breeds and climate change is predicted to have significant effects in the future. It is less clear how climate change will affect emperor goose reproduction, and ultimately their population dynamics. Therefore, in this study, our objective was to provide a baseline information about emperor goose brood rearing movements and resource use in their core breeding range in the sub-Arctic. We attached GPS backpack transmitters to females that successfully nested (n =13) and monitored them throughout the brood rearing period in 2022 and 2023. We determined that broods dispersed from nest sites to seasonal home ranges used until fledging at a rate of 3.5 km per day over the course of 7-10 days, with a straight-line distance from nesting to brood rearing area being 3.11 ± 0.968 km (SE). The average home range size was approximately 9.75 km² with broods moving within that home range at a rate of approximately 9.5 km per day. This home range area encompassed near equal amounts of tidal sedge and mudflat habitat. Within home ranges, brood rearing females selected for tidal sedge habitat and avoided both tundra and mudflat habitats. Our results demonstrate that emperor geese continue to be dependent on tidal sedge habitat during the brood rearing period and that they are not traveling far from nesting locations on Kigigak Island to brood rearing habitat. This dependency coupled with declines in grazing lawn extent across the Yukon Kuskokwim Delta may lead to

increased competition between emperor goose broods and heterospecific Arctic goose species that also rely on grazing lawn during the brood rearing period.

Introduction

Among wild organisms, like birds, the decisions that an individual makes about habitat use and movement on the landscape has important consequences for lifetime fitness (Mainguy et al., 2006; Webber et al., 2013; Casazza et al., 2020). For example, individuals make decisions about where to raise young based on predation risk (Lopez et al., 2005) and foraging opportunities (Estes et al., 2003); these decisions affect reproductive success through feedbacks on offspring growth and survival, which consequently affects individual fitness, (Bolnick et al., 2003). Many species appear to assess habitat based on forage quality, vegetative structure, predation risk and habitat composition (Saher & Schiegelow, 2005; Ydenberg et al., 2002) and it is therefore critically important to understand these factors when building conservation plans (Festa-Bianchet & Apollonio, 2003).

Globally, many goose species migrate north to Arctic and subarctic regions every summer to breed. For example, between May and September, the Yukon Kuskokwim Delta (YKD) in western Alaska is home to one of the densest populations of migratory breeding birds in the world (Gill & Handel, 1990). Critically, high latitude regions are being affected by climate change at an unprecedented rate, and therefore it is important that we have a baseline understanding of the ecology of geese that are dependent on the region for their future conservation (Dickey et al., 2008; IPCC, 2023; Duffey et al., 2023). One crucial period that impacts long term fitness and subsequent reproduction is brood rearing, which describes the period between goslings hatching from a nest and fledging approximately 2 months later (Johnson et al., 1992; Sedinger et al., 1995).

Gosling growth and survival on the YKD are affected by the movements and habitats used during the brood rearing period (Person et al., 2003; Mainguy et al., 2006; Lohman et al., 2019). During this period, goose broods predominantly use nitrogen rich *Carex ramenskii* and *Carex subspathacea* grazing lawns, a patch of sedge that has been grazed down to a graminoid level (Sedinger, 1984; Laing & Raveling, 1993; Person et al., 2003; Lohman et al., 2019). These grazing lawns are only accessible after snowmelt and accordingly, females can positively affect the growth and survival of their goslings by synchronizing their nesting chronology with the timing of snow melt in the spring (Sedinger & Flint, 1991; Ross et al., 2018). Geese select for protein-rich (high in nitrogen) forage during this period as high protein content supports rapid growth rates and subsequent survival, as larger goslings are less likely to be preyed upon or fatigued and can maintain energy for thermoregulation (Schmutz et al., 2001; Person et al., 2003; Richman et al., 2015; Ross et al., 2018). The growth rate the pre fledging period has lasting effects on an individual, as larger goslings are more likely to survive their initial migration and first year of life compared to smaller goslings (Schmutz, 1993; Sedinger et al., 2016). Because this period lasts for only a short duration (~55- 60 days; Baldassarre, 2014) and has lasting effects on an individual fitness, understanding the ecology of this influential period is crucial to gaining insights into population dynamics.

Emperor geese (*Anser canagicus*) are almost completely dependent on the YKD for breeding and brood rearing, with 80%-90% of the population nesting in the region each year (Eisenhauer & Kirkpatrick, 1977). Emperor geese are unique among Arctic nesting geese in that they remain in the Bering Sea region throughout their life cycle, and winter along the Aleutian Chain and Kodiak Island (Eisenhauer & Kirkpatrick, 1977). They are a species of conservation concern given their relatively narrow geographic range, dependence on intertidal ecosystems that

are predicted to be severely impacted by climate change, and previous population declines from the 1960s to 1980s (Pacific Flyway Council, 2016). Emperor geese are culturally significant to the Alaskan Native Peoples who live along their range and legal sport hunting was reopened in 2017 after their population reached a management threshold of ~28,000 breeding pairs (Pacific Flyway Council, 2016).

Previously, research indicated that goslings may be traveling ~20km from their nesting location to brood rearing habitat, which could put goslings at risk of fatigue, predation and exposure to deleterious weather conditions (Eisenhauer and Kirkpatrick, 1977; Schmutz et al., 2001; Mainguy 2006). Gosling survival is typically lowest during the first five days after hatching, indicating that the time between hatch and establishing a home range for brood rearing may be the most influential for gosling survival (Schmutz et al., 2001). Once they establish a brood rearing range, Emperor geese tend to use the borders of mudflat and *Carex ramenskii* meadow habitat extensively during brood foraging (Schmutz, 2001).

There has been a significant decline in *C. ramenskii* meadows across the YKD during the last ~30 years (Lohman et al., 2019; Uher-Koch et al., 2019). The driving force of the decline is attributed to lack of grazing pressure from brood rearing geese and the decrease in available resources may have consequences for juvenile recruitment, as the spatial extent of grazing lawn is negatively correlated with gosling growth rates (Sedinger et al., 2001; Person et al., 2003; Lohman et al., 2019). Further, mean air temperatures have increased and affected the chronology of snow-melt on the YKD since previous work on emperor goose brood rearing ecology was completed in the early 2000s (Jorgenson, 2018; Lohman et al., 2019; NOAA, 2023). Not only has the vegetation and climate been changing over the past 20 years, but technology has also advanced, including the development of fine scale GPS transmitters that provide greater insights

into resource use. The development of GPS transmitters has also led to the development of more complex and effective models for examining animal movements (Calabrese et al., 2016; Silva et al., 2021).

Here, we conducted a study with two main objectives: (1) examine how and where emperor goose adults were traveling to rear broods around Kigigak Island, AK, and (2) determine what resources emperor goose broods were using during the period between hatch and fledging. We used harness attached GPS satellite transmitters attached to nesting adult female geese as surrogates for their family group, and analyzed these data using movement models and a logistic resource selection function (RSF). We predicted that the distance from nesting site to brood rearing area would be relatively large (~10-20km) and that broods would disperse using tidal sloughs and rivers. We predicted that broods would favorably select tidal sedge habitat as grazing lawns are generally located around ponds and lakes, and scattered amongst *Carex spp* meadows. Given that there are no previous studies on home range area specifically using transmitters, it was difficult to predict a specific size of brood rearing area, however we predicted that home range size would generally be quite small (<10km²) given the size of goslings and of the spatial extent of grazing lawns near our study area.

Methods

1.1 Study Site

The YKD is the largest riverine delta in western North America and is one of the most important breeding areas for migratory water birds in the world (Gill & Handel, 1990; Jorgenson et al., 2018). It is located in western Alaska north of the peninsula is shaped by the deltas of the Yukon and Kuskokwim rivers as they flow into the Bering Sea (Jorgenson 2000; Jorgenson et al.,

2018). Kigigak Island (60°50'44.1"N, 164°58'28.2"W) is a small island located on the western edge of YKD, Alaska (Figure 2-1). The island is approximately 35km² in size and is located 20.5 km west of the town of Newtok, and northwest of Nelson Island. It is bordered by the Ninglick River and the Bering Sea, making it highly intertidal. The island contains several different vegetation types including brackish wet sedge meadows, wet graminoid meadows, sedge marshes and lowland tundra (Jorgenson, 2000). The island is surrounded by expanses of barren mudflat, especially on its northern edge. This unique array of habitat types provides habitat for a diverse community of nesting waterfowl, including emperor geese. The U.S. Fish and Wildlife Service has maintained a long-term field site on Kigigak Island because of its importance to nesting waterfowl, where they have been conducting nest monitoring efforts and mark-recapture studies to determine reproductive output and survival rate of adult female emperor geese for the past 7 years (2017-2023). The entire Yukon-Kuskokwim Delta is located on native Yupi'k and Cupi'k lands.

Another study area used in this research project was based along the Kashunak River, about 60 km north of Kigigak Island and 20 km south of the village of Chevak (Figure 2-1). This area was used opportunistically after visually searching for brood rearing females during helicopter drives. Most of this region's habitat is dominated by North American Arctic – Subarctic Tidal Salt and Brackish Marsh (Landfire, USGS, 2023).

1.2 Capture and Transmitter Deployment

We captured geese using two different methods: (1) by hand during helicopter banding drives (2022) and (2) on the nest using bow-net traps, typically within four days of their estimated hatch date (2023) (Salyer, 1962). We originally planned to tag all birds during nesting, however difficulties with transmitter connection prevented this from being possible during 2022.

Accordingly, we captured brood rearing females during helicopter brood banding drives in late July 2022.

After capture, we uniquely tagged all birds with steel tarsal bands provided by the USGS bird banding lab and collected morphometrics to assess body size and mass. We attached a unique 3 number/letter combination plastic tarsal band in order to identify individuals. Due to the size, sensitivity and low survival rate of goslings, we used harness backpack transmitters on adult female emperor geese with broods to collect data on brood movements (Rappole et al., 1998). In 2022 and 2023 we tagged emperor goose females with a harness attached ‘backpack’ ES-150 transmitter (Cellular Tracking Technologies) that use the Argos satellite network, have an error radius of 10-20m, and weigh 30g which is approximately 2% of the body mass of an average emperor goose female (Eisenhauer & Kirkpatrick, 1977; Phillips et al., 2003). This study includes the first ever attempt at tagging emperor geese using harness style (backpack) attached transmitters, as well as the first to use modern GPS data.

We attached transmitters using a typical waterfowl harness attachment method with a front strap going just beneath the esophagus and the back strap going behind the wings with the transmitter sitting within the birds’ center of gravity (McDuie et al., 2019). Specifically, we attached each transmitter using a 5 mm automotive elastic band which is less likely to wick moisture to down feathers (McDuie et al., 2019). We then fastened each elastic band using a simple overhand knot affixed with cyanoacrylic glue, which is an improved attachment method over traditional crimps (McDuie et al., 2019). Birds were handled for approximately 20 minutes per deployment and were monitored for signs of stress throughout the process. We programmed each transmitter to have a duty cycle of 10 minutes (2022) and 30 minutes (2023) to collect

location data at a fine spatial scale. We selected female geese based on current brood rearing status in 2022 and whether they were known to have hatched a nest in 2023.

1.3 Home Range and Dispersal Distance Calculations

We determined that broods fledged if 4 conditions were met: (1) the individual had to have a successful nesting attempt (hatch), (2) the individual did not migrate to St. Lawrence Island or Russia to molt within a 60 day time period, (3) the individual only initiated migration following a time period of 55-60 days remaining on the YKD, and (4) the individual established range residency during the time before first migration (as defined by Fleming et al., 2019) to more accurately determine home range size. A range resident individual should have a variogram that reaches an asymptote when the semi-variance of movement is plotted over time, indicating that the individual remains within a home area and an analysis of the home range will be accurate (Calabrese et al., 2016). Emperor geese are known to fledge after a time period of approximately 60 days, and maintain their family group for the first year of life (Baldassarre, 2014). For family groups captured and tagged in 2022, we assumed that nests were successful if goslings were present at capture. Individuals that did not meet all four of these criteria were omitted from the analysis.

We calculated dispersal distance by first truncating data to the period of 7-10 days after hatch and before the individual established 'range residency' (as defined by Fleming et al., 2019). Then calculated the speed of individuals using the SPEED function as a meta-analysis in the continuous time movement modeling ('ctmm') package (Fleming, 2019) in R (R Core Studio, 2023). We used an error radius for GPS fixes of 20 m per manufacturer specifications. We calculated distance in total using the results meta-analysis described above in km per day, multiplied by the number of days each individual took before establishing range residency. We

used the measure tool in geodesic format in ArcGIS Pro (Esri, 2023) to calculate the straight line distance from nesting points to the center of home ranges.

We modeled home ranges using a weighted autocorrelated kernel density estimate (wAKDE; Calabrese et al., 2016) using the package *ctmm* (Calabrese et al., 2016) in R (R Core Team, 2023). Autocorrelation in animal movement is inherent given that an individual's future location is, in part, a function of their current location, and therefore each successive movement lacks independence (Gurarie et al., 2009; Boyce et al., 2010). Home range was determined by the time period when individuals maintained range residency, a term defined by an area that an individual crosses over a set period of time (Silva et al., 2021). We truncated data to exclude the first 7- 10 days after the transmitter was deployed to remove the dispersal time period and ended data collection when locations indicated that flight was the method of movement, (i.e moving from the brood rearing area to a point 20 miles away in 1-2 days). We determined range residency by visually assessing model fit to a movement variogram using the *ctmm* R package (Supplemental Material 2-A), and incorporated an error radius of 20 m per manufacturer specifications. An IID model uses the same method as a traditional Kernel Density Estimate without weighting or autocorrelation (Calabrese et al., 2016) and an OU model includes position autocorrelation. The OUF Anisotropic model includes position autocorrelation and velocity autocorrelation (Calabrese et al., 2016). We evaluated competing movement modeling frameworks through an AIC table (Burnham & Anderson, 1998). We conducted a meta-analysis of all birds to estimate mean home range size and also analyzed each individual on its own to confirm relative home range size. We projected range usage decision (UD) shapefiles across satellite imagery using ArcGIS Pro (Esri, 2023). Following the home range analysis, we used a

funnel calculation to assess time sample bias in home range size (Fleming, 2019) because some individuals lacked a full sampling period of 60 days due to lack of transmitter connectivity.

Finally, we calculated the distance traveled per day within the home range. To do so, we used the same SPEED meta-analysis in ctmm using the same data set that was used to calculate home range, during the time period at which birds were considered range resident (Calabrese et al., 2016). An OUF Anisotropic model with foraging was the best fit model for all individuals. An error radius of 20 m was incorporated. This metric was used as comparison to the distance traveled per day during the dispersal period, to examine change throughout the brood rearing period.

1.4 Resource Selection Function Modeling and Percent Habitat Composition

We considered goose habitat selection within individual home-ranges or at the third order resource selection function (RSF) following Johnson's (1980) hierarchy of scales of selection. Third order selection evaluates the habitat types an individual used vs. what habitats were available within its' established home range (Johnson 1980). We chose this spatial scale to determine most important resource types for broods after the dispersal period. Given that geese can walk and swim, all habitat within each home range was determined to be potentially suitable habitat. We used ArcGIS Pro (Esri, 2023) to generate home range polygons, plot used points from GPS data, and generate random points.

We generated 10 random points for each used point within the boundaries of each individual home range following Northrup (2013), where random points were generated within the 95th percentile of our weighted autocorrelated kernel density estimate (Silva et al., 2021). These points were considered 'available' in our estimates.

To determine habitats preferred or avoided by emperor geese, we incorporated available and used points into a generalized linear mixed model that included fixed and random effects. This comparison of used vs. available points follows a standard RSF design where resource covariates are compared at used and available locations within a home range (Manly et al., 2002). We constructed models using the glmmTMB package (Brooks et al., 2017) in R (R Core Team, 2023). Covariates included: the categorical variable of vegetation cover (tidal sedge, mudflat, tundra), continuous variable of distance to water that we z-standardized, and a random effect of individual goose. Models were built so that every possible combination of variables was used to build a selection of 5 different models. This resulted in a global model with all variables, accompanied by a set of models that tested all covariates in different combinations. A null model was also run for comparison. After generating this list of potential GLMMs we used Akaike's information criterion (AIC_c) to identify those covariates most supported by the data (Burnham & Anderson, 1998). Finally, we computed odds ratios for model coefficients to examine resource use by emperor geese (the measure of association between exposure and outcome; Szumilas, 2010). Preferred habitats resulted in an odds ratio that was greater than 1, and avoided habitats had an odds ratio that was less than 1. Odds ratios (hereafter OR) with confidence intervals that crossed 1 were considered neither preferred or avoided.

We used vegetation cover raster data from Landfire 2022 (USGS) to determine cover type with a resolution of 30 m. We used the Tabulate Area tool within ArcGIS Pro (Esri, 2023) to calculate the area of each vegetation cover type within an individual's home range. To reduce colinearity among the 13 different vegetation types present, we grouped vegetation types into three broad categories that describe the majority of the landscape available on the YKD. These categories included (1) tidal sedge, which included wet sedge and brackish marsh vegetation

types, (2) mudflat, which included barren and open water cover types, and (3) tundra, which included tussock tundra, shrub and similar vegetation categories. This maintained consistency of vegetation cover types for our RSF. Vegetation categories were combined and the percent composition of each habitat type (mudflat, tidal sedge and tundra) were calculated in program R (R Core Team, 2023). Finally, we calculated a quick generalized linear model to test for a relationship between home range size and percent habitat composition (R Core Team, 2023).

We used this same vegetation cover raster data to create an an open water polygon in order to test if birds were selecting for areas closer or farther away from the waters edge. Open water was qualified as rivers, tidal sloughs, lakes, ocean and ponds. Areas of open water for intertidal areas were measured at low tide as this was the tidal phase that imagery was collected at. We calculated distance from used and available points to water using the Near function and vegetation type beneath each point was generated using the Pair Intersect function in ArcGIS Pro. Slope and elevation are not variable throughout the area (Landfire, USGS, 2022) and thus were omitted from calculation.

Results

We deployed 20 transmitters on adult female emperor geese in 2022 and 2023, and used 13 of them for analyses of home range size and resource use during brood rearing. Of the 10 transmitters with known nesting locations, 7 individuals had sufficient data to calculate dispersal speed and all 10 were used to calculate mean straight line distance.

We used data from 7 individuals to calculate dispersal distance from the nest. The mean distance traveled from the nest calculated using straight line distance was 3.11 ± 0.968 km (SE). The mean distance traveled during the dispersal period was 3.5 km per day (95% CI: 1.9 – 6.2 km per day; Figure 2-3). The mean distance traveled within the home range during the brood

rearing period was 9.5 km per day (95% CI: 7.7 - 11.7 km per day; Figure 2-3). An inverse-Gaussian model was the best fit model for the meta-analysis (Supplemental Material 2-D).

Among all individuals ($n = 13$), the mean home range size was 9.75 km^2 (95% CI: $5.5 \text{ km}^2 - 15.88 \text{ km}^2$; Figure 2-2). For the meta-analysis of home range size, an inverse Gaussian model was the best fit model (Supplemental Material 2-B). The mean core (50%) home range size was 2.3 km^2 (95% CI: $1.8 \text{ km}^2 - 2.7 \text{ km}^2$; Figure 2-2). A funnel calculation that plotted home range size (km^2) as compared to sampling period (months) was calculated to determine if sample bias was present (Supplemental Material 2-B). The result of this calculation indicated that there was no sample bias in our data (Supplemental Material 2-B).

We used vegetation raster cover data from Landfire (USGS, 2022) and our generated home range polygons to calculate the percent composition of habitat types within each individual's home range. Mudflat habitat was the largest area of habitat within all home ranges (52.3, 95% CI: 43.8 – 60.8; Table 2-1), followed by tidal sedge (44.1, 95% CI: 37.4 – 50.8; Table 2-1). Tundra comprised of the smallest area within all home ranges at just 3.64 (95% CI: 1.3 - 6.0; Table 2-1). Birds tagged along the Kashunak River had more tidal sedge habitat within their home ranges (65.5, 95% CI: 63.9 - 67.1; Table 2-1) than those tagged on Kigigak Island (40.2, 95% CI: 34.9 – 45.6; Table 2-1). There was not a significant correlation between habitat composition and home range size when analyzed using a generalized linear mixed model ($\beta = 1.04$, 95% CI: 0.83 – 1.30).

We used goose locations ($n = 8379$) and random point locations ($n = 91951$) generated in each individual's home range to examine resource selection during the brood rearing period (Brooks et al., 2017). Our global model (including all fixed effects and random effect) was the best fit model (Table 2-2). All covariates except for tundra were considered significant given that

the confidence intervals of their odds ratios did not cross the value of 1. From this model we found that brood rearing females selected habitat that was farther from the waters' edge than random points (OR = 0.87, 95% CI: 0.83 – 0.92; Figure 2-5), and strongly selected for tidal sedge habitat (OR = 1.56, 95% CI: 1.42 – 1.71; Figure 2-5). Brood rearing females neither selected for or against tundra habitat (OR = 0.76, 95% CI: 0.57 – 1.01; Figure 2-5) given the confidence interval values. Individuals avoided mudflat habitat (OR = 0.07, 95% CI: 0.067 – 0.088; Figure 2-5).

Discussion

We found that the daily rate of dispersal after hatch was relatively small (3.5 km per day; Figure 2-4) and that the straight-line dispersal distance from nesting site to the center of each home range was approximately 3.11 km (Figure 2-4). The time frame of dispersal from hatch date until the bird established range residency was 7-11 days, which when multiplied by the average kilometers traveled per day (3.5 km), each brood walked about 30 km total before establishing a home range. Given that this calculation is done including the error radius of the transmitter and assumes the bird is not traveling in a direct, straight line between two locations, this is a reasonable distance for a bird and its brood to move after hatch. This distance was shorter than anticipated given observations of emperor geese being difficult to relocate after hatch and previous documentation alluding to broods using rivers and sloughs for stints of about 20 km (Eisenhauer & Kirkpatrick, 1977, Daniels 2022, *pers comm*). This could also be a aspect of our study site, as preferred resources seem to be near Kigigak Island as opposed past studies nesting locations may have been further from preferred brood rearing habitats. Eisenhauer and Kirkpatrick (1977) estimated similar daily movement rates at 1.5 km per day by following color-dyed broods, however it was thought that birds were traveling further from the nest before

reaching the brood rearing area. This may differ based on nesting location within the YKD, but it would appear from our analysis that birds appear to be dispersing to areas directly surrounding Kigigak Island rather than using waterways to disperse to farther locations throughout the YKD.

Our meta analysis indicated that the mean home range area used by brood rearing emperor geese was 9.75 km² (Figure 2-2). This is comparable to home range estimates in graylag geese (*Anser anser*) of 9.4 km² during the flightless period (Kleinhenz & Koenig, 2018). There was considerable variation in home range size among individuals, with brood rearing area ranging from approximately 2 km² in size to approximately 15 km² in size (Figure 2-2). There was no relationship between resource use and home range area however, and we believe that these differences may be driven by competition from other species in the area, or simply an individual preference.

During the brood rearing period we found that broods moved 9.54 km (95% CI: 7.7 - 11.7) per day inside their home range (Figure 2-3). When compared to our mean estimate of home range size at 9.76 km², the mean speed estimate (9.54 km per day) is reasonable to traverse their home range around once per day and based on speeds found in similar species (graylag and bar-headed geese, *Anser indicus*) during this time period (Kleinhenz & Koenig, 2018; Zheng et al., 2018; Figure 2-2). The increased speed from dispersal to brood rearing period is most likely due to goslings growing over the course of 8 weeks, and thus being able to cover increasingly more distance as they age at a faster rate. There was considerable difference in distance traveled per day between individuals, with the most sedentary individuals traveling about 7 km per day and the least sedentary traveling about 15 km per day (Figure 2-3). There did not appear to be a relationship between speed of movement and home range size, but this was not formally evaluated (Figure 2-2; Figure 2-3).

Emperor goose home ranges were comprised of mostly mudflat (52.3, 95% CI: 60.8 – 43.8; Table 2-1) and tidal sedge habitat (44.1, 95% CI: 50.8 – 37.4; Table 2-1). Tundra habitat was present in small amounts within home ranges (3.64, 95% CI: 6.0 – 1.3; Table 2-1). Our data is consistent with previous knowledge that tidal sedge is the most important habitat for Emperor broods, as it contains patches of grazing lawns which are used extensively by growing goslings for their high amounts of nutrients (Sedinger, 1983; Sedinger et al., 2001; Schmutz, 2001; Person et al., 2003). The use of extensive mudflat substrate habitat within the home range is notable, as mudflat comprised of about half of the home range of most individuals, with some individuals having a home range that encompassed ~70% mud (Table 2-1). This is higher than anticipated, and shows that the mudflat habitat has some value during the brood rearing period as otherwise individuals would avoid the area completely. Birds that were tagged farther north on the Kashunak River in 2022 had home ranges that comprised of less mud, and more tidal sedge and tundra, likely due to these resources being more available around that study site as compared to Kigigak Island (Table 2-1).

Our third order RSF indicated that tidal sedge continues to be the most preferred habitat type by emperor geese (OR = 1.56, 95% CI: 1.42 – 1.71; Figure 2-5). Individuals avoided tundra habitat (OR = 0.76, 95% CI: 0.57 – 1.01; Figure 2-5) and selected for areas that were slightly farther from the water's edge (OR = 0.87, 95% CI: 0.83 – 0.92; Figure 2-5). The avoidance of tundra habitat is consistent with our knowledge of the breeding ecology of the species, as they nest in lower elevation tidal sedge habitat and are not known to forage on lichens or mosses found in tundra (Eisenhauer and Kirkpatrick, 1977; Petersen, 1993). Broods used areas relatively farther from the water's edge which is consistent with observations of grazing lawn being common along the interfaces of mud and sedge rather than being closer to the silty areas around

water. This is aligned with observations that other forms of aquatic vegetation (algae, seaweeds) appear to grow most readily in zones that were most intertidal and not submerged completely throughout the day. Geese may be preferring areas farther from the water as the system is tidal, so birds may avoid open water unless absolutely necessary to prevent excess energy expenditure as swimming requires higher metabolic output (Wooley Jr. & Owen Jr., 1978)

While mudflat accounted for more than half of the home range area composition on average, individuals avoided the substrate (OR = 0.07, 95% CI: 0.067 – 0.088; Figure 2-5; Table 2-1). Emperor goose broods may be avoiding this area due to lack of high quality forage or increased exposure to aerial predators (such as glaucous gulls, *Larus hyperboreus*; (Schmutz, 2001; Lopez et al., 2005). Mudflat could be a resource that is used by emperor geese because it is widely available at low tide, but it is not likely the primary resource for growing goslings. Observations of emperor geese foraging on mudflat habitat has been documented during this study, as well as members of nearby indigenous villages have noted that emperor geese spend significant portions of time walking and eating on the mudflat (Murphy, 2022 *pers obs.*; Larson, 2022 *pers comm*). Individuals tagged along the Kashunak River contained a higher proportion of tidal sedge habitat (65.5, 95% CI: 67.1 – 63.9; Table 2-1) which is reflective of mudflat being less expansive in that region as compared to at Kigigak Island.

Mudflat covers a much larger area than tidal sedge around Kigigak Island but is inundated by water for large portions of the day during high tides. This makes it difficult to model resource selection as many points lie on the edges of sedge and mud or water, and the resolution of our land cover data (30m; Landfire, 2022) may not be able accurately capture this fine scale habitat selection. For this study site, the statistical tool of an RSF may be affected by the fluid nature of the landscape around Kigigak Island, given that mudflat habitat covers a larger

area but is unavailable for up to 50% of the day depending on the tidal cycle, and that makes the habitat very difficult to quantify. For comparison, tidal sedge habitat covers a smaller area in total but is dry and accessible throughout the day.

Schmutz (2001) found that family groups of emperor geese selected for *C. ramenskii* meadows and mudflats, and avoided meadows that contained other sedge species near Manokinak River, a study site ~ 40 km north of Kigigak Island, which aligns with our results. While there is a two decade time difference between the two studies, there is also a marked difference in available habitat surrounding Kigigak Island (2022 – 2023) and Manokinak River (1994-1996) field camps. Kigigak Island has more mudflat habitat, while the area of observation along the Manokinak River contained only 10% of mudflat habitat within a 70 km² area (Schmutz, 2001). We believe that Kigigak Island is a unique field site within the YKD due to these attributes as well as the presence of upland tundra and relatively small spatial extent of grazing lawn (Jorgenson, 2000).

We did not examine how interspecific competition among Arctic nesting goose species during brood rearing might be affecting resource use by emperor geese and we believe that this warrants future investigation. Our results indicate that emperor geese prefer grazing lawn habitat during the brood rearing period, and this is the preferred habitat type for brood rearing that is used by other species of Arctic nesting geese. Given the decline in spatial extent of grazing lawn on the YKD and it's importance to all arctic nesting geese, there is the possibility that heterospecifics are affecting emperor goose habitat selection through competition for this potentially limiting resource (Ely et al., 1985; Sedinger & Raveling, 1988). For example, increased populations of 2 heterospecific species that also breed on the YKD, greater white-fronted geese (*Anser albifrons*) and cackling geese (*Branta hutchinsii minima*), are being driven

by survival and processes off from the breeding grounds that has subsequently increased the competition between these species on the breeding grounds (Schmutz et al., 2020). Further, emperor goose gosling growth rates are negatively related to cackling goose density, indicating a level of interspecific density dependence on the breeding grounds during brood rearing (Schmutz & Laing, 2002; Lake et al., 2008). Given that the individuals marked on Kigigak Island disperse to the surrounding area after nesting, and that they tend to occupy the same area, it is possible that other species may be affecting the movements and home ranges of brood rearing emperor geese. This may also account for the differences in home range area as well.

Challenges faced while determining home range size is likely due to data limitations as transmitters did not charge efficiently in overcast weather during the summer of 2023. This lack of battery power resulted in less usable fixes and time gaps in data which led to more potential error in the results. Another potential source of error was the lack of range residency exhibited by some individuals, causing the model to not fit as well (Supplemental Material 2-A). This lack of consistent movement is simply a characteristic of an individual not staying in a certain area during the specific time period (Silva et al., 2021). This may be an individual strategy during brood rearing to move more frequently to access the best possible resources, or other species may be outcompeting individuals for resources, forcing them to move. The individual with the largest home range and largest confidence intervals (ID = 244764) was resighted by Alaska Department of Fish and Game during the winter with two juveniles, so she was not omitted from the calculations based on lack of certainty of raising a brood. The lack of obvious pattern in our funnel calculation leads us to believe that we had an adequate sample size of individuals collecting data over different time periods (Supplemental Material 2-B). There was no relationship between home range size and the time period of data collection (Supplemental

Material 2-B). Differences in home range estimates are more likely due to lack of data or preferences between individuals rather than sample size.

This is the first instance of backpack style transmitters being used on emperor geese and we assumed that this style of transmitter and attachment had little to no effect on the birds during brood rearing. Harness attachment transmitters have shown to have deleterious effects on waterfowl, mostly through reducing aerodynamics during migration, causing increased rates of divorce in geese and lower rates of nesting (Lameris & Kleyheeg, 2017; Lameris et al., 2018). However, given that female geese are not mating, flying, or nesting during the brood rearing period, we believe that it is reasonable to assume that the attachment of a harness transmitter would not have dramatic effects on their behavior during this time.

Overall, our findings for dispersal movements and habitat use were consistent with those observed by Schmutz 2001 and Eisenhauer and Kirkpatrick 1977; however, with the development of fine scale technology and land cover data, our work was able to examine these trends at a fine scale and examine potential changes in resource use over the last 2 decades (IPCC, 2023). Our research indicates that emperor geese remain dependent on tidal sedge and grazing lawn habitat during the brood rearing period, which may have implications in the future given declines in grazing lawn area across the YKD and competition for resources (Lohman et al., 2019; Uher Koch et al., 2019). We showed that broods were not traveling very far distances to reach brood rearing habitat, and that home ranges may overlap between individuals indicating that good resources for brood rearing are near the nesting site of Kigigak Island. Our work shows that while the species is predominantly using grazing lawn habitat to raise their broods, mudflat habitat accounts for approximately half of the brood rearing home range across our sample, indicating that this habitat may contain some value for broods. To gain a information on driving

forces for emperor brood movements, more information needs to be gained on the current effects of interspecific competition, as well as an investigation of the potential value of mudflat habitats.

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TABLES

Table 2-1: Individual home range areas (km²) with corresponding location and habitat percent composition. Habitat area calculated using the Tabulate Area tool in ArcProGIS (Esri, 2023).

Habitat types grouped using same method as in RSF.

ID	Location	Home Range Area (km²)	Habitat	Percent Composition
236514	Kigigak	16.8	<i>Tidal Sedge</i>	35.3
			<i>Mudflat</i>	63.2
			<i>Tundra</i>	1.5
236516	Kigigak	6.1	<i>Tidal Sedge</i>	43.2
			<i>Mudflat</i>	56.7
			<i>Tundra</i>	0.14
236517	Kashunak River	2.1	<i>Tidal Sedge</i>	64.3
			<i>Mudflat</i>	22.2
			<i>Tundra</i>	13.4
236519	Kashunak River	11.6	<i>Tidal Sedge</i>	66.6
			<i>Mudflat</i>	19.9
			<i>Tundra</i>	13.5
236520	Kigigak	2.2	<i>Tidal Sedge</i>	40.3
			<i>Mudflat</i>	56.0
			<i>Tundra</i>	3.7
236522	Kigigak	12.5	<i>Tidal Sedge</i>	28.9
			<i>Mudflat</i>	67.4

			<i>Tundra</i>	3.7
244755	Kigigak	11.1	<i>Tidal Sedge</i>	51.1
			<i>Mudflat</i>	47.1
			<i>Tundra</i>	2.0
244756	Kigigak	10.4	<i>Tidal Sedge</i>	46.8
			<i>Mudflat</i>	51.0
			<i>Tundra</i>	3.0
244757	Kigigak	3.45	<i>Tidal Sedge</i>	28.3
			<i>Mudflat</i>	71.6
			<i>Tundra</i>	0.04
244758	Kigigak	12.5	<i>Tidal Sedge</i>	45.2
			<i>Mudflat</i>	52.7
			<i>Tundra</i>	2.0
244759	Kigigak	15.8	<i>Tidal Sedge</i>	49.4
			<i>Mudflat</i>	48.6
			<i>Tundra</i>	2.0
244762	Kigigak	2.6	<i>Tidal Sedge</i>	49.2
			<i>Mudflat</i>	50.8
			<i>Tundra</i>	0
244764	Kigigak	21.9	<i>Tidal Sedge</i>	24.5
			<i>Mudflat</i>	73.0
			<i>Tundra</i>	2.4
			<i>Tidal Sedge</i>	44.1 (50.8 – 37.4)

Mean Percent Habitat Composition within Home	<i>Mudflat</i>	52.3 (60.8 – 43.8)
Ranges (95% CI)	<i>Tundra</i>	3.64 (6.0 – 1.3)

Table 2-2: AICc Table of Logistic Regression Models for Resource Selection Function. These were determined using a dredge method and reflect all combinations of covariates as well as a null model. All models were run in the program glmmTMB (Brooks et al., 2017) using a generalized linear mixed model in a logistic regression.

Model Names	AICc	ΔAICc	ModelLik	AICcWt	Cum.Wt	K
<i>globalmodel</i>	26410.86	0	1	0.6551548	0.6551548	5
<i>quadraticdist2water</i>	26412.14	1.283555	0.5263561	0.3448447	0.9999995	6
<i>vegetationtype</i>	26439.03	28.170762	0.00000076	0.00000050	1	4
<i>null</i>	43736.93	17326.069	0	0	1	2
<i>distance2water</i>	43737.62	17326.760	0	0	1	3

Table 2-3: Odds-Ratio CIs for *globalmodel*.

	Estimate	2.5%	97.5%
Distance to Water	0.87062440	0.82804475	0.91539357
Mudflat	0.07662055	0.06701489	0.08760305
Tidal Sedge	1.56277533	1.42201435	1.71746983
Tundra	0.75860403	0.56738591	1.01426571

FIGURES

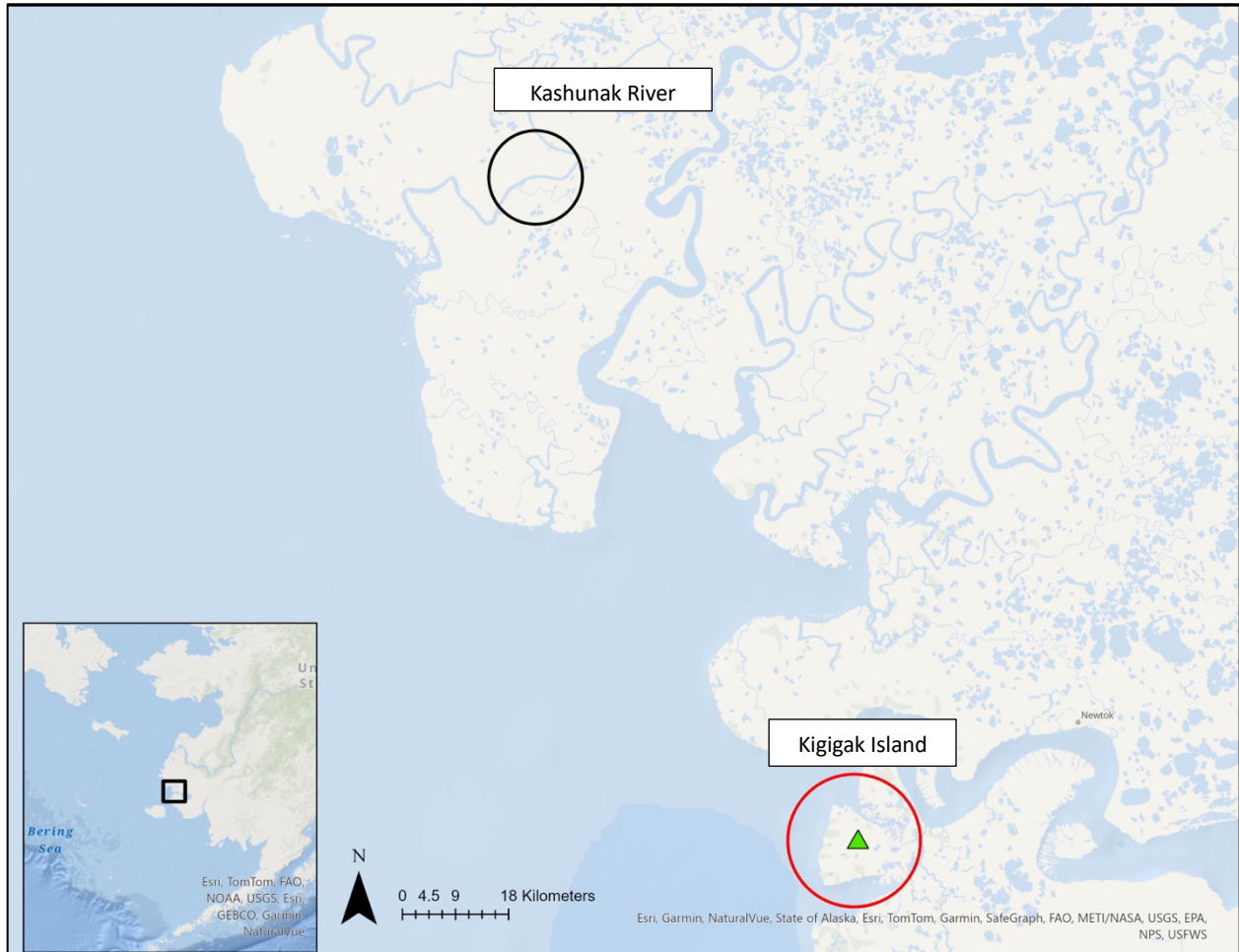


Figure 2-1: Map of locations where transmitters were deployed on the Yukon-Kuskokwim Delta, Alaska. The Yukon Delta is located in western Alaska and Kigigak Island is located 20.5 km west of the village of Newtok. Red circle delineates Kigigak Island study site where transmitters were deployed in 2022 (n = 4) and 2023 (n = 14). Black circle delineates Kashunak River section where transmitters were deployed 2022 (n = 2). Green triangle indicates long term USFWS field camp on Kigigak Island.

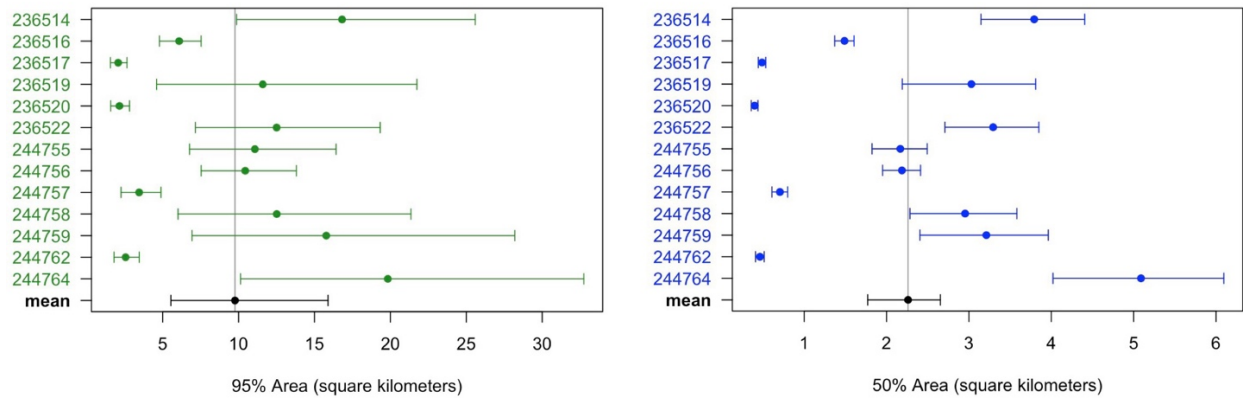


Figure 2-2: Results from meta-analysis of home range size (total – left, core – right) for 13 emperor geese marked on the Yukon-Kuskokwim Delta, Alaska. Total home range indicates 95% of total home range size. Core home range indicates 50% of total home range size or the most used space within a home range. Individual transmitter numbers (ID) are listed along y-axis. Points indicate estimate for area of home range in square kilometers and include 95% confidence intervals. Mean is differentiated in black color. Mean total home range estimate was 9.76 (95% CI: 5.54 - 15.88). Mean core home range estimate was 2.26 (95% CI: 1.77 - 2.652).

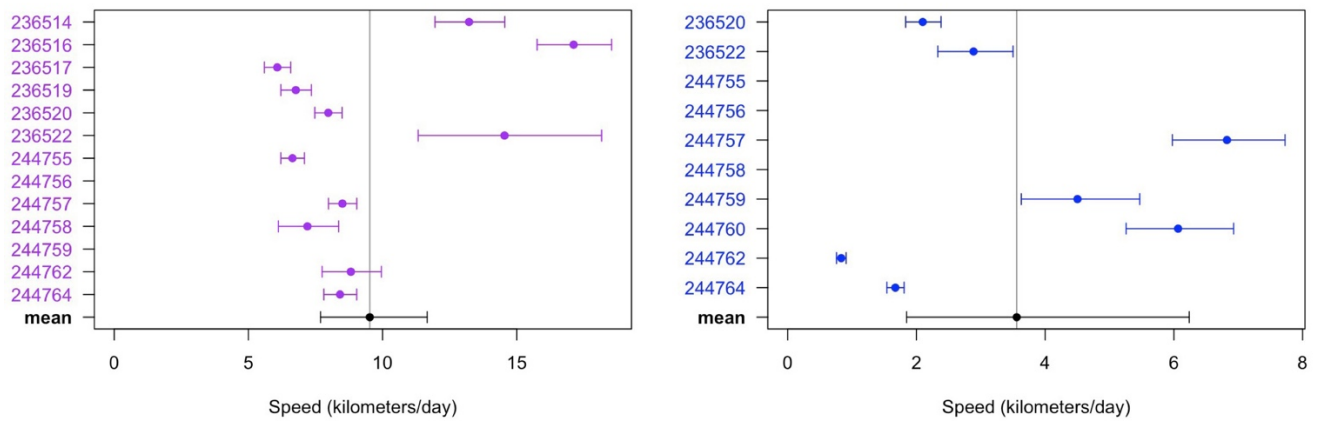
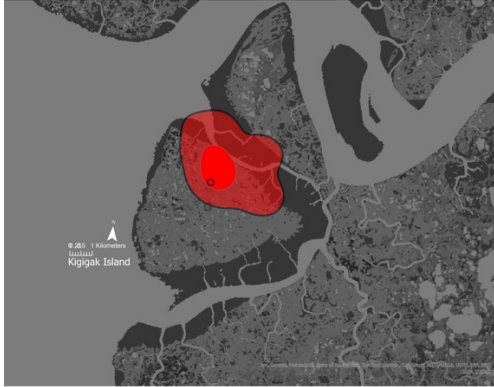


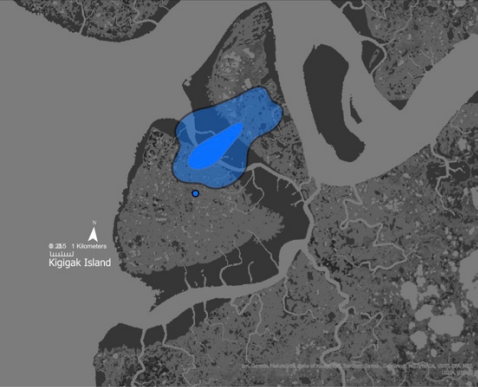
Figure 2-3: Daily distance that emperor goose broods traveled during brood rearing time period

(left) and during the dispersal time period (right) on the Yukon-Kuskokwim Delta, Alaska.

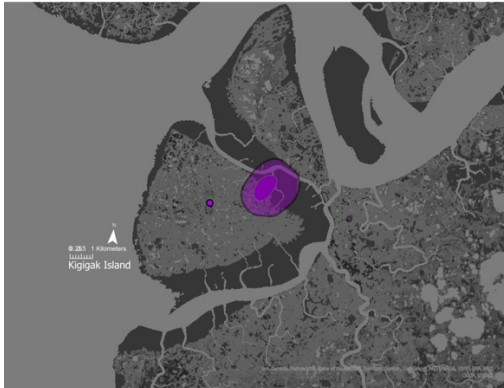
Individual speeds are differentiated by ID on the Y-axis. Points indicate speed estimates with 95% confidence intervals.



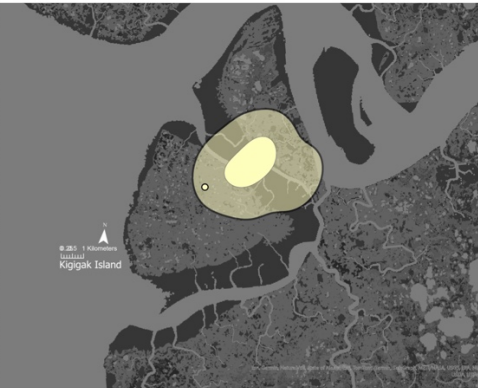
244755



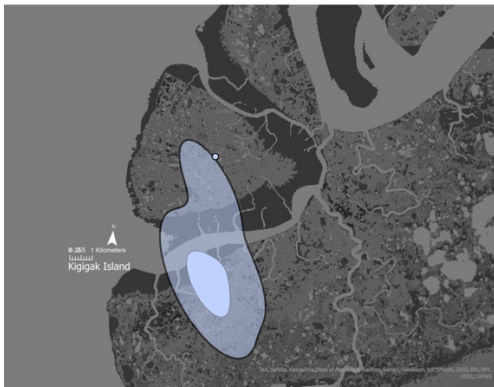
244756



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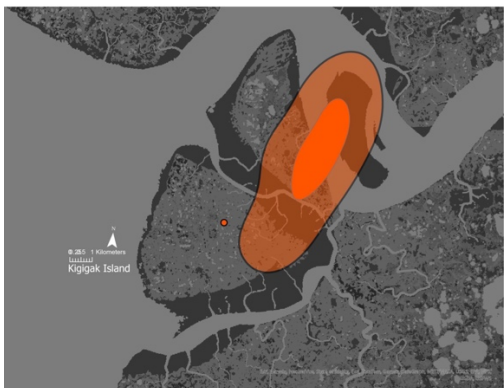
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244762



244764

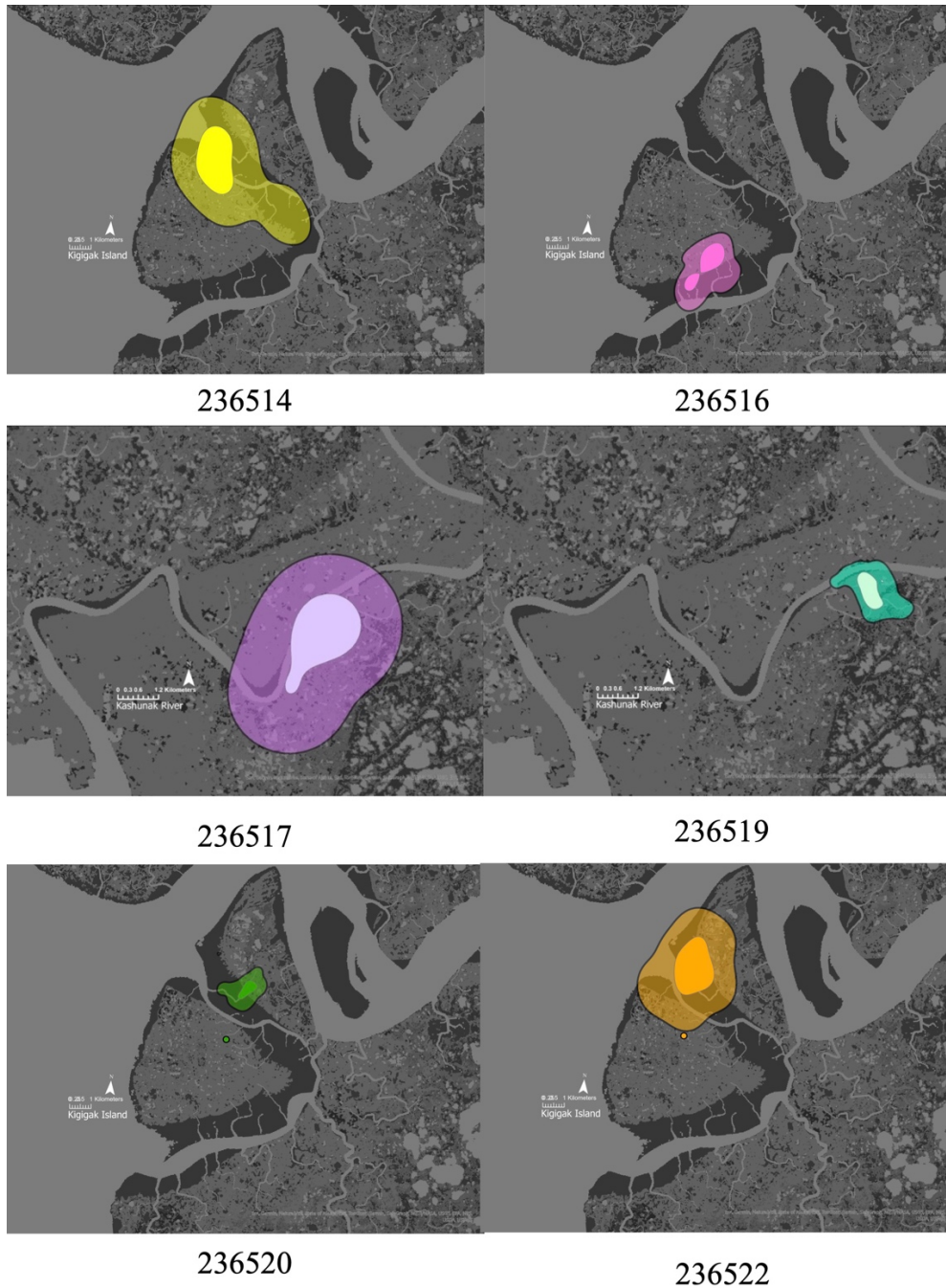


Figure 2-4: Maps of individual home ranges for 13 emperor goose broods on the Yukon-Kuskokwim Delta, Alaska. Solid fill indicates home range extent at 50%, transparent fill indicates home range extent at 95%. Colored dots are nesting locations for all 13 individuals. Maps without nesting locations are those of transmitters deployed in 2022 during the late brood rearing season.

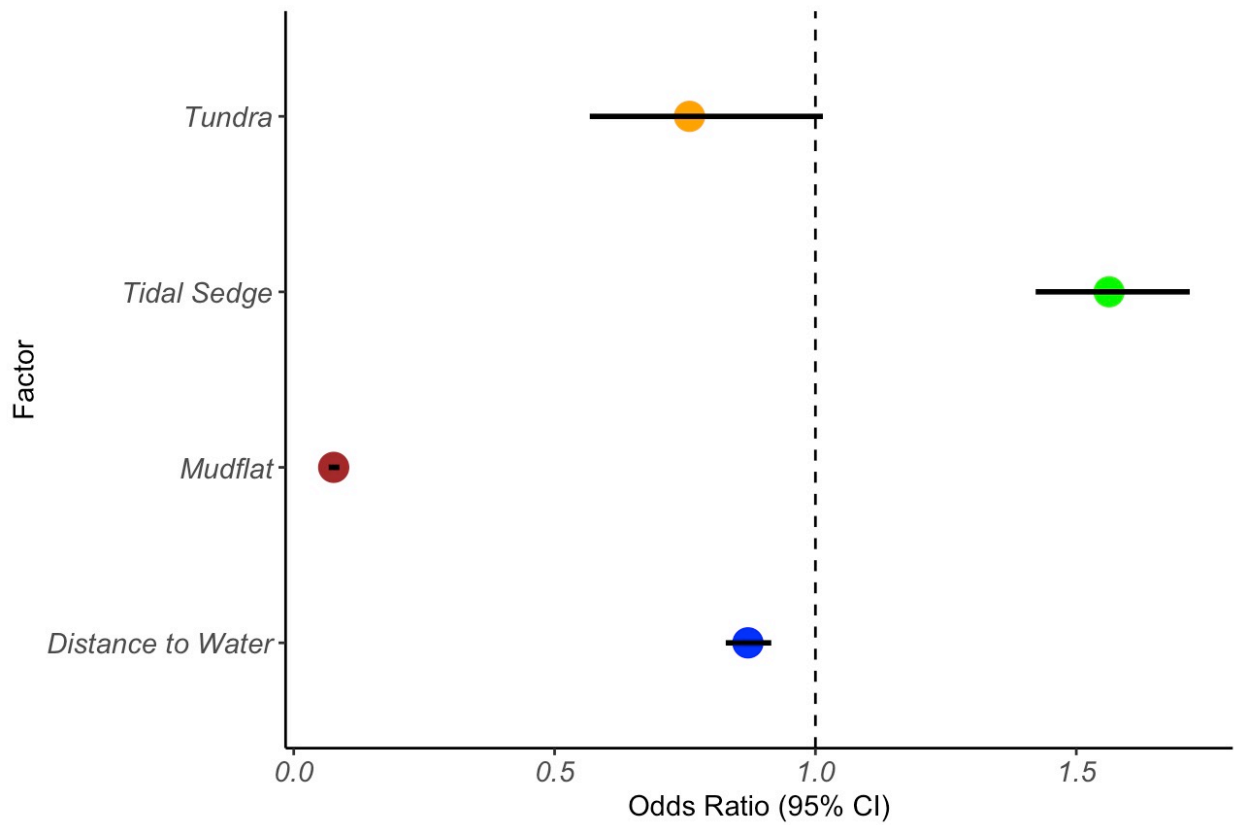
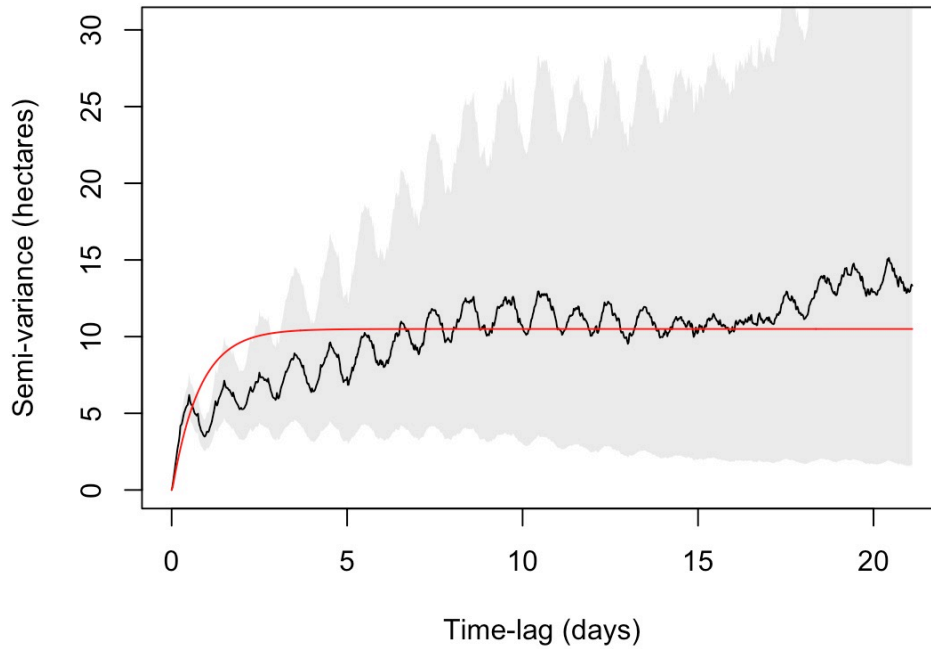
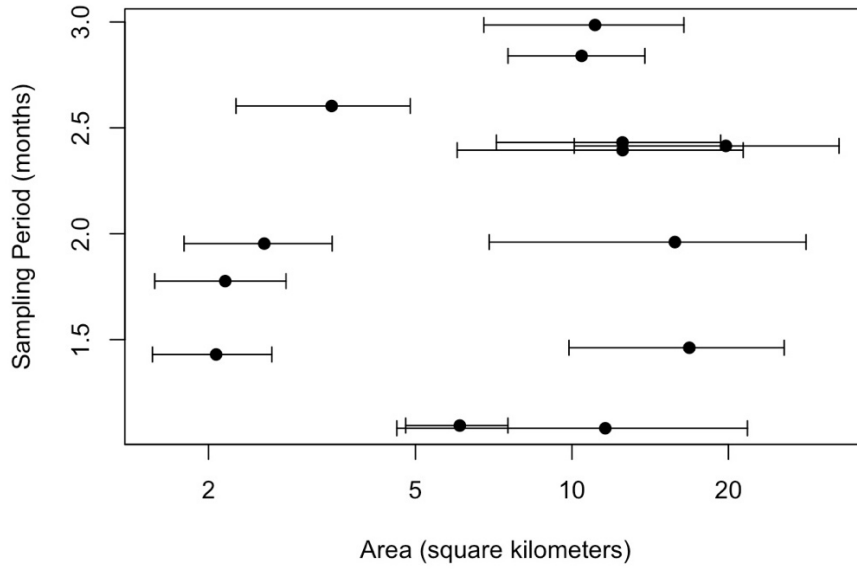


Figure 2-5: Resource selection of emperor geese during brood rearing on the Yukon-Kuskokwim Delta, Alaska. Individuals preferred habitat farther from waters edge (OR = 0.87, 95% CI: 0.83 – 0.92). Individuals strongly preferred tidal sedge habitat (OR = 1.56, 95% CI: 1.42 – 1.71). Individuals avoided tundra habitat (OR = 0.76, 95% CI: 0.57 – 1.01) and mudflat habitat (OR = 0.07, 95% CI: 0.067 – 0.088).

SUPPLEMENTAL FIGURES



Supplemental Material 2-A: An example variogram from a range resident individual (ID = '236517'). The asymptote in red indicates the fitted model to the semi-variance in movement. The black line indicates the variance in movement of an individual between fixes. A better fit asymptote results in smaller confidence intervals in home range estimate.



Supplemental Material 2-B: Comparison of sampling time period per individual (months) to the area calculated for individual's home range (km²), known as a funnel calculation, to determine sample bias. 95% home range estimate is indicated by black dots, 95% confidence interval indicated by thin lines. Sample time period was determined as total time that a bird was transmitting points during the brood rearing period.

SUPPLEMENTAL TABLES

Supplemental Material 2-C: Results of meta-analysis for total home range size (95th Percentile).

Home range area estimates were calculated using a weighted Autocorrelated Kernel Density Estimate. Total home range refers to the size of the home range at the 95th percentile or the total area that was used by geese during the brood rearing period.

<i>$\Delta AICc$</i>		
<i>Inverse-Gaussian</i>	0	
<i>Dirac - δ</i>	159.8286	
	Area	95% CI
<i>Mean (km²)</i>	9.7595740	5.5379850 - 15.884614
<i>CoV² (rvar)</i>	0.8436018	0.2225721 - 1.870719

Supplemental Material 2-D: Results of Meta-Analysis for core Home Range (50th Percentile).

Home range area estimates were calculated using a weighted Autocorrelated Kernel Density Estimate. Core home range refers to the size of the home range at the 50th percentile or the main area that was used by geese during the brood rearing period.

<i>$\Delta AICc$</i>		
<i>Inverse-Gaussian</i>	0	
<i>Dirac - δ</i>	186.0577	
	Area	95% CI

Mean (km²)	2.260183	1.7707574 - 2.652155
CoV² (rvar)	1.043663	0.6444627 - 1.410889

Supplemental Material 2-E: Results from Speed Meta-Analysis during brood rearing period.

CoV indicates the covariance of the autocovariance parameter function. Estimates were calculated using the ‘SPEED’ function (Fleming, 2019).

<i>ΔAICc</i>		
<i>Inverse-Guassian</i>	0	
<i>Dirac - δ</i>	456.9352	
	Estimate	95% CI
Mean (km/day)	9.5489769,	7.68723744 - 11.7197612
CoV² (RVAR)	0.1221764,	0.03825652 - 0.2539417
CoV (RSTD)	0.3586018,	0.20066491 - 0.5169942

Supplemental Material 2-F: Speed Meta-Analysis for Dispersal Period. CoV indicates the covariance of autocovariance parameter function. Estimates were calculated using the ‘SPEED’ function within the program ‘ctmm’ (Fleming, 2019).

<i>ΔAICc</i>	
<i>Inverse-Guassian</i>	0
<i>Dirac - δ</i>	2052.551

	Estimate	95% CI
<i>Mean (km/day)</i>	3.5387374	1.8518622 - 6.168052
<i>CoV² (RVAR)</i>	0.6878639	0.1188200 - 1.746426
<i>CoV (RSTD)</i>	0.8686736	0.3610357 - 1.384141

CHAPTER III: EMPEROR GOOSE BROOD REARING BEHAVIOR: WIDE OPEN MUDFLATS OR VEGETATED GRAZING LAWNS?

Abstract

While the pre-fledging period is relative short in duration in birds, it nonetheless has important implications for lifetime fitness as an individual's behavior and choice of resources during this period can affect juvenile survival and growth rates that carry over to affect adult body size and reproductive output. Thus, successful conservation and management, in part, hinges on understanding how species, and the individuals therein, exhibit variability in behavior across a diversity of resources. The emperor goose (*Anser canagicus*) is an Arctic breeding goose species endemic to the Bering Sea region that breeds primarily on the Yukon- Kuskokwim Delta, Alaska. During the brood rearing period, both adults and goslings consume protein dense *Carex subspathacea* found on grazing lawns to maximize growth rate and improve fitness. Emperor geese compete with other Arctic goose species for these small patches of highly nutritious grass. Following a movement study conducted during the brood rearing period in 2022 and 2023, mudflat, a habitat previously thought to provide limited value to goose broods, was anecdotally identified as a habitat with potential value to emperor geese. Therefore, our objective was to examine the potential value of mudflat habitat by comparing activity budgets from mudflat to those conducted on grazing lawn during the second and third weeks of gosling development. We determined that foraging was the most common behavior performed by goslings and that this behavior was near equal on both substrates (mud and grazing lawn). Adults also spent a significant amount of time foraging on both substrates and spent more time alert on grazing lawn habitat. This difference in behavior may be indicative of more competition or predation concerns on these smaller areas of forage. Other species in highest prevalence with emperor geese across

both habitat types included cackling geese, northern pintail, and Pacific black brant. We examined the protein content on both substrates and concentrations were both ~2% on average. This result, combined with the observations of foraging on both substrates, leads us to believe that emperor geese may be using mudflat when it's available and that the marine vegetation present is beneficial to growth. This observation of foraging on marine vegetation during brood rearing is the first time this behavior has been documented in western science.

Introduction

Within the framework of evolutionary theory, fitness describes how well an organism is adapted to its' environment and is measured by the subsequent rate of reproductive success over a lifespan (Orr, 2009). Fitness is governed by resource availability and environmental conditions, and thus varies among individual animals through time and across space (Lohman et al., 2019; Oro et al., 2004). As environmental conditions change, organisms may alter their behavior in an attempt to maximize fitness (Cooch et al., 2001). For example, individuals may forgo reproduction in an attempt to increase survival probability during years when breeding or staging habitats are limited. Higher survival leads to more opportunities to reproduce and increase fitness, and these vital rates drive population dynamics. Thus, a species' behavior becomes important to examine during periods of environmental change and the sensitive periods of development such as nesting, brood rearing and juvenile recruitment (Oro et al., 2004; Sedinger et al., 1995; Sedinger et al., 2016). When resources change rapidly, species are forced to adapt, including altering their behavior, or be unable to compensate for the change in resources and perish (Moller et al., 2008). Access to resources during the first year of life are especially important as growth rate of juveniles affects body size and survival probability, migration, and

subsequently adult reproductive output (Schmutz, 1993; Sedinger et al., 1995; Sedinger et al., 2004).

In long lived species, natural selection acts strongly during the juvenile growing period, likely because adults have evolved to conserve survival in variable environments (Rose, 1991; Charlesworth, 1994). This phenomenon can be observed in Arctic geese (tribe *Anserini*), as reproductive rates are often more variable within an individual's lifetime in long lived waterfowl species versus those with shorter lifespans (Koons et al., 2014). Further, arctic nesting waterfowl are dependent on high latitude ecosystems which makes them susceptible to environmental changes that may alter resources needed during sensitive periods of development such as brood rearing (Koons et al., 2014; Ross et al., 2018). Therefore, as environmental conditions change, vital rates may drive population dynamics differently than were previously established (e.g. demographic buffering hypothesis; Hilde et al., 2020). Arctic and Subarctic regions are experiencing rapid rates of environmental change, with the past 10 years being some of the warmest on record and permafrost in decline (IPCC, 2023; Jorgenson et al., 2018).

Arctic nesting geese have a growing season of less than 100 days, requiring goslings to grow rapidly and fledge (Sedinger and Raveling, 1986; Herzog & Sedinger, 2004). Geese are obligate herbivores during the breeding season, which may cause goslings to be nutrient limited during development as plant foods are low in protein and high in fiber (Sedinger, 1984). This means that goslings must spend the majority of their time foraging and select for the most nutritious food sources in order to maximize growth rate and survival (Sedinger & Raveling, 1988). Goslings foraging on resources that are higher in protein and lower in undigestible fiber have faster growth rates than goslings consuming lower levels of protein and higher levels of fiber (Richman et al., 2015). Migratory geese experience extra pressure to maximize growth, as

strength and nutrients are needed to initiate and survive their first migration (Owen & Black, 1989; Menu et al., 2005). Larger goslings have higher rates of survival on the brood rearing areas as well as during their first migratory attempt, as these individuals are better equipped to handle the strain of migration (Schmutz, 1993).

Protein rich ‘grazing lawns’ of *Carex subspathacea* (Hoppner’s sedge) are the preferred forage for multiple Arctic goose species on the Yukon – Kuskokwim Delta (YKD) including Pacific black brant (*Branta bernicla nigricans*), cackling geese (*Branta hutchinsii minima*) and emperor geese (*Anser canagicus*) (Sedinger & Raveling, 1988; Sedinger et al., 1995; Schmutz, 2001). Grazing lawns are characterized as patches of short-cropped sedge that are maintained by the heavy grazing pressures of Arctic geese (Sedinger, 1984; Sedinger et al., 1995; Person et al., 2003). Brood rearing geese have a unique relationship with this vegetation as their grazing pressure maintains the extent of these patches, while their feces simultaneously recycle nitrogen that is critical to further grazing lawn growth (Bazely & Jeffries, 1985). When there is sufficient grazing pressure, grazing lawns may be maintained or expanded in size (Person et al., 2003). This expansion in turn creates a positive feedback loop, in that larger goslings are produced with larger areas of grazing lawn (Person et al., 2003).

From 1987-2015, there has been a decline in grazing lawns across the YKD (Lohman et al., 2019; Uher – Koch et al., 2019). When grazing lawn extent changes, goose behaviors also change and it has been observed that as grazing lawn patches have declined geese spend more of their time traveling from one patch to another (Lohman et al., 2019). This increased movement results in higher metabolic output required to reach the highest quality resources on the landscape (Nudds et al., 2010; Lohman et al., 2019).

Emperor geese forage on *C. subspathacea* lawns for maximized gosling growth and survival (Schmutz et al., 1993; Schmutz, 2001). Emperor geese have marked declines in their historical population and currently have slow growing population rates (Pacific Flyway Council, 2016). Given that the species is endemic to the climatically changing Bering Sea region and is a culturally important subsistence species for the indigenous communities (Mengak et al., 2022), it is important to understand more of their reproductive ecology and strategy to make the most informed conservation plans (Festa-Bianchet & Apollonio, 2003).

Previous work on gosling behavior conducted by Schmutz (1993, 2001) and Sedinger (1989, 1995, 2016) targeted these important grazing lawns. Their methods involved observing individually marked birds with unique tags and conducting observations of birds from high deck towers overlooking expanses of tidal sedge flat. While it is known that these tidal sedges are mainly used for foraging, it is relatively unknown behaviors may be exhibited on other environments such as tidal mudflats. Previous work indicates that both tidal sedge and mudflat habitat are important brood rearing areas for emperor geese, however direct observations of what behaviors exhibited on these mudflats have yet to be determined (Schmutz, 2001; Murphy, *unpublished*). Given that vegetation cover on the YKD continues to be affected by climate change, combined with grazing lawn extent in decline, geese may be “undermatching” and losing fitness, or compensating through use of different resources to maintain fitness (Jorgenson et al., 2018; Vickery et al., 1995; Lohman et al., 2019; DiNuzzo & Griffen, 2020).

Here we aim to examine how mudflats and grazing lawns are being used by brood rearing emperor geese through an in-depth examination of their behavior. We did so through an observational method that followed GPS tagged geese to areas that they were currently using, rather than static observation towers. We also compare the nutritional (nitrogen) value of

potential foraging types present in different habitats to discover potential tradeoffs of diet preference.

Methods

1.1 Study Site

Kigigak Island (-164.9815, 60. 8478) is a small island located on the edge of the Yukon-Kuskokwim Delta in western Alaska (Figure 3-1). The island is approximately 35km² in size and is situated 20.5km west of the village of Newtok, and northwest of Nelson Island. It is bordered by the Ninglick River and the Bering Sea, making it highly intertidal. The island contains several different vegetation types including brackish wet sedge meadows, wet graminoid meadows, sedge marshes and lowland tundra (Jorgenson, 2000). The island is surrounded by expanses of barren mudflat, especially to the northern edge. This unique array of habitat types provides the preferred nesting habitat for a diverse set of waterfowl, including cackling geese, greater-white fronted geese (*Anser albifrons*), tundra swans (*Cygnus columbianus*) and spectacled eiders (*Somateria fischeri*) (Solovyeva et al., 2017). Because of these features, a long-term field camp has been operated by US Fish and Wildlife Service since 1993 to monitor the densely nesting populations of waterfowl on the island. Research assistants and technicians have been conducting nest monitoring efforts and capture-mark-reencounter studies to determine reproductive output and survival rate of adult female emperor geese for the past 7 years. The entire YKD is located on native Yupi'k and Cupi'k lands.

1.2 Behavioral Observations

We conducted behavioral observations of emperor geese from 06/29/2023 – 07/10/2023 between the hours of 10 am and 7 pm. Observations began 11 days after the peak hatch of emperor geese to allow for goslings to disperse and settle within individual home range

territories. Each observation period was concluded after 30 minutes of observation and the total observation time ranged from 4 to 7 hours per day in a location to maximize data collection and allow for birds to become fully acclimated to the blind and reduce human disturbance.

We chose locations for behavioral surveys based on recently used locations from 10 GPS transmitters deployed on emperor goose adult females in 2023 and known calculated home ranges of 3 individuals that were marked with GPS transmitters in 2022 (Figure 3-2; Murphy 2024 *unpublished*). We monitored these locations daily for to observe emperor goose broods. Details on the capture methodology, transmitter attachment and transmitter data collection can be found in Chapter 2.

We conducted observations simultaneously using a paired habitat sampling method in which one group observed broods located on tidal mudflats while the other group observed broods located in tidal sedge that contained multiple grazing lawns. Each observer was equipped with a Swarovski spotting scope (20x – 60x magnification), camouflage blind to hide observers, notebooks, and time recording device. Blinds were set up as far away as possible to reduce any disturbance caused by the blind while simultaneously being close enough to determine individual gosling behavior. Each observation period began after 20 minutes of observers setting up the blinds to allow for settling and normalization of behaviors exhibited by geese and surrounding birds. Prior to initiating observations, observers recorded data on other species present, tide stage (high, low, ebb, incoming), general weather conditions, and emperor goose family group size.

We employed an instantaneous scan sampling method to collect behavioral data (Altmann, 1973). Instantaneous scan sampling involves the observer repeatedly scanning a predetermined area from left to right every minute to observe all emperor goose brood behaviors in the moment seen (Altmann, 1973). Specifically, we recorded the species, age, and behavior of

each observed individual as being alert, foraging, traveling, resting, or interacting with other individuals. Individuals that were in our field of view but were too far away to identify or accurately determine behaviors were recorded as a 'not applicable.' We used one-minute intervals between observations to maximize observations while a group was within field of view while maintaining enough time to accurately record data (Table 3-1). Knowing that geese tend to change positions and move frequently, a one-minute interval was deemed sufficient time for observations to be un-correlated and unbiased.

1.3 Game Camera Observations

We deployed 14 Reconyx game cameras for 13 days (06/26/23 to 07/10/23) to observe goose behavior without human disturbance. The cameras were placed facing directions that would maximize observations and data collection. We placed each camera following a paired design, with 7 cameras located on grazing lawns previously used by our GPS tagged near areas emperor geese, while the other 7 cameras were located on highly trafficked mudflats near GPS tag locations (Figure 3-2). We assumed that locations recorded by the 13 birds equipped with GPS transmitters were representative of regions commonly trafficked by emperor goose broods. Human observations taken near cameras were conducted on opposite habitat types (i.e. humans observing grazing lawn while camera was facing mudflat). Cameras were also placed at a distance from human observation locations to prevent double counting during overlaps of human and camera observations (Figure 3-2). Each camera was programmed to take a photo on a 10-minute interval. Images and in person observations were recorded as behaviors based on the same ethogram (Table 3-1). We recorded variables including weather, other species present, time and family group size for each image.

1.3 Nutritional Analysis

We collected forage samples from game camera locations on 7/11/23. Game camera locations were used as collection sites to be able to confirm that sampled forage types were being consumed by emperor goose adults and goslings. Samples included *Carex subspathacea* grazing lawn, *Carex subspathacea* fully grown, *Ulva spp.*, green algae and an algae/biofilm layer that was present on the mudflat. A small sample of approximately 1oz was collected from 3 camera sites (2 mudflat and 1 grazing lawn) and were frozen and transported by cooler until freeze dried in a laboratory setting. A single sample of each vegetation type was collected. Vegetation samples were tested for nitrogen content using chemical testing at the Soil and Forage Lab at University of Wisconsin – Madison.

1.4 Data Analysis

We first summed the counts of each behavior during an observation period of 30 minutes. We grouped related behaviors into general categories to reduce redundancy in the results. Behaviors observed such as “Head down – grass” and “Head down – mud” were behaviors that we indicated and were grouped as “Foraging” and the behavior of “Brooding,” “Resting,” and “Head Up” were grouped as a “Resting” category. The behavior type of “Traveling” included “Walking,” “Running” and “Swimming” behaviors, and “Alert” remained in its’ own category. “Alert” behavior was classified as an individual standing upright with its’ neck near to fully stretched upward. This was to differentiate between the resting behavior of “Head Up” where the bird was standing or sitting with its’ head and neck upward but not stretched or looking around. Age classes were split into adults and goslings given that behavior would be different based on age (Sedinger & Raveling, 1988; Lohman et al., 2019).

From the count data, an activity budget was calculated using R (R Core Studio, 2023) to determine the proportion of time spent exhibiting each behavior class, regardless of habitat. This

gives an overview of what behaviors are most important for emperor geese during the brood rearing period.

We used generalized linear mixed effects models to test for differences in emperor goose behavior between mudflat and sedge habitats. To do this we grouped sets by age and observation period, and further partitioned the dataset to differentiate between grazing lawn and mudflat habitats. The count data for these observation periods was then z-standardized to account for differences in number of counts between habitats. We included day of survey as a random effect to control for lack of independence among surveys conducted in the same general vicinity during a given day. We modeled coefficients using vague priors, sampled 4 MCMC chains for 2000 iterations, and a burn in of 1000 iterations. We ran models using the program brms (Bürkner, 2017) in R (R Core Team, 2023).

Results

Over the 13-day observation period (06/26/23 – 07/10/23), we collected 9179 observations of adult and juvenile emperor geese (8217 from human observers, 962 from cameras). Of those observations, 7677 were recorded on mudflats and 1502 were recorded on grazing lawns (Figure 3-3). We collected 5532 observations of goslings and 3647 of adults (Figure 3-4; Figure 3-5).

Adult behaviors fell into 5 main behavior categories and gosling behavior consisted of 3 main behavior types (Table 3-2). Regardless of habitat type adults spent the most of their time foraging (0.346; Table 3-2) followed by traveling (0.239; Table 3-2). Adults spent near equal amounts of time alert (0.204) and resting (0.206; Table 3-2) and we observed relatively few observations of adults interacting with other species ($n = 14$, 0.004; Table 3-2). Goslings predominantly spent their time foraging (0.654; Table 3-2) and were observed traveling in about

one-quarter of all observations (0.271; Table 3-2). Goslings spent the least amount of time resting throughout our observations (0.074; Table 3-2). There were no observations of goslings alert or interacting with other species.

When comparing the two substrates, adult emperor geese spent more time alert while on grazing lawns (GL) ($\beta_{GL} = 0.23$, 95% CI: $-0.08 - 0.52$, Table 3-3) than when on mudflat (MF) habitat ($\beta_{MF} = -0.36$, 95% CI: $-0.60 - -0.12$; Table 3-3). Adults spent a significant amount of time foraging on both habitats ($\beta_{GL} = -0.08$, 95% CI: $-0.29 - 0.15$; $\beta_{MF} = 0.53$, 95% CI: $0.19 - 0.87$; Table 3-3), and less time interacting with other species ($\beta_{GL} = -0.49$, 95% CI: $-0.29 - 0.15$; $\beta_{MF} = 0.08$, 95% CI: $-0.26 - 0.42$; Table 3-3). Finally, adults spent a more time resting ($\beta_{GL} = -0.16$, 95% CI: $-0.38 - 0.06$; Table 3-3) and traveling across ($\beta_{GL} = -0.24$, 95% CI: $-0.46-0.00$; Table 3-3) grazing lawns during our observations as compared to the amount of time resting and traveling on mudflats. Resting, traveling and alert behaviors on mudflats were not significantly positive or negative (Table 3-3; Figure 3-6).

Of the three gosling behaviors (foraging, resting and traveling), goslings spent most of their time foraging on both substrates ($\beta_{GL} = 0.49$, 95% CI: $0.21 - 0.77$, $\beta_{MF} = -0.07$, 95% CI: $-0.35 - 0.20$; Table 3-4). Goslings spent more time resting ($\beta_{MF} = -0.08$, 95% CI: $-0.46 - 0.30$; Table 3-4) and less time traveling ($\beta_{MF} = 0.22$, 95% CI: $-0.16 - 0.61$; Table 3-4) while on mudflats although the time spent in either of these behaviors were significantly different than the behaviors they exhibited while on grazing lawns ($\beta_{GL} = -0.76$, 95% CI: $-1.03 - -0.48$, $\beta_{GL} = -0.79$, 95% CI: $-1.06 - -0.52$; Table 3-4).

Cackling geese were the most abundant conspecific species in both habitats ($n = 8123$; Figure 3-8), followed by northern pintail (*Anas acuta*; $n = 6044$; Figure 3-8) and Pacific black brant ($n = 5967$; Figure 3-8), common eider (*Somateria mollissima nigricum*; $n = 4306$), and

glaucous gulls (*Larus hyperboreus*; n = 3802; Figure 3-8). Other species present on both habitats, but less abundant, were tundra swans, sandhill crane (*Grus canadensis*), sabine's gull (*Xema sabini*) and several shorebird species (order *Charadriiformes*). This set of observational data included counts from both habitats.

Vegetation samples were collected to derive nitrogen (indicative of protein) content. Our samples of vegetation included *C. subspathacea* grazing lawn, an *Ulva* spp., a biofilm/algal mat present on mudflat, green algae and *C. subspathacea* tall form for a total of 5 samples (Table 3-5). Nitrogen content was higher in full grown *C. subspathacea* than in the samples collected from grazing lawn (2.31%, 1.77%; Table 3-5). Nitrogen content was highest in the green macroalgae collected (2.06%; Table 3-5), followed by a species of *Ulva* (1.38%; Table 3-5) and the algal mat that covered most of the mudflat had the lowest nitrogen content (0.33%; Table 3-5). Fiber content was not calculated because of the low volume of sample.

Discussion

Understanding how individuals use resources is important to understanding factors that may impact individual fitness, which ultimately drive population dynamics (Oro et al., 2004). Our work observing emperor goose brood behavior revealed that broods exhibited foraging behavior on both mudflat and grazing lawn habitat, and emperor geese were observed to consume both macroalgae and *Carex subspathacea* during the brood rearing period. Previous studies such as Schmutz 2001, and Schmutz 2000, had not included visual or camera observations that targeted mudflat substrate due to grazing lawn being a well established preferred forage of Arctic nesting geese. In Laing & Raveling (1993) observers targeted mudflat habitat but observed goslings selecting *Carex subspathacea* most favorably. This trend is supported by our research as well, in that our resource selection function (Chapter 2; Figure 2-6)

shows that tidal sedge remains the most preferred habitat type for broods, but mudflat comprises a significant portion of an individual's home range (Chapter 2; Table 2-1).

Our study found that goslings spent most of their time foraging, regardless of substrate (Table 3-2; Figure 3-7). This reflects the need for goslings to consume high quality forage as fast as possible to maximize growth rate during the pre-fledging period (Schmutz, 1993; Sedinger et al., 1995). Traveling and resting were observed in relatively equal amounts across both habitats (Figure 3-7). Goslings spent more than double the amount of time traveling (0.27; Table 3-2) as resting (0.07; Table 3-2) but did not have a significant difference in these behaviors on different substrates (Figure 3-7). The lack of difference in these behaviors indicates that there may not be a tradeoff of metabolic output of goslings foraging on grazing lawns in comparison to mudflats. Walking, running and swimming require higher metabolic rates, and a significantly higher amount of traveling would likely have a negative effect on gosling growth as more calories would be necessary to maintain a high growth rate (Nudds et al., 2010; Richman et al., 2015). Ultimately, goslings maximized foraging while they followed their parents across substrates which is consistent with previous studies on the subject (Sedinger & Raveling, 1988).

Adults had more complicated activity budgets compared to goslings that included significant time (0.20; Table 3-2) being alert for predators, a trait that is consistent across goose species (Sedinger & Raveling, 1988; Sedinger et al., 1995). Adults spent more time alert on grazing lawn (Figure 3-6), which may be indicative of competition between other species such as black brant, cackling geese and greater white grouted geese who all prefer to rear their broods on grazing lawn habitat (Ely et al., 1985; Sedinger & Raveling, 1988; Sedinger et al., 1995; Schmutz, 2001; Lohman et al., 2019; Uher-Koch et al., 2019). This increased alert behavior may also be indicative of adults actively looking for threats of predators over the vegetated landscape.

While vegetation may provide cover from predators, it also may prevent adults from easily anticipating oncoming terrestrial predators by being a physical barrier. This may have a cost associated with increased stress and metabolic rate due to higher heart rate during periods of alertness (Ely et al., 1999). Standing and being alert requires higher metabolic stress than resting or sitting in adult geese (Tickle et al., 2012), which may contribute to reduced fitness if this is significantly higher on grazing lawn substrates.

Adults spent significantly more time traveling while on grazing lawn than on mudflat (Figure 3-6) which may be due to increased competition on these smaller areas of forage by moving from one small grazing lawn to another. This trend of increased traveling on grazing lawns has also been observed over time in black brant populations with grazing lawn declines (Lohman et al., 2019). While our observations were not over the same time scale as observations taken at the Tutakoke brant colony, the greater traveling time on grazing lawn versus mudflat habitat may be indicative of less habitat available and higher rates of competition for these smaller patches of resources (Lohman et al., 2019; Uher-Koch et al., 2019).

We also found that adult emperor geese spent significantly more time resting on grazing lawns than on mudflats (Figure 3-6). The intertidal area of mudflat is exposed and prone to flooding, thus adult emperor geese may be maximizing their time in protected, dry areas by recuperating and resting.

Anecdotally, emperor geese tend to be less aggressive than other goose species on the YKD, and avoid confrontation with other waterbird species. This was reflected in our counts of observations that involved interacting with conspecifics ($n < 15$) which may have been due to our method of instantaneous sampling once per minute, or may have been an effect of emperor geese not directly confronting other species often. Given the open nature of mudflat and large

area it covers around Kigigak Island, emperor geese may be including this habitat in their home ranges (Chapter 2; Table 2-1) as it allows individuals to see and avoid interference competition more freely. Avoiding interference competition has benefits to fitness, as there is lower risk of injury and lower metabolic output than engaging in confrontation (Newton, 1998; Goodale et al., 2017). To gain more insight into these interactions, one could use a continuous time sampling method (Tacha et al., 1985) as an alternative to our instantaneous method.

When looking at the nutrient content on both habitat types, macroalgae samples had a wide range of nitrogen content, from 0.33% nitrogen present in the biofilm sampled, to 2.06% in the leafier, green macroalgae sampled (Table 3-5). *C. subspathacea* had a smaller range in nitrogen levels, with old growth having a nitrogen content of 2.31% and new growth (grazing lawn) at 1.77% (Table 3-5). We observed adults eating old growth *C. subspathacea* during camera and human observation time periods, but goslings were only observed eating new growth, which contained less nitrogen (1.77%) than in old growth (2.31%) and green algae (2.06%) (Table 3-5). Goslings were observed to be eating all types of algae on mudflat habitat over the course of the study. Protein content is directly correlated to faster gosling growth rate and higher survival (Schmutz, 1993; Richman et al., 2015). In testing of fiber content of green and blue green algae in related studies, Neutral Detergent Fiber (NDF) as a metric of digestibility in algae is generally less than that of *C. subspathacea* collected and tested from the YKD (Misurcova et al., 2010; Richman et al., 2015). Low fiber content leads to a slightly higher survival rate in goslings than a higher fiber content, as lower amounts of fiber in vegetation leads to higher digestibility (Richman et al., 2015). Based on this evidence, resources available on mudflat habitat appear to be comparable to grazing lawn (Richman et al., 2015).

Cackling geese were the most abundant goose species during our observations, which is consistent with both species historically using the same brood rearing habitat. Cackling geese have a much greater population index (161,000), compared to the emperor goose population index of 24,000 in 2023 (USFWS, 2023). Both species primarily nest on the YKD (Eisenhauer & Kirkpatrick, 1977; Mickelson, 1975) in the same habitat types. Previous work suggests that increasing cackling goose numbers have potentially negative effects on emperor goose broods; with high numbers of cackling geese resulting in smaller emperor goslings (Lake, et al., 2008). This competition for similar resources is likely to continue given that emperor broods continue to select for grazing lawn and tidal sedge habitat most strongly (Figure 2-6; Chapter 2).

Finally, the majority of our observations of emperor geese were on mudflat substrate. This is likely due to higher rates of detection by human observers, as mudflats are barren and large birds such as geese can be easily seen. This higher detection would be influenced by our methods, as the small stature of goslings make it difficult to observe them in sedge when sitting at ground level. This could be improved by using raised observation towers (Sedinger & Raveling, 1988; Sedinger et al., 1995) to look down at the birds and have a better view.

Through our behavioral observations we were able to confirm that geese and their broods are consuming green algae and other marine vegetation from mudflat habitats, as well as consuming *Carex subspathacea* as historically described (Schmutz, 2001). Adults had more complicated activity budgets spent more time alert, resting and traveling while on grazing lawn habitat, which may be indicative of competition from similar species on these small patches of forage. Goslings spent most of their time foraging regardless of substrate. Mudflat was identified as having apparent value in our work on home range and percent habitat composition (Table 2-1;

Chapter 2), and our behavioral observations revealed that both adults and goslings are spending their time foraging on this substrate.

Our resource selection function (Chapter 2), percent habitat composition calculation (Chapter 2) and behavior types (Chapter 3) exhibited by emperor geese indicate that they use mudflat habitat when it is available during low tide, but do not explicitly select for the habitat. This mudflat habitat holds other potential positive qualities to adult emperor geese in that it provides good line of sight, a large area to avoid interference competition and ample marine vegetation to forage on. The area is unavailable to broods for a significant period during high tide, which may be an influence our resource selection calculation (Figure 2-6; Chapter 2). Our research supports historical knowledge that tidal sedge and grazing lawn are still the dominant habitat and forage type used by emperor goose broods on the YKD and suggests that mudflat habitat may be used by emperor geese when available as a comparable resource for brood rearing.

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TABLES

Table 3-1: Ethogram used to delineate behaviors exhibited by emperor goose broods and adults.

Other information recorded during the observational period included tidal information, conspecifics present, weather metrics (wind, precipitation, temperature), family group size, coordinates, and time at start/end.

Behavior	Code	Definition	Behavior Type
<i>Alert</i>	A	Head up, scanning horizon for predators, active	Alert
<i>Head Up</i>	Hu	At rest, just normal head up vs alert	Resting
<i>Resting</i>	Re	Still or sitting, eyes closed/sleeping, not alert, head tucked	Resting
<i>Brooding</i>	Br	Goslings gathered beneath goose	Resting
<i>Preening</i>	P	Reaching around and reorganizing feathers using bill	Resting
<i>Head down (mud)</i>	Dm	Eating/drinking/gritting, foraging in mud	Foraging
<i>Head down (grass)</i>	Dg	Eating/drinking/gritting, foraging in grass	Foraging
<i>Head down (water)</i>	Dw	Eating/drinking/gritting, foraging in water	Foraging
<i>Interacting</i>	In	Interspecific or intraspecific communication between individuals, positive or negative	Interacting
<i>Fleeing</i>	Fl	Running away from predators/people	Traveling
<i>Flying</i>	Fly	Flying/traveling	Traveling
<i>Swimming</i>	Sw	Floating and moving through water	Traveling
<i>Walking</i>	Wa	Walking across substrate	Traveling
<i>Running</i>	Ru	Running across substrate	Traveling
<i>Calling</i>	C	Open mouthed vocalizations, head up, peeping/honking to communicate to others	Not Observed
<i>Bathing</i>	Ba	Fluffing feathers in water	Not Observed

<i>Tip Up</i>	Tu	Head down butt up	Not Observed
<i>Other</i>	O	Any behavior not described	Not Observed

Table 3-2: Overall activity budget of adult and gosling emperor geese across both substrates.

Proportion of time spent exhibiting each behavior calculated using Program R (R Core Team 2023).

Age Class	Behavior Type	Frequency	Proportion of Time
Adult	Alert	702	0.204
	Foraging	1190	0.346
	Interacting	14	0.004
	Resting	708	0.206
	Traveling	820	0.239
Gosling	Foraging	2738	0.654
	Resting	313	0.074
	Traveling	1133	0.271

Table 3-3: Results of generalized linear mixed model run in the modeling framework of brms in Program R (R Core Team, 2023) for emperor goose adult behavior by habitat with a random effect of day.

z – standardized counts of adult observations ~ Behavior Type * Habitat + (1|Day)

Regression Coefficients	Estimate	Std. Error	95% CI
Alert – Grazing Lawn	0.23	0.15	-0.08 - 0.52
Foraging – Grazing Lawn	-0.08	0.11	-0.20 - 0.15
Interacting – Grazing Lawn	-0.49	0.12	-0.72 – 0.26
Resting – Grazing Lawn	-0.16	0.11	-0.38 – 0.06
Traveling – Grazing Lawn	0.24	0.12	-0.46 – 0.00
Alert – Mudflat	-0.36	0.12	-0.60 - -0.12
Foraging - Mudflat	0.53	0.17	0.19 – 0.87
Interacting – Mudflat	0.08	0.17	-0.26 – 0.42
Resting – Mudflat	0.22	0.17	0.09 – 0.76
Traveling – Mudflat	0.43	0.17	0.09 – 0.76
~Day	0.40	0.11	0.24-0.66

Table 3-4: Results of generalized linear mixed model run in the modeling framework of brms in Program R (R Core Team, 2023) for emperor goose gosling behavior by habitat with a random effect of day.

$$z - \text{standardized counts of adult observations} \sim \text{Behavior Type} * \text{Habitat} + (1|\text{Day})$$

Regression Coefficients	Estimate	Std. Error	95% CI
Foraging – Grazing Lawn	0.49	0.14	0.21 – 0.77
Resting – Grazing Lawn	-0.76	0.14	-1.03 - -0.48
Traveling – Grazing Lawn	-0.79	0.14	-1.06 - -0.52
Foraging - Mudflat	-0.07	0.14	-0.35 – 0.20
Resting – Mudflat	-0.08	0.20	-0.46 – 0.30
Traveling – Mudflat	0.22	0.20	-0.16 – 0.61
~Day	0.30	0.10	0.14 – 0.52

Table 3-5: Total nitrogen content of forage items for emperor goose goslings on mudflat and grazing lawns on Yukon-Kuskokwim Delta in 2023. Type of forage was sampled following observations of emperor geese eating each forage type.

Forage Type	Total Nitrogen (%)
Macroalgae	2.06
Carex subspathacea Grazing Lawn	1.77
Algal Mat/Biofilm	0.33
Macroalgae/Seaweed	1.38
Carex subspathacea (tall form)	2.31

FIGURES

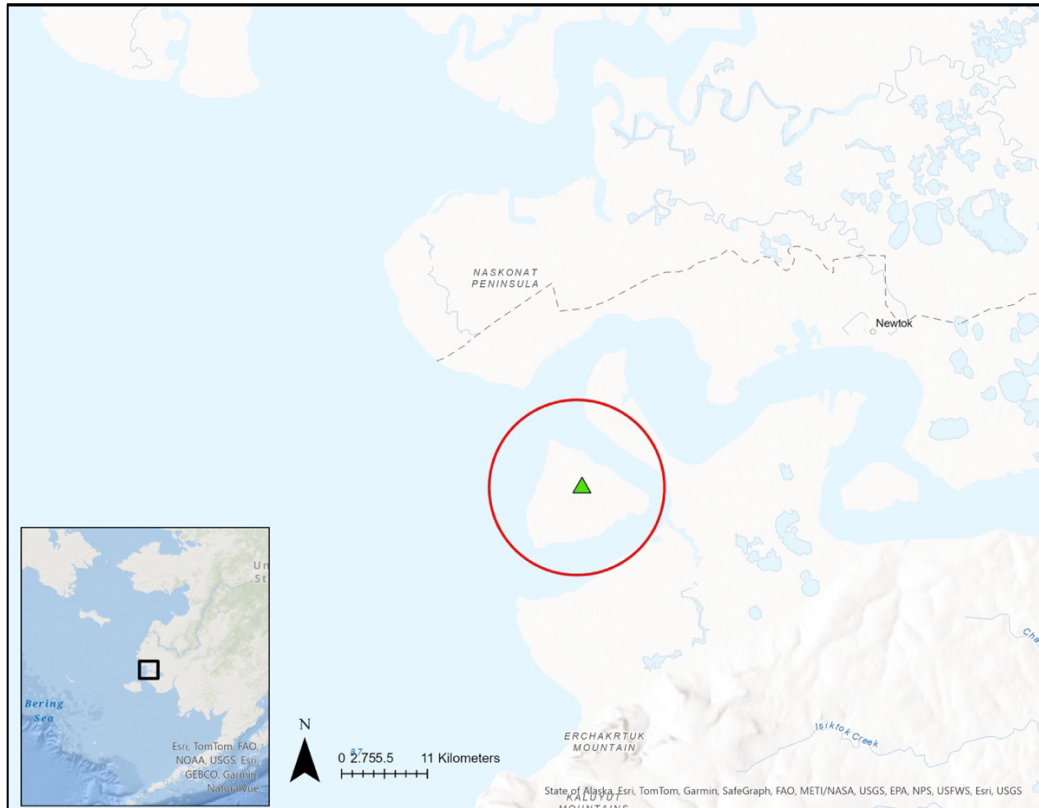


Figure 3-1: Map of Kigigak Island study site (red circle) on the Yukon-Kuskokwim Delta.

Location of field camp is designated by green triangle.



Figure 3-2: Map of camera locations and human locations for behavioral observations of emperor geese on mudflats and grazing lawns. Location of field camp is designated by green triangle. Green dots indicate locations where game cameras were deployed. Yellow dots indicate where human observations occurred.

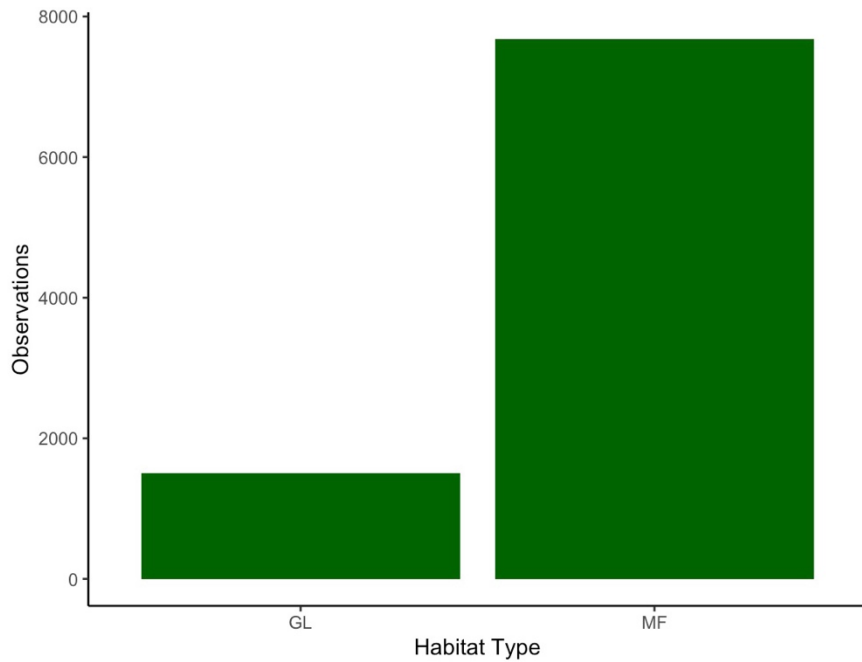


Figure 3-3: Number of Observations of emperor geese recorded on grazing lawn (GL) and mudflat (MF) habitats using both observation methods (human and camera).

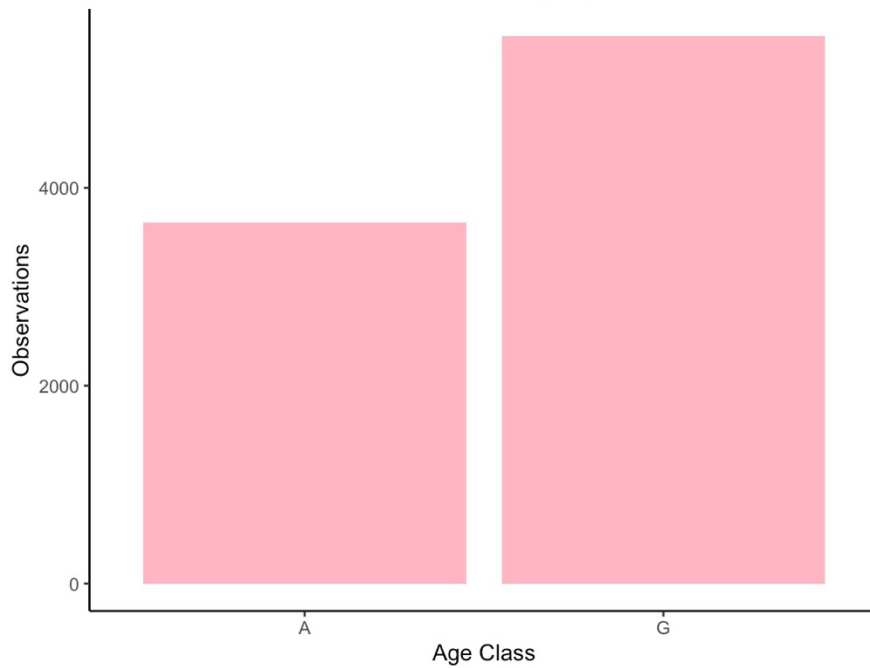


Figure 3-4: Number of observations of emperor geese recorded by each age class on both grazing lawn and mudflat habitats using both observation methods (human and camera).

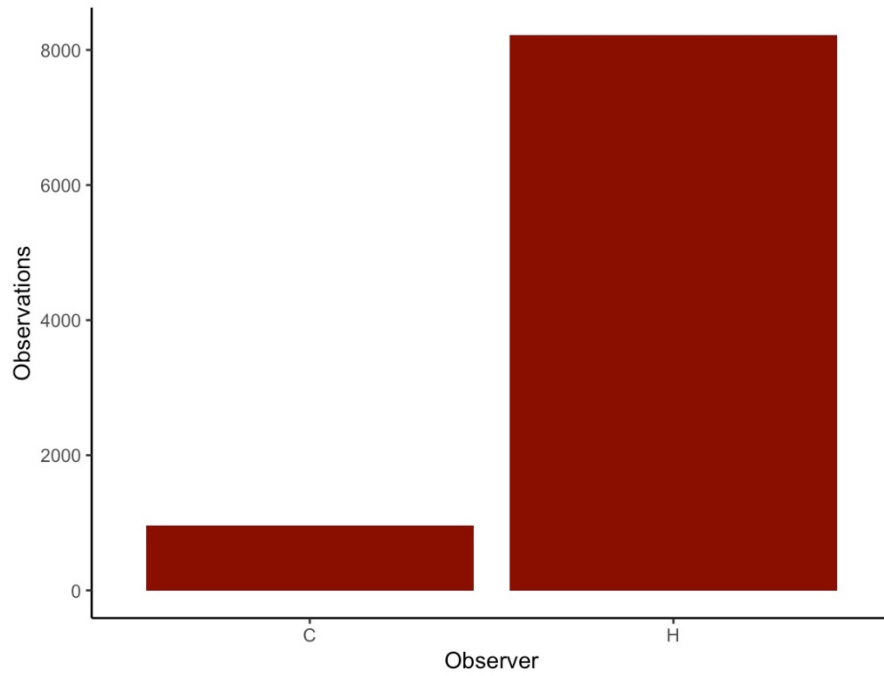


Figure 3-5: Number of observations of emperor geese of both goslings and adults on mudflat and grazing lawn habitat recorded by each method: human observation (H) and camera (C).

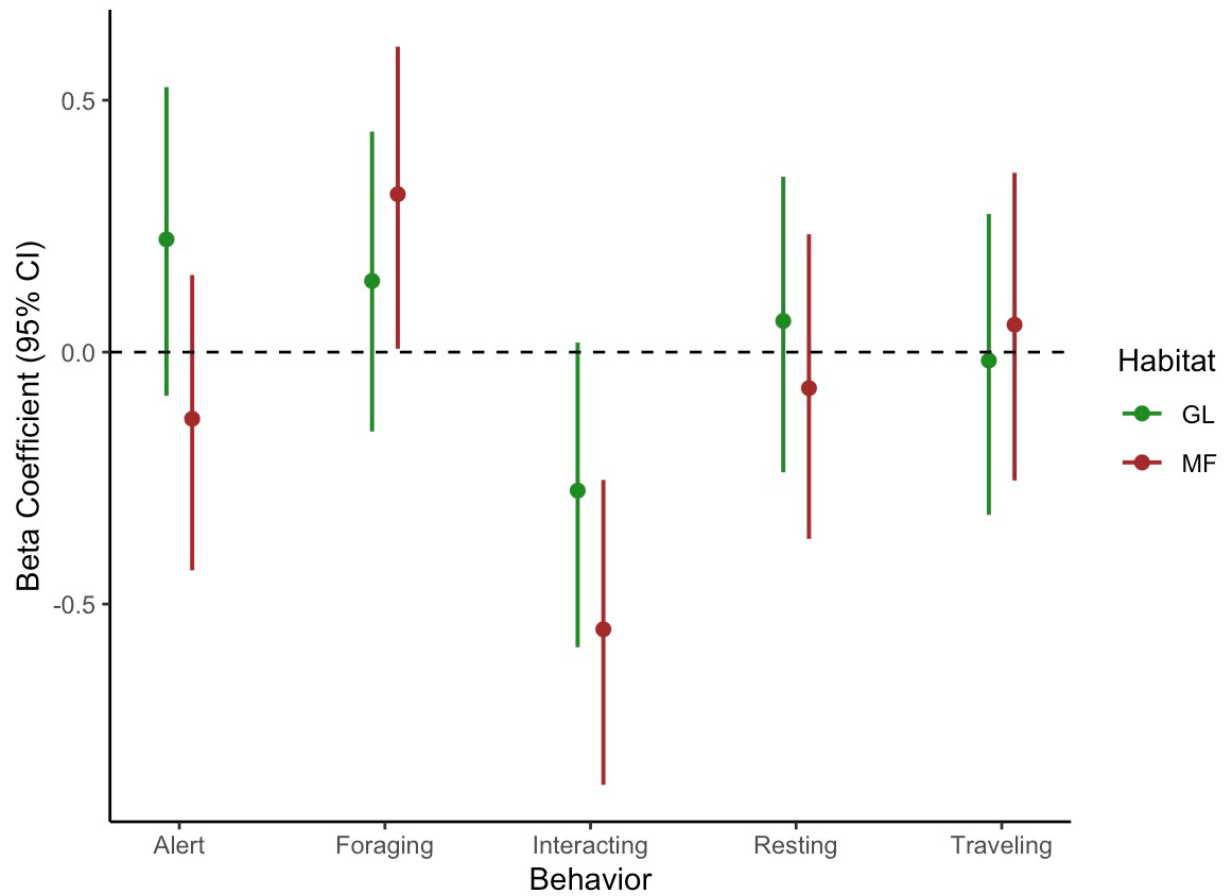


Figure 3-6: Probability of adult emperor goose behavior by habitat type. Dashed line indicates the y-intercept of zero. Grazing lawn (GL) behavior probability is indicated in green color and mudflat (MF) is indicated by brown color.

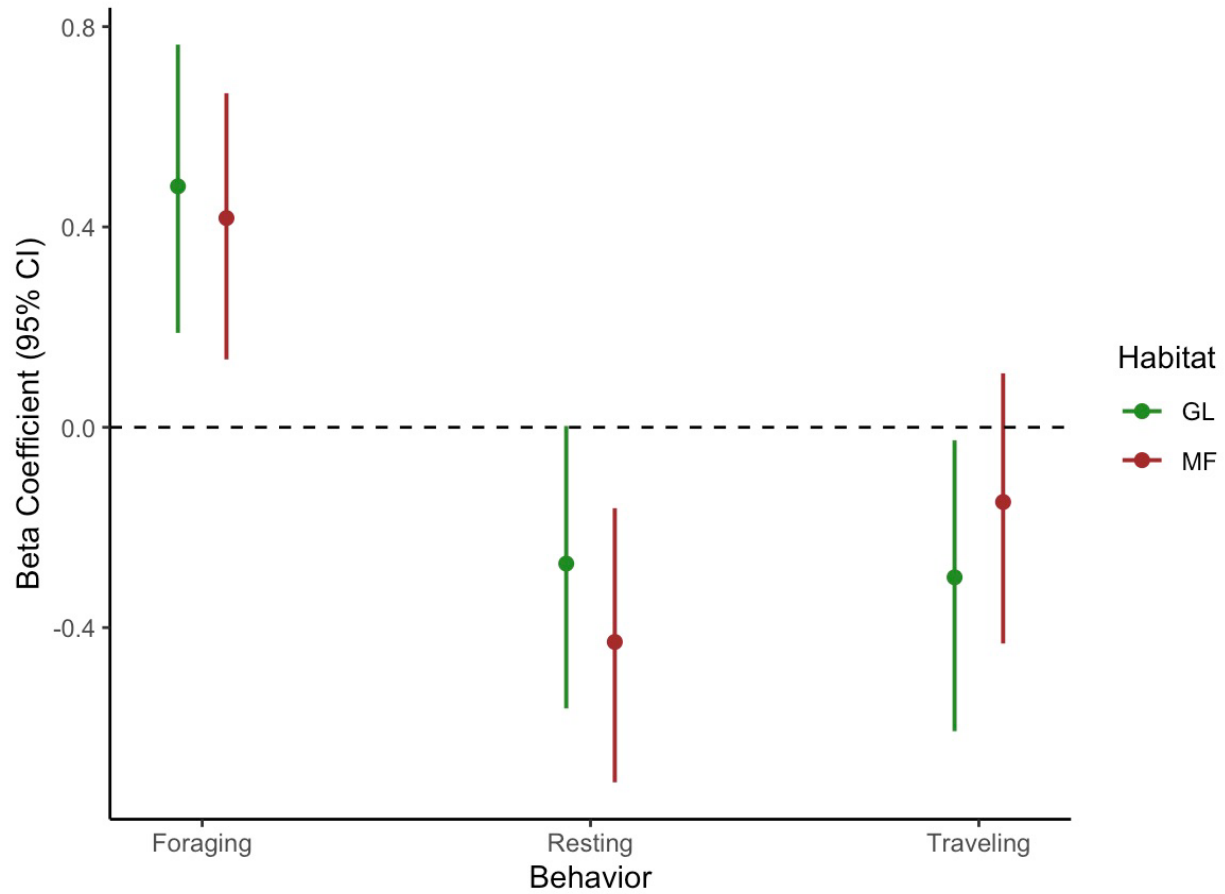


Figure 3-7: Probability of emperor goose gosling behavior by habitat. Dashed line indicates the y-intercept of zero. Grazing lawn (GL) behavior probability is indicated in green color and mudflat (MF) is indicated by brown color.

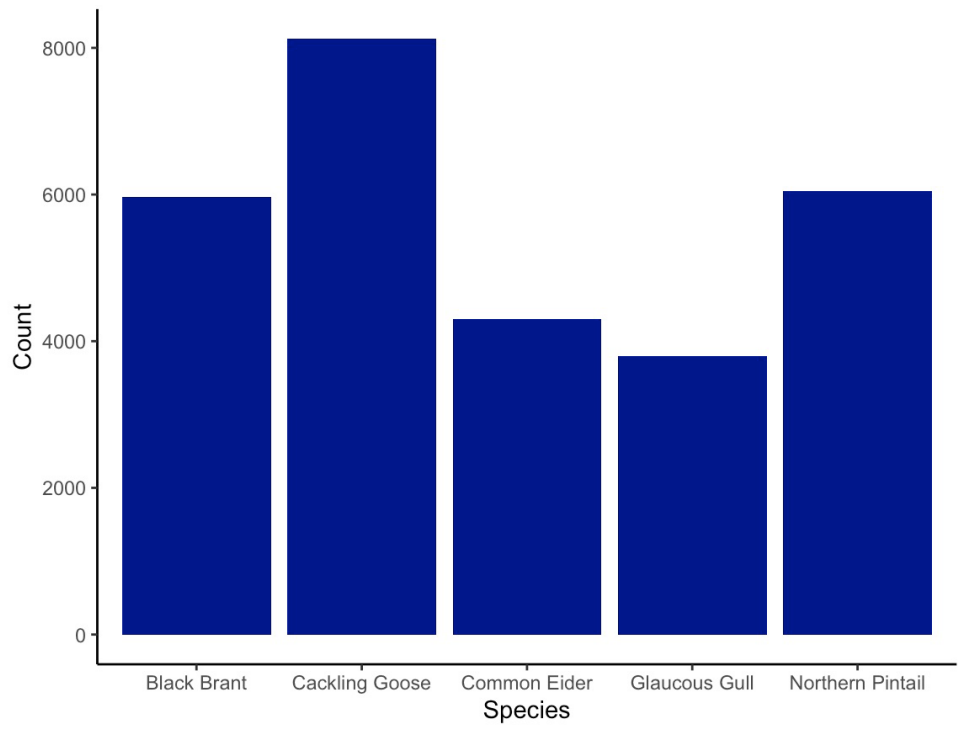


Figure 3-8: Number of observations grouped by the most species present during emperor goose behavioral observations. All other species accounted for were present very infrequently during observation periods.