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# Distribution and Population Size of Emperor Geese during the Breeding Season on the Seward Peninsula, Alaska

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ABSTRACT. The Emperor Goose (*Anser canagicus*) is a year-round occupant of northern latitudes, spending its entire annual cycle in coastal habitats of western Alaska and the Russian Far East. Over the last several decades, the Emperor Goose population underwent a pronounced decline, prompting 30 consecutive years of harvest closures, followed by a protracted recovery and the recent reopening of harvest. This recovery was primarily documented on the Yukon-Kuskokwim Delta in western Alaska, where an estimated 80%–90% of the world's Emperor Goose population breeds. However, the size and status of their population on the Seward Peninsula, Alaska, which is their only other significant breeding area in North America, remains almost completely unknown. Therefore, to better inform population and harvest management of Emperor Geese in western Alaska, we conducted extensive aerial surveys of Emperor Geese along the northern coast of the Seward Peninsula during the breeding season. During the summer of 2018, we surveyed 150 transects totaling 351 km$^2$, for a total sampled fraction of 7.2% of the 4853 km$^2$ survey area. Using a double-observer technique that accounted for detection probability, we estimated a population of 1226 (95% CI: 792–1660) Emperor Geese on the Seward Peninsula, of which 614 (95% CI: 416–811) were considered breeding birds based on their observed status as singles or pairs. Most Emperor Geese (61%) were found on barrier islands, even though these islands accounted for just 3.5% of the total survey area; the remaining geese were found in lowland coastal habitats (23% of geese) or upland tundra (16%). Overall, our surveys indicate a small breeding population of Emperor Geese on the Seward Peninsula, which raises some conservation concern. Further reductions or extinction of this small population would leave Emperor Geese with only one significant breeding area in North America. Because Emperor Geese typically display high breeding site fidelity and female natal philopatry, any future growth of this small population will likely need to come from within.

Key words: aerial survey; Alaska; detection probability; Emperor Geese; Seward Peninsula; population

RÉSUMÉ. L'oie empereur (*Anser canagicus*) occupe les latitudes boréales à l'année. Elle passe la totalité de son cycle annuel dans les habitats côtiers de l'ouest de l'Alaska et de l'Extrême-Orient russe. Au cours des dernières décennies, la population d'oies empereurs a connu une diminution prononcée, ce qui a donné lieu à des interdictions de récoltes échelonnées sur 30 années consécutives, suivies d'un regain prolongé et de la réouverture récente des récoltes. Ce regain a principalement été enregistré dans le delta Yukon-Kuskokwim de l'ouest de l'Alaska, où l'on estime que 80 % à 90 % de la population mondiale d'oies empereurs se reproduit. Cependant, la taille et l'état de la population d'oies empereurs dans la péninsule Seward, en Alaska, soit leur seule autre aire de reproduction importante en Amérique du Nord, sont pratiquement toujours inconnus. Afin de mieux éclairer la gestion de la population et de la récolte d'oies empereurs dans l'ouest de l'Alaska, nous avons réalisé des levés aériens substantiels des oies empereurs le long de la côte nord de la péninsule Seward pendant la saison de reproduction. Dans le courant de l'été de 2018, nous avons effectué le relevé de 150 transects totalisant 351 km$^2$, ce qui correspondait en tout à une fraction échantillonnée de 7,2 % de l'aire de 4 853 km$^2$ à l'étude. À l'aide d'une technique d'observation double tenant compte de la probabilité de détection, nous avons estimé une population de 1 226 (IC de 95 % : 792–1 660) oies empereurs dans la péninsule Seward, dont 614 (IC de 95 % : 416–811) étaient considérées comme des oies reproductrices en fonction de l'état observé, à savoir si elles étaient seules ou accouplées. La plupart des oies empereurs (61 %) se trouvaient dans le cordon d'îles, même si ces îles ne représentaient que 3,5 % de l'aire totale étudiée. Le reste des oies se trouvait dans les habitats côtiers des basses terres (23 % des oies) ou dans la toundra des hautes terres (16 %). Dans l'ensemble, nos levés indiquent la présence d'une petite population reproductrice d'oies empereurs dans la péninsule Seward, ce qui soulève certaines inquiétudes en matière de conservation. La réduction encore plus prononcée, voire l'extinction, de cette petite population ferait en sorte qu'il resterait seulement une aire de reproduction importante d'oies empereurs en Amérique du Nord. Puisque généralement parlant, les oies empereurs semblent très fidèles à leur lieu de reproduction et que les femelles retournent à leur frayère natale, toute croissance future de cette petite population devra vraisemblablement venir de l'intérieur.

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Mots clés : levé aérien; Alaska; probabilité de détection; oie empereur; péninsule Seward; population

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## INTRODUCTION

The Emperor Goose (*Anser canagicus*) is a maritime bird of the North—summers are spent in Arctic and sub-Arctic tundra habitats of Alaska and the Russian Far East, while winter finds them no farther south than the harsh coastal climates of the Bering Sea and Gulf of Alaska. Over the last several decades of monitoring in western Alaska, populations of Emperor Geese have undergone two pronounced changes in abundance, beginning with a decline from nearly 140 000 birds in 1964 to less than 45 000 by 1986 (Schmutz et al., 2020). This precipitous decline prompted full closures of Alaska's Emperor Goose harvests, including the sport harvest in 1986 and the subsistence harvest in 1987 (Stehn and Wilson, 2014). These closures remained in place for 30 years, during which time the Emperor Goose population slowly recovered towards its former abundance. By 2017, Emperor Goose numbers had exceeded management objectives (3-year average count > 80 000 birds), and subsistence and sport harvests were reinstated throughout western Alaska (Pacific Flyway Council, 2016).

An estimated 80% – 90% of the worlds' Emperor Goose population breeds on the Yukon-Kuskokwim Delta in western Alaska (Schmutz et al., 2020), and our knowledge of their breeding biology and population size are largely limited to this region. Since the reopening of harvest in 2017, the population status and trend of Emperor Geese have been assessed via an aerial survey conducted during the breeding season on the Yukon-Kuskokwim Delta. From this survey, managers annually regulate statewide harvest openings and closures, including spring and summer subsistence harvests at breeding areas (Pacific Flyway Council, 2016). Outside of this survey, no other targeted counts of Emperor Geese are regularly conducted throughout their annual range in Alaska.

The recent harvest opening for Emperor Geese also extended to their breeding grounds on the Seward Peninsula in northwest Alaska, where no population monitoring has occurred. Outside the Yukon-Kuskokwim Delta, the Seward Peninsula is the only significant breeding area in North America for Emperor Geese (Eisenhauer and Kirkpatrick, 1977; Kessel, 1989), and their harvest is an important subsistence resource in this region (AMBCC, 2016). Historical accounts suggest that the northern side of the Seward Peninsula may have had a sizeable breeding population of Emperor Geese in the past (Bailey, 1925, 1943; Eisenhauer and Kirkpatrick, 1977); however, by the 1960s the population was anecdotally estimated at fewer than 500 breeding pairs (King, 1968). Since that time, the size and health of this small breeding population have not been monitored, and almost no current information exists regarding its status. Similarly, the distribution of breeding Emperor Geese on the Seward Peninsula has never been thoroughly documented, obscuring the location of important breeding sites and habitats. Overall, this lack of knowledge creates significant management gaps as well as conservation concern for an ostensibly small population of breeding Emperor Geese.

To improve population and harvest management of Emperor Geese in western Alaska, we conducted extensive aerial surveys of Emperor Geese along the northern coast of the Seward Peninsula during the breeding season. These surveys provide the first-known estimate of population size and systematic charting of distribution for Emperor Geese of the Seward Peninsula, Alaska.

## METHODS

### *Study Area*

The Seward Peninsula is located between 64˚20′ and 66˚35′ N and extends westward from the mainland of Alaska towards Russia, forming the eastern edge of the Bering Strait that separates the Bering and Chukchi Seas. The region is situated within a zone of continuous permafrost and has a mean annual temperature of −5˚C and mean annual precipitation of 27.9 cm (WRCC, 2021). While much of the peninsula is rugged and mountainous, the northern peninsula is defined by extensive coastal lowlands punctuated with numerous lakes, ponds, and tundra wetlands. The outer coastline of the northern peninsula, spanning nearly 250 km from east to west, is mainly composed of narrow barrier islands that protect several large lagoons from wave action of the Chukchi Sea. These coastal lowlands and protected lagoons serve as the primary habitat for nesting waterfowl on the Seward Peninsula, including several species of geese (Kessel, 1989).

### *Aerial Survey*

We conducted aerial surveys of geese in 2018 and 2019 along the coastal lowlands and barrier islands of the northern Seward Peninsula, Alaska, surveying five species of geese: Brant (*Branta bernicla*), Canada/Cackling Geese (*B. canadensis/hutchinsii*), Emperor Geese, Greater White-fronted Geese (*Anser albifrons*), and Snow Geese (*A. caerulescens*). Our surveys were timed to be slightly earlier than historical accounts of early incubation dates of Emperor Geese on the Seward Peninsula (Thayer, 1951; Kessel, 1989), and occurred from 11 – 14 June 2018 and 17 – 19 June 2019. Both of our surveys consisted of identical sets of straight-line transects, where each transect was

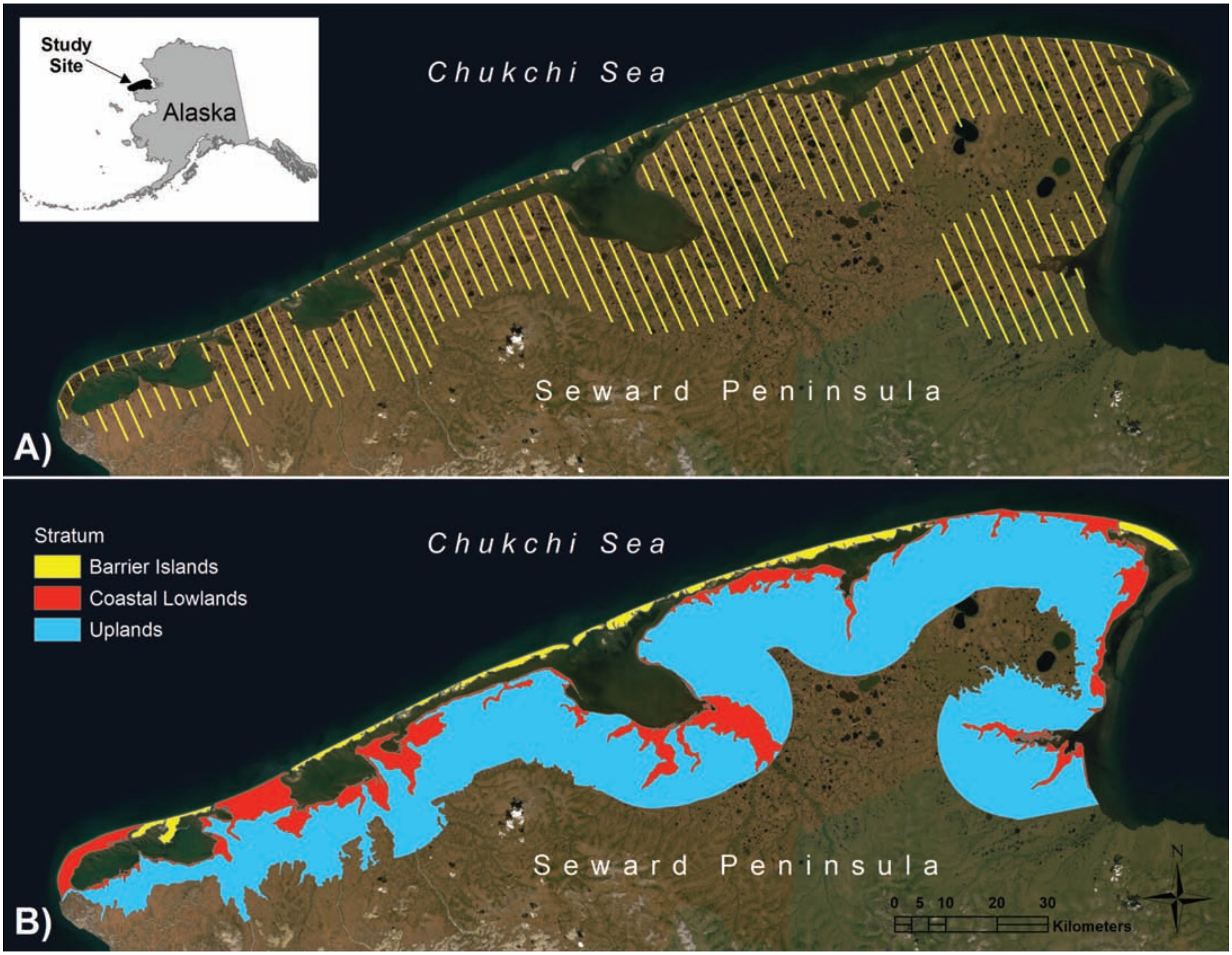


FIG. 1. A) Transect lines from aerial surveys of Emperor Geese on the Seward Peninsula, Alaska, 2018 and 2019. Transects were spaced every 3 km and extended inland 15 km from the coast or to the 50 m elevation contour. B) Map showing our survey area and its division into three habitat strata (barrier islands, coastal lowlands, and uplands). Barrier islands included all islands along the northern coast, while coastal lowlands were defined as mainland habitats with elevations of 6 m or less, and uplands as mainland habitats above 6 m.

oriented parallel to each other and roughly perpendicular to the dominant orientation of the northern Seward Peninsula coastline (Fig. 1A). Transects were separated from neighboring transects by 3 km and were restricted to terrestrial and freshwater environments, excluding all marine waters. We flew our transects in fixed-wing aircraft (Cessna 206) at altitudes of 30–45 m and speeds of 145–170 km hr$^{-1}$. Observers on the right side of the plane recorded observations of geese within 200 m of the aircraft, for a total sample width of 200 m per transect. To define the outer 200 m viewing boundary, we trigonometrically calculated the maximum viewing angle and then used a clinometer to mark this point on the airplane wing strut.

Having little preexisting information on nesting distributions of Emperor Geese on the Seward Peninsula, we used aerial survey data from the Yukon-Kuskokwim Delta to determine the distance that transects extended inland from the coast. Specifically, by measuring the distance to the coast for each of 41 136 aerial observations of Emperor Geese on the Yukon-Kuskokwim Delta from 1988–2015 (Fischer et al., 2018), we found that 95% of Emperor Geese were observed within 15 km of the coast. Given this finding, we used geographic information system (GIS) software to generate a buffer that extended 15 km inland from the coastline of the northern Seward Peninsula, thereby creating a survey zone in which we focused our efforts. This survey zone included all the barrier islands and extended completely around the numerous lagoons and deltas of the region. Each of our transects spanned the complete length of the survey zone, from coast to inland edge, and differed in length depending on the permutations of the survey zone and coastal geography. For example, transects on barrier islands were much shorter than those aligned over the mainland. In addition to distance to the coast, distributions of Emperor Geese are limited by elevation, occurring almost exclusively at low elevations

(Petersen, 1990; Schmutz et al., 2020). Thus, as a second step, we clipped out all elevations above 50 m from our survey zone; this reduced our survey zone by less than 10%, largely because the northern Seward Peninsula is dominated by low-lying tundra with little elevational relief. Our final survey zone consisted of 4853 $km^2$ of potential Emperor Goose habitat, 351 $km^2$ (7.2%) of which was sampled by our aerial transects.

*Double-Observer Counts*

We used a double-observer method that allowed us to estimate detection rates of geese, whereby two observers independently and simultaneously recorded observations of geese from the same transect space (Koneff et al., 2008, Wilson et al., 2017). Both observers, who were the same individuals in 2018 and 2019, were seated on the right side of the plane (one observer in the front-right seat and one in the rear-right seat) and intermittently alternated seats to reduce the confounding effect of observer identity on seat (front, rear) in subsequent analyses. Observers independently counted all adult geese encountered within 200 m of the right side of the plane, and each observation was dictated into a laptop computer using a custom aerial survey recording program (RECORD; J. Hodges, U.S. Fish and Wildlife Service, Juneau, Alaska) that concurrently logged GPS coordinates of the aircraft at the beginning of the recording. Voice recordings for each discrete observation consisted of the following data fields: species of goose, count, and group composition (single, pair, or flock). During surveys, headset communication between front and rear seat observers was completely restricted to ensure independence of observers. Following completion of the survey, voice recordings were transcribed by each observer to comma-delimited text files using custom transcription software (TRANSCRIBE; J. Hodges, U.S. Fish and Wildlife Service, Juneau, Alaska).

*Modeling Detection Probability*

To estimate our detection probability of geese during aerial surveys, we first had to match front and rear seat observations to create capture histories. For example, a goose that was observed only by the front seat observer would have a capture history of “10” (0 = unobserved, 1 = observed), versus a history of “11” had both observers detected the bird. While some studies recommend in-flight reconciling of observations via verbal communication between observers (Koneff et al., 2008), we did not use this technique because it may violate the independence of observers. Instead, we used a post-hoc matching scheme that adhered to several criteria established by Wilson et al. (2017) for aerial observations of waterfowl in Alaska. Specifically, we confirmed a match (i.e., capture history of “11”) when the front and rear observations were: 1) recorded within 8 seconds of each other, 2) the same species, and 3) the same group composition (single, pair, or flock). This post-hoc scheme worked well for our survey area because geese densities were not exceptionally high, thus reducing the likelihood of inadvertent matches.

We used Huggins closed population capture-recapture models, which assume the population was closed between sampling periods, to model variation in detection probability of geese during aerial surveys (Wilson et al., 2017; Lukacs, 2018). This assumption is valid for our models because our two sampling periods, that of the front seat and that of the rear seat, occurred nearly simultaneously. We modeled detection in relation to three categorical covariates: observer position in the plane (front seat, rear seat), goose species (Brant, Canada/Cackling Goose, Emperor Goose, Greater White-fronted Goose), and group size (single, pair, small flock [3–5 geese], large flock [> 5 geese]). We included four species of geese in our analysis, as opposed to solely Emperor Geese, to augment our sample size for estimating detection probabilities; Snow Geese were omitted from analysis due to small sample size (n = 8 observations). Using these covariates, we fit a set of seven a priori models in RMark that included the following model combinations: a model with observer seat only; three models that included observer seat as a main effect, plus all additive combinations of species and group size; two models with an interaction between observer seat and either species or group size; and one model with a main effect of group size and an interaction between observer seat and species. We included observer seat in all models so that front and rear seat detection were always estimated separately.

We used an information-theoretic approach to model selection (Burnham and Anderson, 2002), in which the relative fit of models within our candidate set were compared with Akaike’s Information Criterion adjusted for small sample sizes ($AIC_c$) and $AIC_c$ weights ($w_i$). We converted raw $AIC_c$ values to $\Delta AIC_c$, with $\Delta AIC_c$ defined as the difference between the best-fitting model (smallest $AIC_c$) and each respective model in our candidate set; thus, $\Delta AIC_c = 0$ for the model of best fit. Because a clear top model emerged from our model set, we estimated detection probabilities and associated confidence intervals from this model.

*Estimating Population Size*

Using our aerial survey data, we estimated population size of Emperor Geese on the Seward Peninsula; however, we restricted this estimation to our 2018 survey data, omitting the 2019 survey because it was conducted too late in the nesting season to provide reliable count data. Specifically, we observed several broods of Emperor Geese and other goose species during the 2019 survey, indicating that our survey occurred well after egg laying and early incubation. Aerial surveys conducted this late in the breeding season are prone to significant undercounting because, as the nesting season progresses, an increasing proportion of nests have failed. Geese from failed nests are apt to prematurely take flight in response to airplane disturbance, becoming unavailable for detection, or to depart the survey area altogether (Fischer et al., 2018; Lewis et al., 2019).

Prior to calculating population size, we stratified our study area into three distinct habitat strata to account for habitat-specific differences in densities of Emperor Geese (Fig. 1B). While we conducted this stratification post-hoc, failure to do so would have assumed uniform population and variance estimates across the entire survey area, which was clearly erroneous. Most of our survey area was upland tundra, which is generally inappropriate habitat for breeding Emperor Geese, and its inclusion was strictly intended to ensure that our survey completely encapsulated the breeding range of Emperor Geese on the Seward Peninsula. Our stratification included the following three habitat strata: (1) all barrier islands (168 $km^2$) of the northern coastline; (2) coastal lowlands (754 $km^2$), which were all mainland habitats with elevations of 6 m or less; and (3) uplands (3925 $km^2$), which were all mainland habitats with elevations above 6 m.

We calculated two estimates of population size for Emperor Geese on the Seward Peninsula: (1) the estimate of "indicated breeding birds" was restricted to observations of singles and pairs, which are presumed to be breeding birds; and (2) the estimate of "total birds" included all group sizes, from singles and pairs to flocks, and makes no assumptions of breeding status. We followed the protocol of the North American Waterfowl Breeding Pair Survey for defining indicated breeding birds (Smith, 1995), in which singles and pairs are presumed to be associated with a nest, while flocks are assumed to be non-breeders. To estimate indicated breeding birds, we doubled the number of single geese observed under the assumption that these birds are accompanied by unobserved mates on nests; this doubling of single geese was not performed during our calculation of total birds. We restricted our estimation of indicated breeding birds and total birds to those observations from the front seat, which had a significantly wider and less obstructed viewing range.

We followed the procedures of Lewis et al. (2019) to calculate detection-adjusted estimates of population size from aerial transect surveys of breeding waterfowl in Alaska. First, we calculated aerial indices and associated variances for each group size (i.e., single, pair, small flock, large flock) per strata using ratio-estimation procedures (Cochran, 1977; Fischer et al., 2018). Specifically, our aerial indices are the average density of Emperor Geese per group size per stratum, where density is the number of geese counted per transect multiplied by the respective stratum area. We then summed across strata to produce aerial indices of indicated breeding and total birds for the entire survey area, these being indices because they are not corrected for incomplete detection. Accordingly, to move from indices to population estimates of indicated breeding and total Emperor Geese on the Seward Peninsula, we divided our aerial indices by their respective detection probabilities, restricting our use of detection probabilities to those of the front-seat observer. We then combined variance estimates from aerial indices and detection probabilities using the variance of a quotient of two independent variables (Bart et al., 1998), thereby producing variance estimates for indicated breeding and total birds that include both sources of variation (i.e., transect and detection variation). Lastly, because we applied common detection rates across multiple strata, our population estimates are correlated and no longer considered independent (Fieberg and Guidice, 2008). Thus, to correct for this potential bias, we adjusted our variance estimates for covariance among strata following equation A3 in Fieberg and Guidice (2008).

## RESULTS

We surveyed 150 and 135 transects, totaling 351 and 310 $km^2$, for Emperor Geese in 2018 and 2019, respectively. Of the five goose species that breed on the Seward Peninsula, Greater White-fronted Geese were most abundant, followed in descending order of abundance by Canada/Cackling Geese, Brant, Emperor Geese, and Snow Geese. During our 2018 survey, which was properly timed to coincide with early nesting of geese, we observed 70 individual Emperor Geese on transect, of which eight were singles, 20 were in pairs (i.e., 10 pairs), 16 were in small flocks, and 26 were in large flocks (Fig. 2A). During 2019, our survey occurred late relative to egg laying and early nesting, and we observed fewer Emperor Geese; specifically, we counted 22 Emperor Geese on transect, of which seven were singles, six were in pairs, three were in small flocks, and six were in large flocks.

Our dataset from our 2018 survey consisted of 24 discrete observations of Emperor Geese (Fig. 2A), of which 12 were observed by both front and rear observers, 10 by the front observer only, and two by the rear observer only. Using these data along with observations of other goose species, we constructed a set of seven capture-recapture models to examine variation in detection probability of geese, finding that the best-fitting model ($\Delta AIC_c = 0$) contained a main effect of group size and an interaction between observer seat and species. Because this model received most of the model support ($w_i = 0.71$), we used its parameter estimates to derive detection probabilities for each group size of Emperor Geese. Front-seat detection probabilities for Emperor Geese were the highest among the four goose species included in our model set, ranging from 0.84 (95% CI: 0.58 – 0.97) for pairs up to 0.91 (95% CI: 0.68 – 0.98) for small flocks (Table 1). Rear-seat detection probabilities of Emperor Geese were much lower than those of the front seat, ranging from 0.40 (95% CI: 0.22 – 0.61) for pairs up to 0.61 (95% CI: 0.38 – 0.79) for large flocks.

Using front-seat detection probabilities, we derived detection-adjusted estimates of 614 (95% CI: 416 – 811) indicated breeding and 1226 (95% CI: 792 – 1660) total Emperor Geese on the Seward Peninsula. Of our three

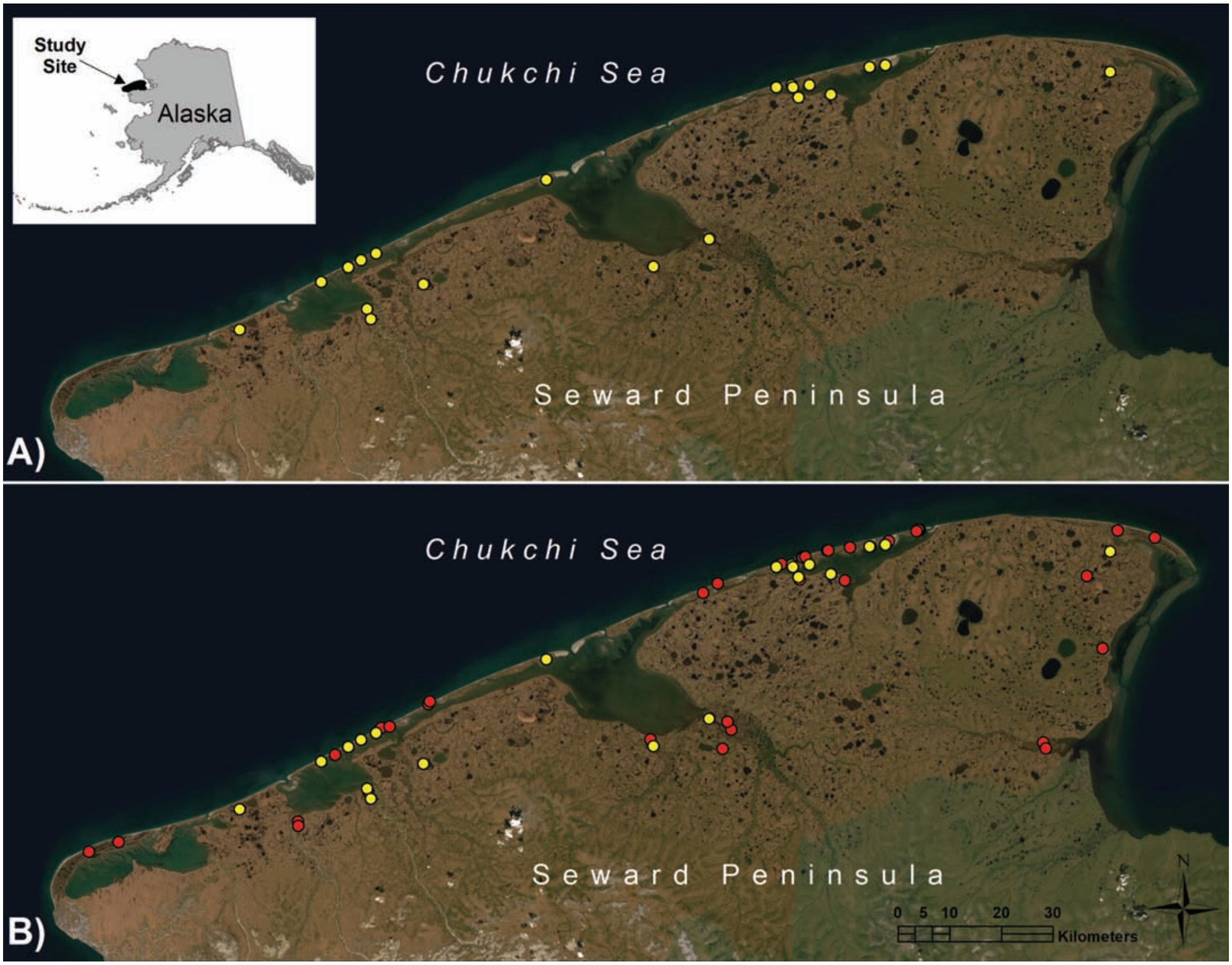


FIG. 2. A) Aerial observations of Emperor Geese on the Seward Peninsula, 2018, showing only those observations that were used to estimate population size. B) Aerial observations of Emperor Geese on the Seward Peninsula, 2018 and 2019, showing in yellow those observations that were used to estimate population size, and in red those observations that were not used to estimate population size (i.e., observations that were off-transect, from the back-seat observer only, or from 2019).

TABLE 1. Front-seat detection probabilities (± 95% confidence interval [CI]) of Emperor Geese during aerial surveys on the Seward Peninsula, Alaska, 2018. Detection probabilities are shown for each of four group sizes: singles, pairs, small flocks (3–5 geese), and large flocks (> 5 geese).

| Group size | Detection probability | 95% CI |
|---|---|---|
| Single | 0.87 | 0.58–0.97 |
| Pair | 0.84 | 0.48–0.95 |
| Small Flock (3–5) | 0.91 | 0.68–0.98 |
| Large Flock (> 5) | 0.90 | 0.64–0.98 |

habitat strata, the majority of Emperor Geese (56% of indicated breeding and 61% of total geese) were found on the barrier islands, even though this stratum comprised just 3.5% of the total survey area (Table 2). Of the remaining habitat strata, the coastal lowlands and upland stratum accounted for 44% and 0% of indicated breeding, and 23% and 16% of total Emperor Geese, respectively (Table 2). This preference for barrier island and coastal lowland habitats was also reflected in the proximity of our Emperor Goose observations to the coastline, with the average observation being 966 m (95% CI: 442–1490) from the coastline of barrier islands and coastal lowlands.

## DISCUSSION

Our aerial survey provides the first known estimate of the size of the Emperor Goose population on the Seward Peninsula, finding that, at most, 1660 birds (upper limit of our 95% CI) inhabit this area. Of these birds, we estimated that half were actively breeding the year of our survey, suggesting that a low proportion of this population attempts to breed in any given year. This observation is slightly lower than long-term survey results from the Yukon-Kuskokwim

TABLE 2. Detection-adjusted estimates of population size (± 95% confidence interval [CI]) of indicated breeding and total Emperor Geese from aerial surveys conducted on the Seward Peninsula, Alaska, 2018. Population estimates are shown for each of three habitat strata (barrier islands, coastal lowlands, and uplands), as well as for the entire survey area (TOTAL).

| | Indicated Breeding Emperor Geese | | Total Emperor Geese | |
|---|---|---|---|---|
| Stratum | Population size | 95% CI | Population size | 95% CI |
| Barrier Islands | 345 | 179–512 | 742 | 365–1118 |
| Coastal Lowlands | 268 | 161–375 | 283 | 164–401 |
| Uplands | 0 | 0 | 202 | 21–382 |
| TOTAL | 614 | 416–811 | 1226 | 792–1660 |

Delta, in which 65% of Emperor Geese on average are categorized as breeding birds during aerial surveys (Dooley et al., 2016; Fischer et al., 2018). We are confident that our survey, by sampling nearly 5000 $km^2$ of the study area, covered nearly the entire breeding range of Emperor Geese on the Seward Peninsula, with the exception of a small pocket of habitat in the Imuruk Basin where small numbers of Emperor Geese are occasionally observed (U.S. Fish and Wildlife Service, unpubl. data). Moreover, we used a double-observer technique that allowed us to account for aerial detection probability of Emperor Geese (Koneff et al., 2008). Accordingly, we contend that our survey provides a robust estimate of the Emperor Goose population on the Seward Peninsula, which will help inform future management and conservation efforts in the region.

While the low number of Emperor Geese on the Seward Peninsula is not necessarily concerning when viewed against a global population that likely exceeds 100 000 birds (Dooley et al., 2016), it is important to note that this region is the only significant breeding area in North America outside their primary breeding grounds on the Yukon-Kuskokwim Delta. As such, we suggest that the Emperor Goose population of the Seward Peninsula merits heightened conservation concern. Further reductions or extinction of this small population would leave Emperor Geese with only one significant breeding area in North America (Fischer et al., 2018), increasing their vulnerability to natural or manmade stochastic catastrophes. This contention is especially notable in light of the significant and rapid landscape changes occurring on the Yukon-Kuskokwim Delta, which because of its extremely low elevational gradient and loss of sea-ice, is becoming increasingly affected by tidal flooding, wetland salinization, and permafrost degradation, with most of these changes occurring in habitats used by breeding Emperor Geese (Jorgenson and Ely, 2001; Jorgenson et al., 2018). These changes threaten the long-term population status of Emperor Geese on the Yukon-Kuskokwim Delta, thus increasing the significance of maintaining other breeding populations of Emperor Geese, including that of the Seward Peninsula.

Our abundance estimates of Emperor Geese on the Seward Peninsula, while clearly revealing a small population, was based on one year of survey data, thus not describing year-to-year variation in population size. As an alternative, we can look to the aerial survey of the Yukon-Kuskokwim Delta for a better understanding of year-to-year variability in Emperor Goose counts—over the last 35 years, these counts differed by 13% on average from one year to the next (Fischer et al., 2018). This average, when applied to our point estimate of 1226 Emperor Geese during 2018, produces point estimates of total Emperor Geese that range from 1066 (−13% change) to 1385 (+13%), which provides some idea of the potential degree of annual variability. Even if annual variability in population size is considerably higher on the Seward Peninsula, it would take numerous years of sustained positive growth to lift this population towards a size that would ease conservation concern.

We omitted our second year of survey data from further analysis due to its late timing relative to the early nesting period of Emperor Geese. As explained in the Methods, late surveys are prone to undercounting because, as the nesting season progresses, an increasing proportion of nests have failed, and adults from these nests may not be available for counting (Fischer et al., 2018; Lewis et al., 2019). Moreover, on-the-ground reconnaissance during this same summer suggested an abnormally high degree of nest failure for waterfowl on the Seward Peninsula, which would further exacerbate the degree of undercounting during our aerial survey. In general, given the absence of contemporary data from this region, we timed our surveys to be several days earlier than historical accounts of early nesting (Thayer, 1951; Kessel, 1989), thus accounting for a likely advancement in nesting season associated with climate warming.

If nesting dates advanced still further since that time, as has occurred for some Arctic-nesting birds (Liebezeit et al., 2014), then our first year of survey data from 2018 may likewise be compromised by poor timing. It should be noted, however, that our 2018 survey occurred six days earlier than our 2019 survey, and no broods of Emperor Geese or other waterfowl were observed. Moreover, on-the-ground nest data collected during June 2020 on the Seward Peninsula, the first such data collected in nearly 50 years, found that Emperor Geese ($n = 48$) mainly began incubation during the first week of June. While nesting chronology varies from year-to-year, these results suggest that our 2018 survey, which occurred from 11–14 June, likely coincided with early to mid-nesting, and that this survey was appropriately timed for generating estimates of abundance.

Although no historical estimates of population size exist for Emperor Geese on the Seward Peninsula, anecdotal accounts from early naturalists suggest a more sizeable population once inhabited this region (Bailey, 1925, 1943; Thayer, 1951). The reasons behind their apparent decline are unknown, but biologists had noted a small population as early as the 1960s (King, 1968). Around the same time, counts of staging Emperor Geese on the Alaska Peninsula, which is primarily composed of birds that breed on the Yukon-Kuskokwim Delta, declined from a high count of 140 000 birds in 1964 to less than 45 000 by 1986 (Pacific Flyway Council, 2016). That particular decline prompted the closure of sport and subsistence harvest of Emperor Geese in Alaska for 30 years (1987–2016), including the entirety of the Seward Peninsula. These closures fostered, at least in part, an eventual recovery of the Emperor Goose population on the Yukon-Kuskokwim Delta to levels deemed suitable for harvest reinstatement (Fischer et al., 2018). Our data, however, suggest that the population on the Seward Peninsula, even if positively affected by 30 years of harvest closures, remains relatively small. In view of this, further closures of harvest on the Seward Peninsula, while likely beneficial for population maintenance at minimum, appear unlikely to yield a sizeable population in the near term. Nor is this population likely to grow substantially via immigration from other breeding regions; Emperor Geese display high breeding site fidelity, returning to the same location to breed each year (Petersen, 1992; Schmutz and Morse, 2000), as well as high female natal philopatry (Schmutz et al., 2020). Furthermore, prior research of Emperor Geese marked with satellite transmitters while breeding on the Yukon-Kuskokwim Delta indicated little movement of these birds into the Seward Peninsula and surrounding regions (Hupp et al., 2007; T.L. Lewis, unpubl. data). This observation, in combination with their high breeding site fidelity, suggests that Emperor Geese observed on the northern Seward Peninsula are those individuals that breed in the region, not non-breeding migrants from other breeding populations.

The recovery potential of Emperor Geese on the Seward Peninsula may be further hampered by rapid climate change in the region. Over the last 40 years, a progressive reduction in sea ice has increased the open-water season in the southern Chukchi Sea by ~10 days per decade (Mahoney et al., 2014). With this change comes an increased probability that autumn storms, which are the region's strongest, make landfall before the winter sea ice has re-formed, causing substantial coastal erosion (Forbes, 2011). From 2003 to 2014, shorelines of the northern Seward Peninsula eroded an average of 0.68 m $yr^{-1}$, and this rate of change was even more pronounced on the region's barrier islands, with an erosion rate averaging 1.5 m $yr^{-1}$ (Farquharson et al., 2018). These rapid rates of change are concerning in view of our aerial observations, in which 75% of Emperor Geese were observed less than 1 km from shore and 61% were found on barrier islands. That is, the primary breeding habitats of Emperor Geese on the Seward Peninsula appear to be those most at risk to the region's rapid climate change, especially the barrier islands. Over the next 50 to 100 years, it has been suggested that the coastline of the northern Seward Peninsula may cross a major geomorphic threshold in which the barrier islands will fragment and eventually disintegrate (Farquharson et al., 2018). Such a scenario could possibly preclude Emperor Geese from future habitation of the region.

In conclusion, due to its small size, low levels of immigration, and risk imposed by environmental change, the Emperor Goose population on the Seward Peninsula should be closely monitored and managed. At present, Emperor Geese are primarily managed at a statewide level in Alaska, with little differentiation in management and harvest practices throughout various parts of the state (Pacific Flyway Council, 2016). Going forward, however, Emperor Geese of the Seward Peninsula may need to be recognized as a discrete breeding population for which distinct management actions may be warranted given its small size. We plan to mark a small sample of Emperor Geese from the Seward Peninsula with satellite transmitters in future years, which will provide important insights into their annual movements, including their degree of overlap with the much larger population from the Yukon-Kuskokwim Delta. As well, we will be genetically comparing the Seward Peninsula and Yukon-Kuskokwim Delta populations, which will further elucidate the distinctiveness of these two breeding populations and the potential need for their consideration as discrete management units.

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