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Using Mark-recapture Distance Sampling to Estimate Sitka Black-tailed Deer Densities in Non-forested Habitats of Kodiak Island, Alaska

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Kodiak National Wildlife Refuge
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McCrea A. Cobb

Abstract

Management goals for Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) at Kodiak National Wildlife Refuge are to minimize deer impacts to native flora and fauna while maintaining subsistence harvest opportunities. Accomplishment of these goals requires statistically-robust estimates of deer abundance. We estimated deer abundances in non-forested, non-mountainous habitats of southern Kodiak Island using double observer (mark-recapture) distance sampling applied to traditional line-transect aerial counts. We conducted two replicate surveys in non-forested grassland, tundra, and shrub habitats at the Aliulik Peninsula, Olga Flats, and the Ayukulik River valley of Kodiak Island, between 16 May and 21 May 2014. We observed an average of 92 deer/survey replicate, with an average deer group size of 1.73 deer/group. After correcting for estimated deer detection, which accounted for imperfect detection on the transect line, distance to the observer, habitat types, and deer group size effects, we estimated 432 deer (SE=65.70) occupied the survey area at a density of 0.74 deer/km^2 (SE=0.12). Observer detection on the transect line was 0.93 (SE=0.02). Deer densities at the Aliulik Peninsula (0.86, SE=0.16) were 62% higher than during a 2012 survey (0.53 deer/km^2, SE=0.07). We opportunistically counted deer carcasses and other wildlife (bears, swans, and whale carcasses), which could be used as an index of annual changes in their abundances. This survey provides the first statistically-robust means of indexing annual trends in deer densities and abundances on Kodiak Island.

Introduction

Sitka black-tailed deer were introduced to Kodiak Island between 1924 and 1934 (Burris and McKnight 1973). The population subsequently increased in size and range and, by the mid-1980s, possibly exceeded 100,000 deer (Smith 1989). Abundances have since fluctuated annually and appear to be primarily regulated by winter severity. Deer currently play a central economic and ecological role on Kodiak Island. Deer meat is the most important terrestrial source of subsistence protein for rural residents. In addition to their economic importance, deer likely play a keystone ecological role by affecting plant biodiversity and structure (Danell et al. 1994), nitrogen processing (Olofsson et al. 2001), and soil composition (Hobbs 1996). Non-native ungulates can have profound, undesirable, and often irreversible effects on native flora and fauna (Savidge 1987, Courchamp et al. 2003), and these impacts can be particularly magnified in island and northern latitude systems that have comparably low levels of resiliency to change (Pojar et al. 1980, Gaston et al. 2006). The impacts of deer on Kodiak's ecosystem are unknown. For all these reasons, effective management of Kodiak's deer is critical.

The ability to effectively maximize deer hunter harvest opportunity and minimize undesirable ecological impacts from overabundant deer is constrained in the absence of empirical population estimates with statistical confidence. Without a quantitative estimate of abundance, objectives established by the Alaska Board of Game (a population of 70,000-75,000 and an annual harvest of 8,000-8,500 deer) are difficult to justify to the public and have limited management utility. Between 2005 and 2010, estimated annual deer harvest levels fluctuated between 3,948 deer (2007-2008) and 7,885 deer (2005-2006) (Van Daele and Crye 2009); however, it was unclear whether variation in harvest corresponded with variation in deer abundance or other factors.

In addition to improving harvest management, monitoring of deer abundances facilitate an evaluation of impacts of environmental and anthropogenic factors on deer population dynamics. Results of ground-based surveys of deer carcasses conducted in early spring, a crude index of winter-mortality, suggest that deer mortality is greater during colder and snowier winters (Cobb 2011b). However, a quantitative estimate of population abundance is needed to determine how winter weather affects rates of mortality, changes in population abundance, and harvest opportunities. Potential factors that may influence deer population growth include hunting, disease, predation, habitat conditions, and endocrine disrupting environmental contaminants causing testis dysgenesis (Veeramachaneni et al. 2006). The relative role of these factors is unclear because deer abundances have not been directly estimated with statistically valid methods.

Initial attempts to estimate deer abundances and trends on Kodiak have had limited success (Cobb 2011a), so alternative methods were needed. Aerial transect surveys are commonly used to count ungulates in non-forested habitats (White et al. 1989, Hone 2008), and appear to be an effective method to innumerate deer in the non-forested habitats of central and southern Kodiak Island where cover of tall deciduous shrubs and trees is limited (Cobb 2012). Generating an estimate of wildlife abundances with statistical confidence from surveys requires an estimate of detection probability: the probability that an observer enumerates an animal present within the survey area. Two approaches commonly used to estimate detection probabilities for aerial survey data are distance sampling and mark-recapture methods (Buckland et al. 2001, Barker 2008, Schmidt et al. 2012). For distance sampling, observers record distances to target animal groups and use these measurements to estimate a detection function, which is then applied to raw counts to estimate population abundance. Distance sampling also allows for inclusion of multiple environmental covariates, such as habitat types, in estimating the detection function (Buckland et al. 2007). An assumption of conventional distance sampling is that detection on the transect line (distance of zero) is perfect; however, in practice this is often not the case in aerial surveys. Ignoring this assumption can lead to substantial overestimates of detection and underestimates of abundance. Mark-recapture/double observer methods have been recommended as an alternative method that attempt to estimate absolute detection and thereby avoid biases associated with incomplete detection (Pollock and Kendall 1987). However, results from these methods in aerial surveys are often also biased because of unmodelled heterogeneity in detection probability estimates (differences in the observer's ability to detect animals over time and space). The limitations associated with these individual models led researchers to combine models into mark recapture distance sampling (MRDS) models, which together can address these biases in detection estimates (Borchers et al. 2006, Becker and Quang 2009) and can be used to quantify deer abundances on Kodiak.

Our goal was to estimate, with statistical confidence, densities and abundances of Sitka black-tailed deer within three discrete regions of southern Kodiak Island (Aliulik Peninsula, Olga Flats, and Ayakulik Valley) using MRDS models. We also intended to quantify the effects of habitat type, deer group size and behavior, and distance between deer and observers, on deer detection probabilities during fixed-wing aerial line-transect surveys.

Study Area

The study sites (592 km^2) were located in southern Kodiak Island and included the southern lowlands of the Aliulik Peninsula (215 km^2), Olga Flats (including Alitak) (236 km^2), and the Ayakulik River drainage from Grant's Lagoon to the outlet (141 km^2) (Figure 1). To allow us to complete straight line transects at a consistent above ground elevation, we selected sites with slopes less than 20 degrees and those less than 250 m above sea level. We selected non-forested sites to facilitate detection of deer.

Habitats consisted of a mixture of rolling and hummocky tundra habitat dominated by black crowberry (*Empetrum nigrum*), herbaceous grassland habitat, and patchily-distributed deciduous shrub habitat (Barnes and Smith 1997, Fleming and Spencer 2007). Willow and alder-dominated shrub habitats bordered some streams, lowlands, and small lakes. Patches of salmonberry (*Rubus spectabilis*) and elderberry (*Sambucus racemosa*) mixed with open grass and forb-dominated habitats at mid-elevations. Grass and forb-dominated alpine tundra meadows, and patchy exposed bedrock encompassed higher elevations (>750 m). We surveyed prior to full leaf-out (May) to maximize our ability to detect deer.

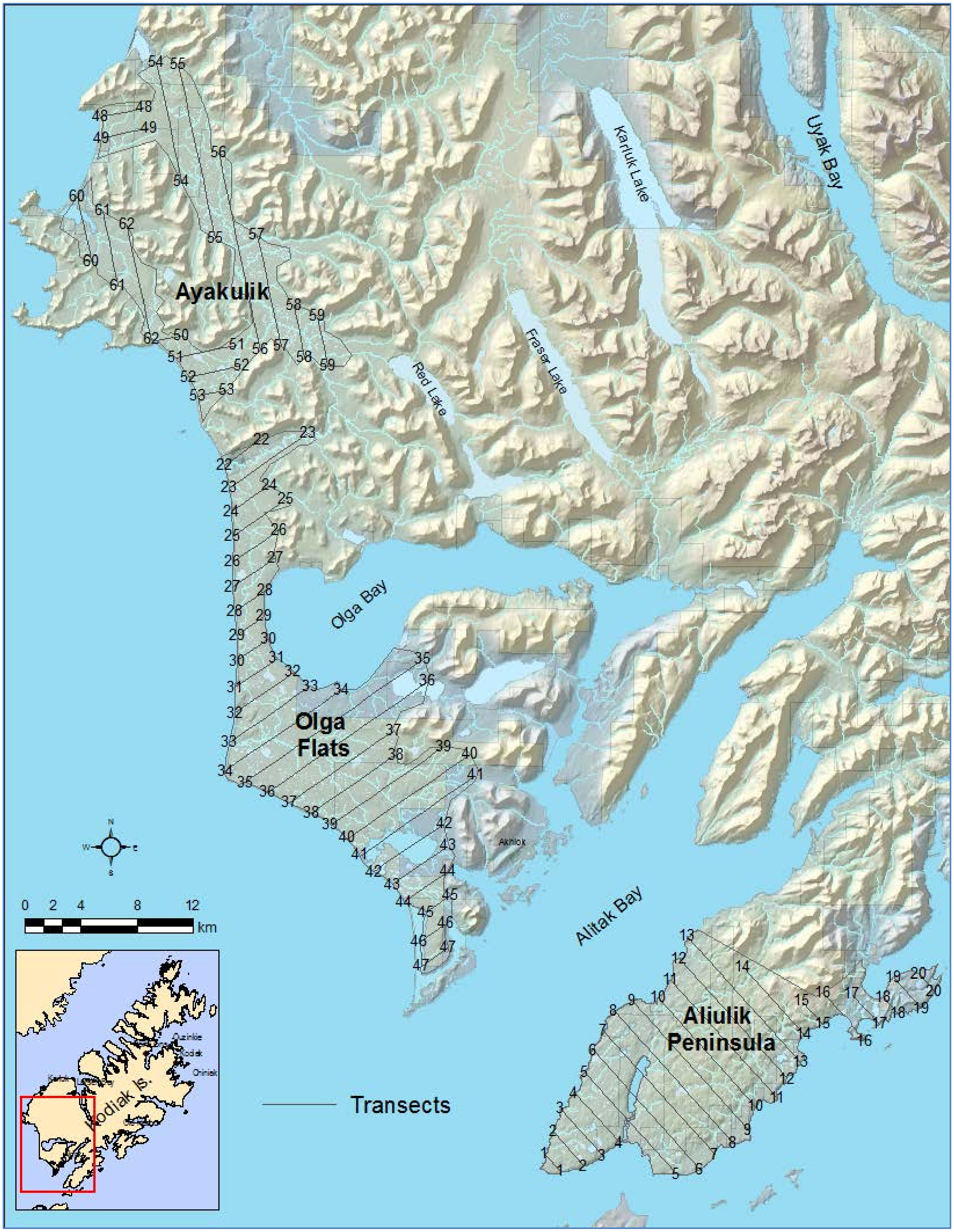


Figure 1. Location of the study sites and line transects on southern Kodiak Island, Alaska

Methods

We flew a systematic sample (n=61) of aerial line transects in the study sites in mid/late May (Figure 1). We selected this time period because our goal was to estimate population densities immediately following winter, when deer on Kodiak experience the highest rates of natural mortality. Although conducting surveys in April would have been ideal, we wanted to avoid conducting low-level aerial surveys during the bear hunting season because of the potential to disturb hunters (1 April-15 May). Adjacent transects were separated by 1,500 m. Both the passenger (McCrea Cobb) and pilot (Kevin Van Hatten) were observers from a fixed-wing airplane (Aviat A1-A Husky on floats). The pilot attempted to maintain an above-ground level (AGL) of 76 m (250 ft) and a ground speed of 105 km/h (65 mph). We scanned for deer on the right side of the aircraft, resulting in a survey window that alternated from the transect line depending on the direction the aircraft was traveling. When a deer group was observed, it was not announced until the group was perpendicular to the flight path (i.e. the group had passed the wing strut during flight). By waiting, both observers had ample opportunity to independently sight the deer. The pilot then circled the aircraft back to the centroid of the location where the deer group was first observed. The passenger used a voice recording GIS software (DNR Survey, Minnesota Dept. of Natural Resources) to record a GPS waypoint and associated data, which included group size, behavior (standing, bedded, walking, or running), habitat class (grass, tundra, water, or rock), and observer (passenger, pilot, or both).

We quantified deer abundances using mark recapture distance sampling (MRDS) (Buckland et al. 2001) in Program Distance 6.2 (Thomas et al. 2010). We used a multiple covariate mark-recapture model to estimate observer detection rates (thereby allows for an estimate of the probability of detection at distance zero) and a multiple covariate distance sampling model to estimate how detection probabilities varied with distance from the aircraft.

We selected 10 covariates that could potentially explain how deer detection rates varied between observers and at different distances from the observers (Table 1). We used a two-stage approach to model selection. First, we examined the relative importance of our covariates on observer detection rates by creating a candidate set of mark-recapture logistic models. We fit the models following a forward step-wise approach and used an information-theoretic approach to rank competing models. We examined additive and interactive effects between covariates in the top models (those separated by <2 ΔAIC_c) to select our final most parsimonious mark-recapture model. This model then served as the base model in the distance sampling candidate model set. We used the same 10 covariates in the distance sampling model and followed the same model selection process. We used the independent observer (point independence) fitting method to estimate the detection function. We selected the half-normal key function for the distance models, which, through exploratory analyses, we found to fit the data better than the hazard-rate key function.

Table 1. List of covariates that could potentially explain variations in deer detection probabilities.

Class	Covariate	Unit	Description
Distance	Distance	m	Perpendicular distance from the aircraft the centroid of the deer group location when first observed
Behavior	Standing	y/n	Were deer standing when first observed?
Behavior	Bedded	y/n	Were deer bedded when first observed?
Behavior	Walking	y/n	Were deer walking when first observed?
Habitat	Grass	y/n	Were deer on grass habitat when first observed?
Habitat	Tundra	y/n	Were deer on tundra habitat when first observed?
Habitat	Shrub	y/n	Were deer on shrub habitat when first observed?
Habitat	Water	y/n	Were deer in the water (river, lakes, and ponds) when first observed?
Habitat	Rock	y/n	Were deer on grass habitat when first observed?
Observer	Observer	Passenger/pilot/both	Who first independently observed the deer? Passenger? Pilot? Or both observers?

We estimated variances of the density estimates based on the R2 estimator in Fewster et al. (2009), which has the advantage of not assuming independence between the estimates of the detection parameter, encounter rate, and mean group sizes.

To increase our sample size and allow for tighter confidence intervals, we fit the detection function to the entire dataset (both replicate surveys). We then applied this detection function to each replicate dataset to estimate individual and group densities and abundances, by study site.

Because deer occur in clustered groups, we estimated deer abundance within the study area ($\widehat{N}$) using a Horovitz-Thompson-like estimator,

$$\widehat{N} = \sum_{i=1}^{n} \frac{S_i}{\widehat{P}_i},$$

where $\widehat{P}_i$ was the estimated inclusion probability for animal i, and n was the number of observations. $\widehat{P}_i$ included two components: the probability that deer i fell within the sampled transect (coverage probability) and the an estimate of its probability of detection, given that it was on the transect. S_i was the size of the deer group i, $i = 1, \dots, n$ (Thomas et al. 2010). We assessed model fit using a Kolmogov-Smirnov test.

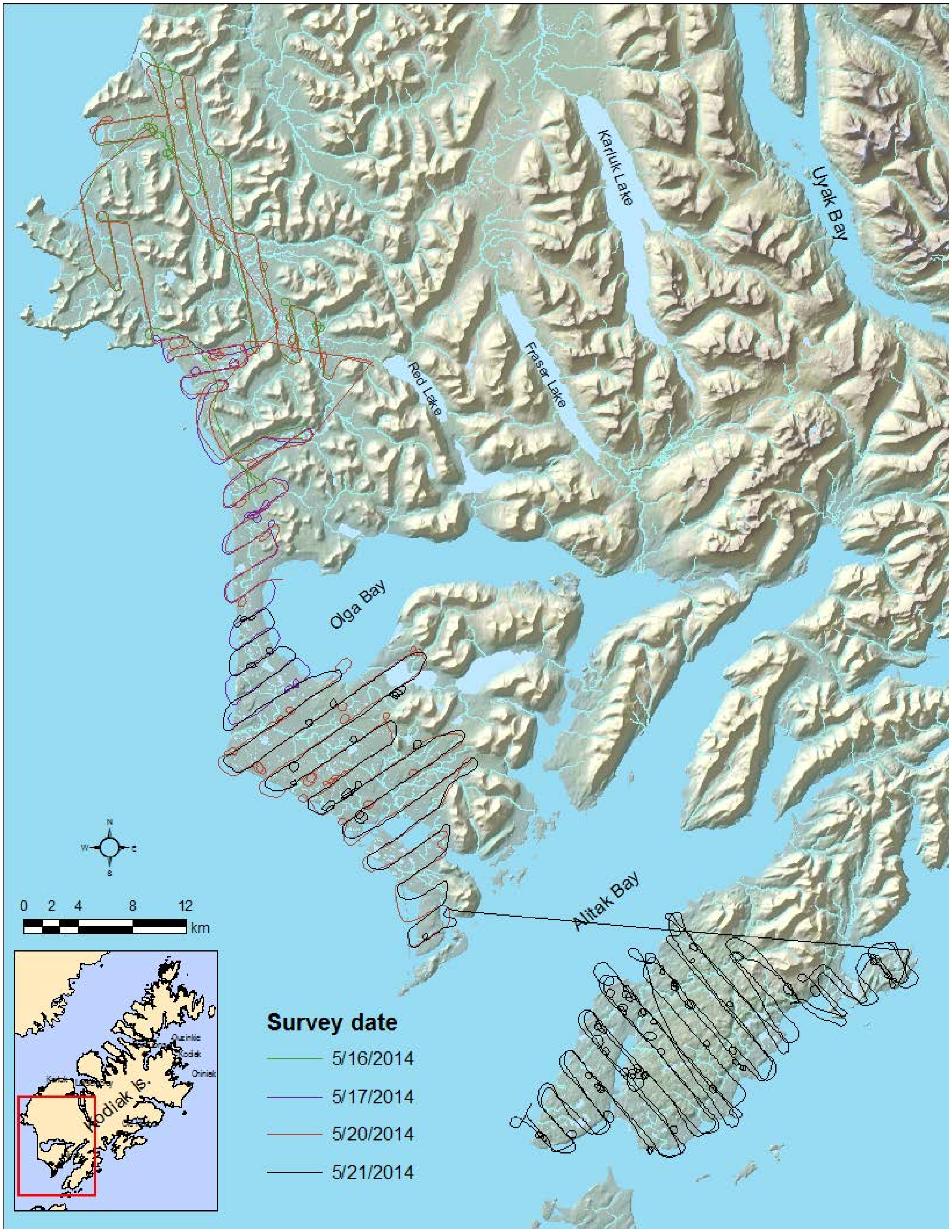
Results of a pilot study conducted in 2012 indicated that deer seldom reacted to the aircraft before prior to detection (i.e., deer movements were random relative to the survey line) (Cobb 2012). When they did change their behavior, the most common reaction was to stand. No deer ran from the plane. Therefore, it was not likely that any deer could have moved far enough to be double counted over adjacent transect lines. In accordance with protocol, random animal movements within the study site relative to the progression of the survey were acceptable and did not bias results. We assumed that distance sampling measurements were unbiased and precise. To meet this assumption in the rolling terrain of southern Kodiak, we GPS-marked the location of each deer group, rather than estimate distance classes using strut marks.

Results

We completed two replicates of 61 aerial line-transects on 16, 17, 20, and 21 May, 2014 (Figures 2 and 3). We flew for a total of 19.1 hrs (Table 2), or 9.5 hrs/replicate. It took approximately 2 hrs to complete a replicate at Ayakulik, 2.5 hrs at Olga, 2.5 hrs at Aliulik, and 2.5 hrs of ferry time/replicate. Total estimated cost (aircraft and fuel) was $4,600 ($200/hr in Aviat Husky), or $2,300/replicate. Surveys were conducted between 09:30 and 21:30 hrs. Weather conditions were sunny with 10-25 km/h winds on 16, 17 and 20 May, changing to partly sunny with variable winds on 21 May. Turbulence was mild to moderate on 16, 17, and 20 May, and absent on 21 May.

Transects totaled 386 km and each ranged from 1.65 km to 15.50 km in length (mean=6.33 km). The 20 transects at Aliulik totaled 139 km, the 26 transects at Olga Flats totaled 158 km, and the 15 transects at Ayakulik totaled 89 km.

Figure 2. Track lines recorded by GPS during Sitka black-tailed deer aerial line-transect surveys, Kodiak Island, 2013.



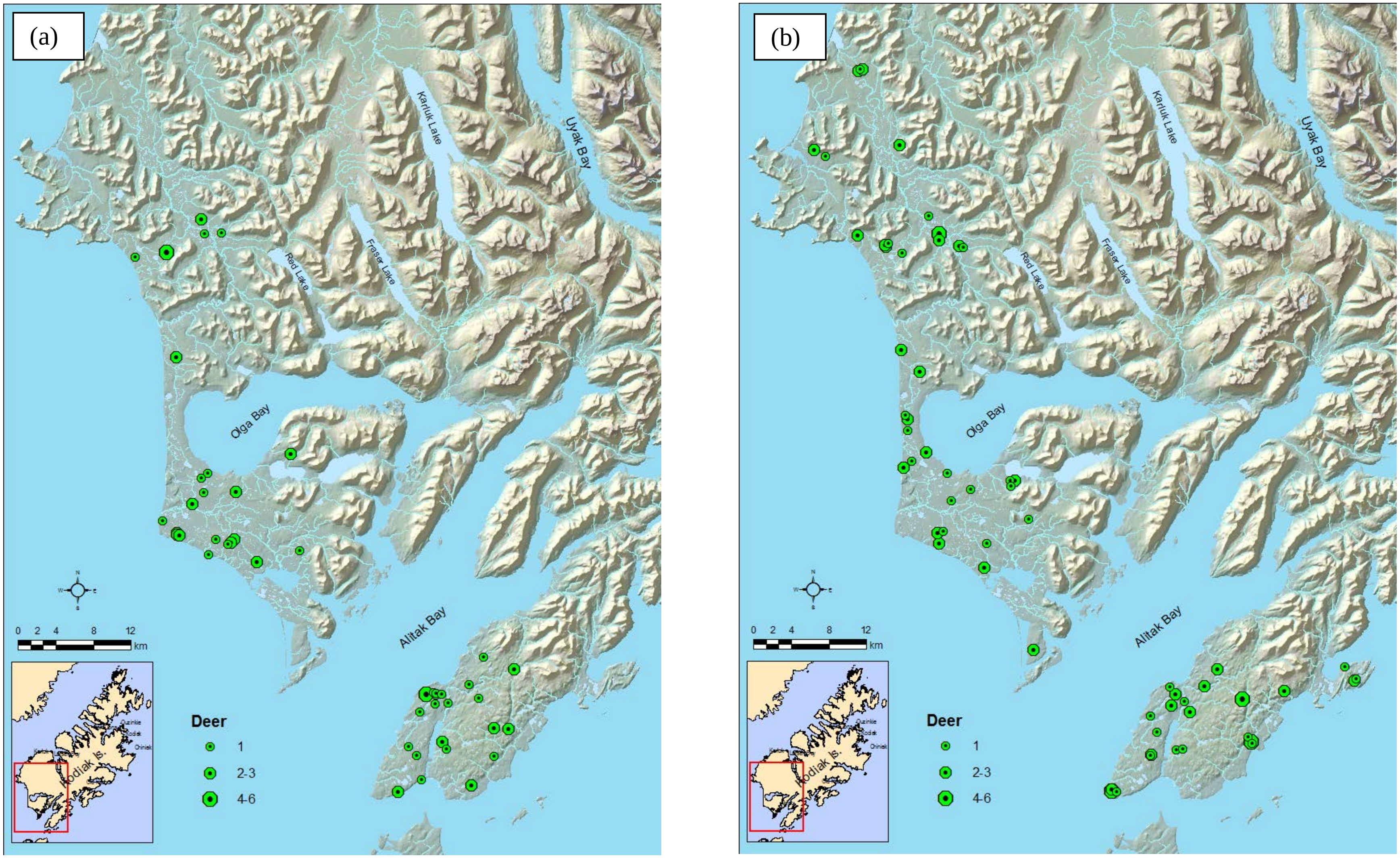


Figure 3. Approximate location of deer groups observed during the first (a) and second (b) replicate aerial survey, Kodiak Island, 2014. The sizes of the points are scaled relative to group size.

Table 2. Summary of the time (hrs) and approximate cost (based on $200/hr wet rate for Aviat Husky) to complete transects.

Location	Date	Survey time (hrs)	Cost
Ayakulik/Olga	5/16/2014	4.0	$800
Ayakulik/Olga	5/17/2014	3.1	$620
Ayakulik/Olga	5/20/2014	6.1	$1,220
Aliulik/Olga	5/21/2014	9.8*	$1,960
Total		19.1	$4,600

*includes 4 hrs of ADF&G flight time in Super Cub

We observed a total of 183 deer (77 deer in the first replicate and 106 in second replicate) in 106 groups (45 groups in the first replicate and 61 in the second replicate) (Table 3). Group size averaged 1.73 deer/group. We most commonly observed deer standing (54 groups), followed by bedded (47 groups). We only observed three groups that were walking and one group running.

Table 3. Summary of deer and deer groups sizes observed during aerial line-transects.

Study site	Replicate	Deer	Groups	Deer/group
Aliulik	1	34	22	1.55
	2	42	24	1.75
Olga	1	33	18	0.86
	2	32	21	0.60
Ayakulik	1	10	5	2.00
	2	32	16	2.00
Total	--	183	106	1.73
Average/replicate	--	92	53	--

Based on the most parsimonious mark-recapture logistic model, detection on the transect line was dependent on deer group sizes, observers, and an interaction term between group size and observer (Tables 4 and 5). We found no evidence for a relationship between detection on the transect line and habitat type or deer behavior ($\Delta AIC_c>2$). According to the best candidate model, detection probability on the transect line was 0.80 (SE=0.05) for the passenger, 0.68 (SE=0.05) for the pilot, and 0.93 (SE = 0.02) for the pooled observers (Figures 4 and 5).

The most parsimonious distance sampling model indicated that deer in water were more likely to be detected (β_{water}=0.98, SE=1.86), and deer in shrub habitat were less likely to be detected (β_{shrub}=-0.55, SE=0.34) than deer in other habitat types (Tables 6 and 7). We found no difference in our ability to detect deer on grass, tundra, or rock habitats. Deer behavior also did not significantly affect observer deer detection. The model indicated that deer detection decreased from a high of 0.93 at distance 0, to 0.09 at the furthest distance that we observed deer (652 m). The average detection probability in the survey area (<652 m from right side of the aircraft) for pooled observers was 0.49 (SE=0.04).

The Kolmogorov-Smirnov test showed no significant difference (D=0.06, p=0.85) between empirical data and model-derived distributions, indicating a good model fit.

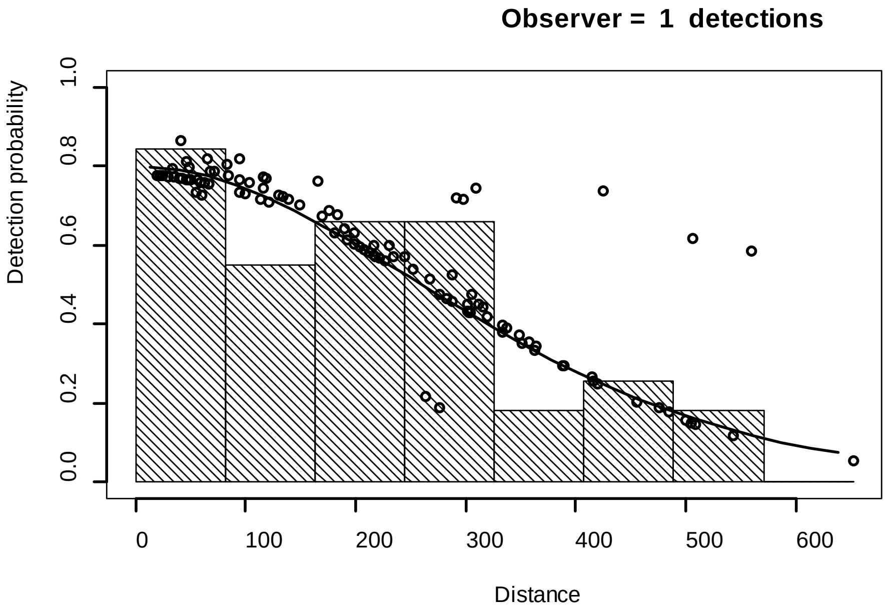
Table 4. Model selection rankings of candidate mark-recapture models. The most parsimonious model (Group size * Observer) was the base model in the distance sampling candidate model set in Table 5.

Model	ΔAIC_c	AIC_c
Group size * Observer	0.00	1531.29
Group size + Observer	2.23	1533.52
Group size	4.77	1536.06
Observer	8.17	1539.46
Observer + Distance	8.34	1539.63
(Intercept)	10.70	1542.00
Distance	10.88	1542.17
Shrub	11.07	1542.36
Grass	11.20	1542.49
Tundra	11.73	1543.02
Bedded	12.35	1543.64
Rock	12.58	1543.87
Standing	12.60	1543.89
Walking	12.62	1543.91

Table 5. Conditional detection function parameters from the most parsimonious mark-recapture model (Group size * Observer).

Parameter	Estimate	SE
(Intercept)	1.04	0.62
Group size	0.21	0.31
Observer (pilot)	-2.03	0.76
Group size: observer (pilot)	0.34	0.47

(a) Passenger



(b) Pilot

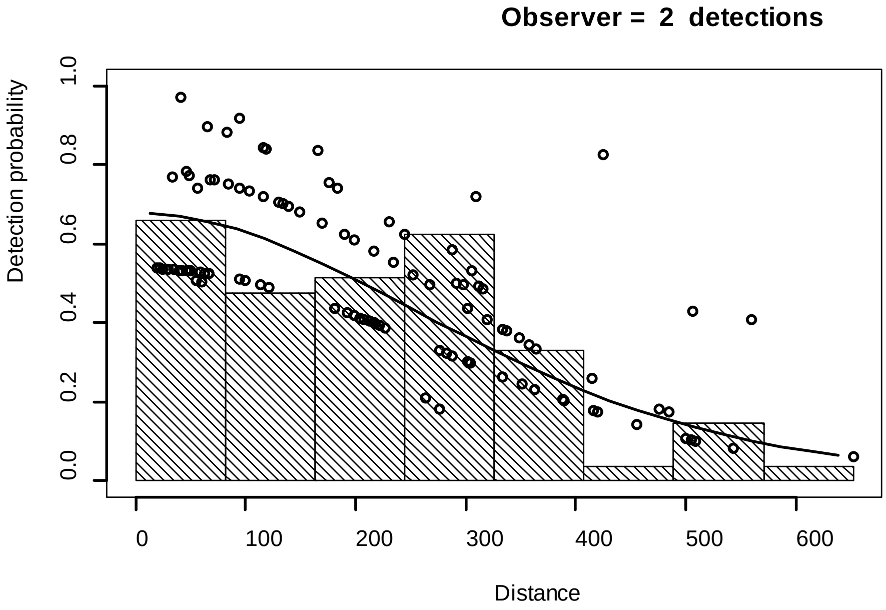


Figure 4. (a) and (b). Fitted average detection function (line) for the passenger (a) and pilot (b) observers, superimposed on a histogram (bars) showing the frequency of counts at various distance (m) classes. The estimated probabilities of detection for each observation are shown as points.

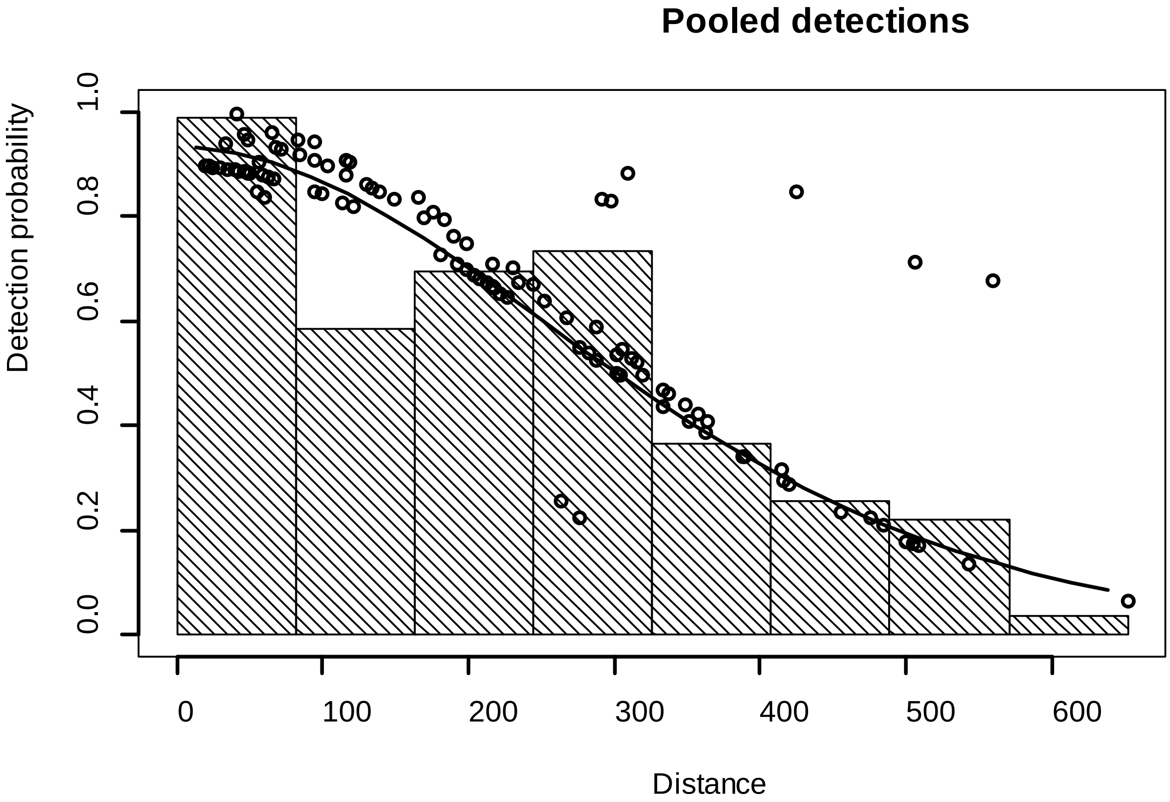


Figure 5. Fitted average detection function (line) for pooled observers (passenger and pilot combined), superimposed on a histogram (bars) showing the frequency of counts at distance (m) classes. The estimated probabilities of detection for each observation are shown as points.

Table 6. Model selection rankings of candidate distance sampling models. DS=distance sampling model, MR=mark-recapture model.

Model	ΔAIC_c	AIC_c
DS(Water + Shrub), MR(Group size * Observer)	0.00	1530.06
DS(Water), MR(Group size * Observer)	0.24	1530.30
DS(Shrub), MR(Group size * Observer)	0.65	1530.71
DS(Intercept), MR(Group size * Observer)	1.23	1531.29
DS(Rock), MR(Group size * Observer)	1.86	1531.92
DS(Bedded), MR(Group size * Observer)	2.13	1532.19
DS(Study site), MR(Group size * Observer)	2.38	1532.44
DS(Standing), MR(Group size * Observer)	2.44	1532.50
DS(Tundra), MR(Group size * Observer)	2.57	1532.63
DS(Walking), MR(Group size * Observer)	2.91	1532.97
DS(Group size), MR(Group size * Observer)	3.14	1533.20
DS(Grass), MR(Group size * Observer)	3.21	1533.27

Table 7. Conditional detection function parameters from the most parsimonious distance sampling model (Water + Shrub).

Parameter	Estimate	SE
(Intercept)	5.63	0.10
Water	0.98	1.86
Shrub	-0.55	0.34

Based on the most parsimonious model, we estimated that the study area contained 432 deer (SE=65.70) at a density of 0.74 deer/km^2 (SE=0.12), and 257 deer groups at a density of 0.44 deer groups/km^2 (SE=0.06) (Table 8). Deer density was highest at the Aliulik study site (0.86 deer/km^2, SE=0.16) and lowest at the Olga study site (0.64 deer/km^2, SE=0.16).

Table 8. Model-derived estimates of deer densities and abundances, by study site. Standard errors are in parentheses.

Study site	Density		Abundance	
	Deer	Groups	Deer	Groups
Aliulik	0.86 (0.16)	0.54 (0.10)	184 (34.74)	114 (21.28)
Olga	0.64 (0.16)	0.38 (0.08)	148 (35.98)	91 (20.08)
Ayakulik	0.72 (0.22)	0.36 (0.10)	100 (30.32)	52 (14.24)
Combined	0.74 (0.12)	0.44 (0.06)	432 (65.70)	257 (37.16)

In addition to counting deer, we opportunistically counted bears, reindeer, swans, and deer and whale carcasses. On each replicate, we saw an average of 10 bears in 5.5 groups, 241 reindeer in 7 groups, 29 swans in 18.5 groups, 10 deer carcasses, and 1 whale carcass (Table 9, Appendices A-E). We saw more bears at Aliulik and Olga than Ayakulik. Most reindeer were in the northern portions of the Ayakulik valley, between Grant's Lagoon and Anvil Mountain, although we did count some bulls in the Olga Flats. Swan abundances were fairly consistent (10.5 – 13 swans) among study sites.

Table 9. Average number of bear, reindeer, swan, and deer and whale carcasses opportunistically-counted per replicate survey. The average number of groups counted per replicate survey is shown in parentheses.

	Bears	Reindeer	Swans	Deer (carcasses)	Whale (carcasses)
Aliulik	4 (2.5)	0 (0)	11 (8)	2	0
Olga	5 (3)	23.5 (2.5)	10.5 (6.5)	3	0
Ayakulik	1 (0.5)	217.5 (4.5)	13 (8)	6	1
Total	10 (5.5)	241 (7)	29 (18.5)	10	1

Discussion

Our results show that mark recapture distance sampling (MRDS) is an effective and repeatable approach to estimating Sitka black-tailed deer densities and abundances, with statistical confidence, in non-mountainous, non-forested habitats of Kodiak Island. Our estimate of deer density at the Aliulik Peninsula (0.86 deer/km^2, SE=0.16) was 62% higher than the 2012 estimate (0.53 deer/km^2, SE=0.07), which equates to an increase in abundance during that period from 115 (SE=15.82) to 184 deer (SE=34.74) (Cobb 2012). These results indicate that the deer population in these areas has grown over the past two years, which we believe was a response to mild winter conditions coupled with low deer population densities.

Our estimate of deer density was approximately 6-times lower than a previous estimate for Kodiak Archipelago in 2009 (5 deer/km^2, or 70,000 deer total), which was based on hunter questionaires and subjective accounts (Van Daele and Crye 2011). If deer abundances theoretically declined by 50% after winter 2011 to 35,000 (3.90 deer/km^2), our estimate would still 3-times lower. At 0.86 deer/km^2, Kodiak Archipelago would have only approximately 7,700 deer. Considering that an estimated 4,046 deer were harvested in 2011 (ADF&G harvest report), it is unlikely that the Archipelago-wide population was that low. Therefore, we surmise that deer densities were lower in the study sites than the Archipelago-wide average. Although our estimates of deer densities may not have been representative of densities across Kodiak Island, we believe that they are accurate for these study sites during the timeframe, and provide an unbiased quantification of annual changes in deer density.

Care should be taken when extrapolating our deer density estimates for the Aliulik, Olga, and Ayakulik lowland regions to the greater Kodiak Archipelago. It is likely that deer densities on Kodiak vary markedly among vegetation types and topography. Little is known of deer habitat selection on Kodiak. However, a study on the Spiridon Peninsula of Kodiak Island found that deer were predominantly seasonally migratory, moving an average of 22 km between summer and winter ranges between mid-April and late June (Selinger 1995). Interannual variation in the timing of spring deer movements were thought to be influenced by environmental factors, such as forage nutrition and availability, snow cover, and weather patterns. The author concluded that deer on Spiridon Peninsula moved from coastal closed tall shrub habitat to interior open tall shrub habitat, and largely avoided alpine habitats. This finding contradicts anecdotal evidence by hunters and biologists, who regularly observe large numbers of deer in the alpine during summer. Seasonal habitat use and movement patterns by deer in southern Kodiak Island, including our study area, have not been examined. Information on the timing and drivers of deer seasonal movement patterns on Kodiak are needed to better understand how our deer density estimates on flat non-forested habitats correspond to deer densities elsewhere on Kodiak. Additionally, expanding the scope of our surveys to include mountainous habitats could provide a more complete understanding of deer densities across Kodiak, but would require adapting the current survey methods (Sensu Schmidt et al. 2012).

Kodiak received almost record snowfall during the winter of 2011-12 (365.25 cm), and January 2012 was the snowiest month on record (135.65 cm) (National Weather Service). Combined with below average winter temperatures, these conditions resulted in an estimated 20-50% population decline. Since 2012, snowfall has been average to low and temperatures average to warm. Deer abundances over the past 10 years on Kodiak, as indexed by hunter reports and spring carcass counts, generally decline after unusually cold and wet winters and rebound following mild winters (Cobb 2011b, Van Daele and Crye 2011). Our results confirm this conclusion and provide the first quantitative estimates of interannual variation in deer abundance in the Kodiak Archipelago.

At high densities, deer populations can adversely impact their environment by damaging habitats, competing with native species, and transferring disease. Understanding the threshold at which impacts from overabundant deer are incongruent with management goals is often unclear, but needed to guide appropriate actions. Densities at which negative impacts occur differ between contexts, so a local understanding of the relationship between densities, habitat selection patterns, and population dynamics is needed. Our estimate of deer densities is a first step toward meeting this goal.

This study yielded the first estimates of Sitka deer abundances with moderate statistical precision on Kodiak Island. The unforested characteristic of southern Kodiak Island is unique among Sitka deer ranges of Alaska and Canada. Consequently our ability to compare our results to other areas where estimates are available may be inappropriate. That being said, densities on Kodiak were substantially lower than most previous estimates reported for forested habitats of southeast Alaska. Sitka deer densities have been estimated on unmanaged forested habitats (12 deer/km^2) and logged forests (7-10 deer/km^2) on Prince of Wales Island using mark-recapture fecal DNA (Brinkman et al. 2011). Traditional pellet count surveys in winter range have estimated densities ranging from 10-57 deer/km^2 on Vancouver Island (Herbert 1979). High deer densities have been reported for Admiralty, Baranof, and Chichagof Islands (155 deer/km^2), using traditional pellet sampling (Kirchhoff 2003). We speculate that Kodiak had lower deer densities than other areas for a few reasons. Tundra habitats on Kodiak offer lower habitat quality that may lower survival and reproductive rates compared to other areas. Kodiak's non-forested habitats do provide insulation from snow and thermodynamic stress during the winter like forest canopy, nor provide snow and ice-free forage. As such, over-winter survival rates on Kodiak would show more interannual variation, especially during unusually cold and wet winters. Deer on Kodiak may encounter greater hunter harvest pressure than other areas because of more hunters in the field and open habitats providing little concealing cover.

Conventional distance sampling has been criticized because it assumes perfect detection on the transect line. Violating this assumption, which is likely common in aerial wildlife surveys, leads to an underestimate of animal density, abundance, and statistical confidence (Buckland et al. 2007). To address this concern, we estimated detection on the transect line using a mark-recapture (double-observer) model and then applied this function to the distance sampling model to estimate an overall detection probability. We found that detection along the transect line was high (0.93), which was not surprising because deer appeared to stand out on the open terrain. We expected the pilot's detection along the transect line to be higher than the passenger because he was the only observer with an unrestricted view forward of the tandem aircraft. Alternatively, we expected passenger detection to be higher at further distances because, unlike the pilot, the passenger could fully focus on scanning for deer. Contrary to our initial expectations, however, we found that the passenger detected more deer than the pilot, and differences in the observers' abilities to detect deer were unrelated to distance. Although the model did not show this, the pilot felt that his ability to spot deer was affected by topography (more varied topography required the pilot to dedicate more time to avoiding obstructions) and wind speed (keeping the aircraft on the transect line was increasingly difficult in higher winds). Therefore, we believe that the added concentration needed to fly the aircraft likely explains some of the differences in observer detection probabilities.

We found evidence for variations in deer densities across southern Kodiak that we surmise was due to differences in habitat quality and proximity to human development. Our surveys indicated that deer densities were highest at the Aliulik study site, where the terrain is the most topographically varied and contains more grass and shrub habitats. Densities were lowest at the Olga study site, which may be due to lower habitat quality (tundra) and because higher harvest pressure because of its proximity to the village of Akhiok. We found intermediate densities at the Ayakulik study area, which is also dominated by tundra habitat. Sitka deer generally inhabit forested habitats and Kodiak is likely unique habitat for the subspecies. In forested habitats of southeast Alaska, Sitka deer show higher densities in unmanaged and clearcut forests, presumably because young clearcuts offer abundant accessible forage and unmanaged forested provide protection from snow (Brinkman et al. 2011). Similarly, we hypothesize that Aliulik supported higher deer densities because deer had more access to forbs, shrub habitat (a potential winter forage, snow cover, and provide overstory for other forage plants), and because the topography there provided more habitat diversity. Alternatively, the Olga and Ayakulik tundra habitats were largely composed of less palatable forage, such as *Empetrum* and lichens.

We recorded sighting and track line data using a recently developed program for wildlife aerial surveys, DNR Survey, which was a substantial improvement over the paper-based data entry method used previously. DNR Survey is an extension in ArcMap (ESRI, Redlands, CA) produced by the Minnesota Department of Natural Resources that allows for custom forms, automatic flight track line recording, and GPS waypoints with linked voice records (.wav files). We ran the program in ArcMap 10.2 on a Dell Latitude laptop and using a Phillips SpeechMike Pro for audio recording. There were a number of advantages to voice rather than paper records. By not having to look down to write observations, the passenger was able to spend more time observing deer and found it easier to keep track of the locations of deer that have been observed, which in turn made it easier to relocate deer as the plane circled. Trackline and waypoint data in DNR Survey were recorded as shapefiles, which removed the additional step of having to upload data from the GPS to the computer when the survey is completed. Although voice data needed to be manually transcribed into the shapefile's data table, we found this to be an easy step by using our custom form and still faster than digitizing written records. Reducing the time needed to write data while in flight allowed us to record additional observations (count non-target species) that would not have been possible using a paper datasheet. Following recommendations from MN DNR, we plan to upgrade to a touch screen ruggedized tablet (Panasonic ToughPad) and a Bluetooth GPS (Garmin GLO) for future surveys.

As noted in previous surveys, deer carcass remnants, demarked by hair piles, were readily observed and could serve as an index of annual winter mortality. Although we did not adjust carcass counts for detection, we counted fewer carcasses (2) than in 2012 (20, when standardized to 2014 survey effort) at Aliulik, which suggests a diminished rate of winter mortality. This is expected, given the high levels of winter mortality observed throughout the Archipelago. We recommend that future efforts should continue to include deer carcasses in the survey. We did not record distances to carcasses, to conserve time and funding. However, if these data were collected, carcass densities could be estimated and compared to deer densities to estimate winter mortality rates.

Management Implications

Our results indicate that deer abundances in flat non-forested habitats of southern Kodiak increased after a substantial decline in deer numbers during winter 2011-12. In addition to observing more deer than in previous two surveys, we also observed fewer deer carcasses, which suggesting that mild winter conditions resulted in low mortality in 2013-14. As an introduced ungulate, deer on Kodiak have the potential to negatively impact native flora and fauna when at high densities. Deer abundances on Kodiak have historically varied widely in response to winter conditions. These oscillations in deer abundances may be repeatedly exposing forage plants to intense grazing pressures during years of high deer densities, which could be affecting plant compositions and distributions. More information on the relationship between deer abundances, population dynamics and habitat selection patterns are needed to develop an effective harvest and range conservation management strategy.

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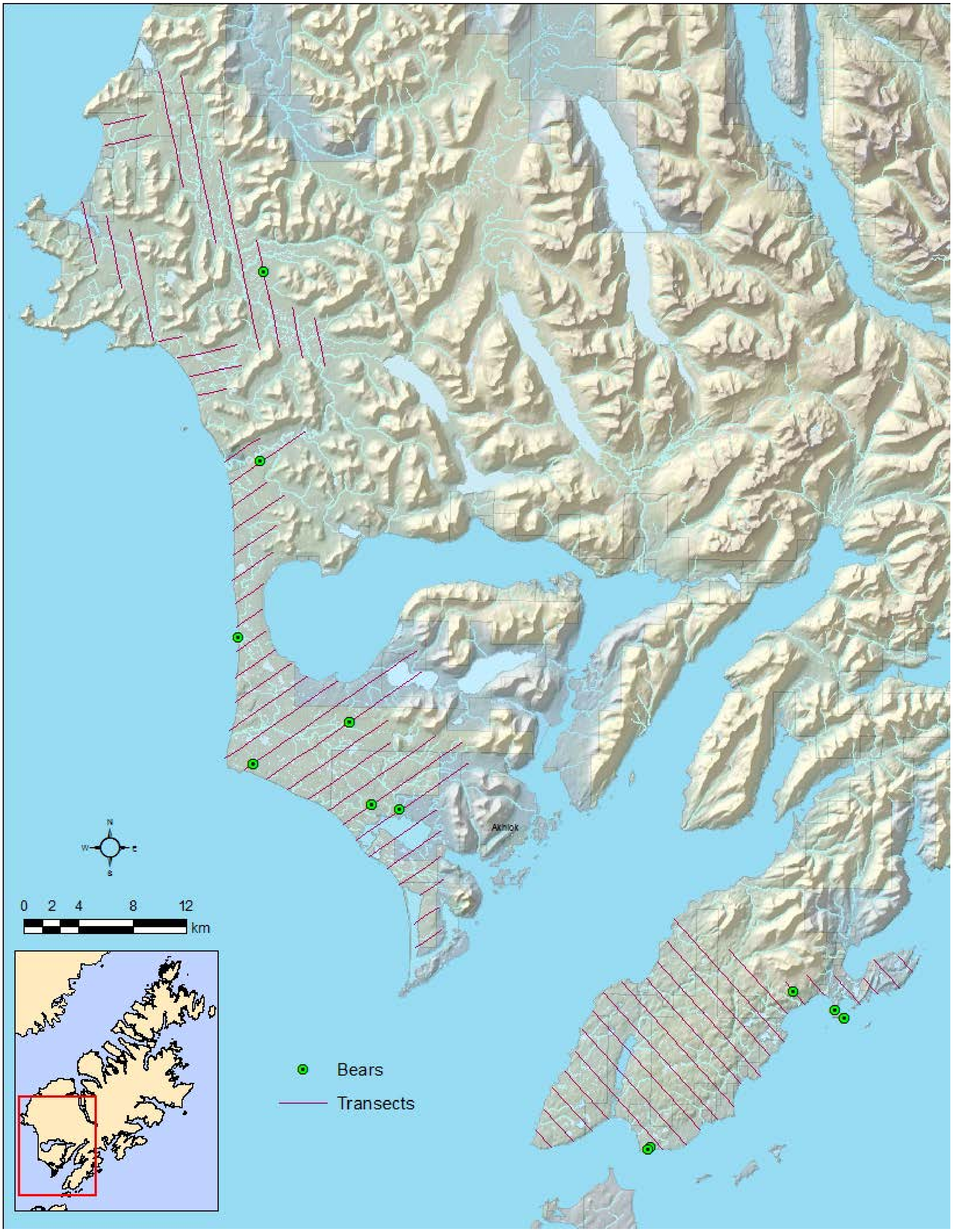
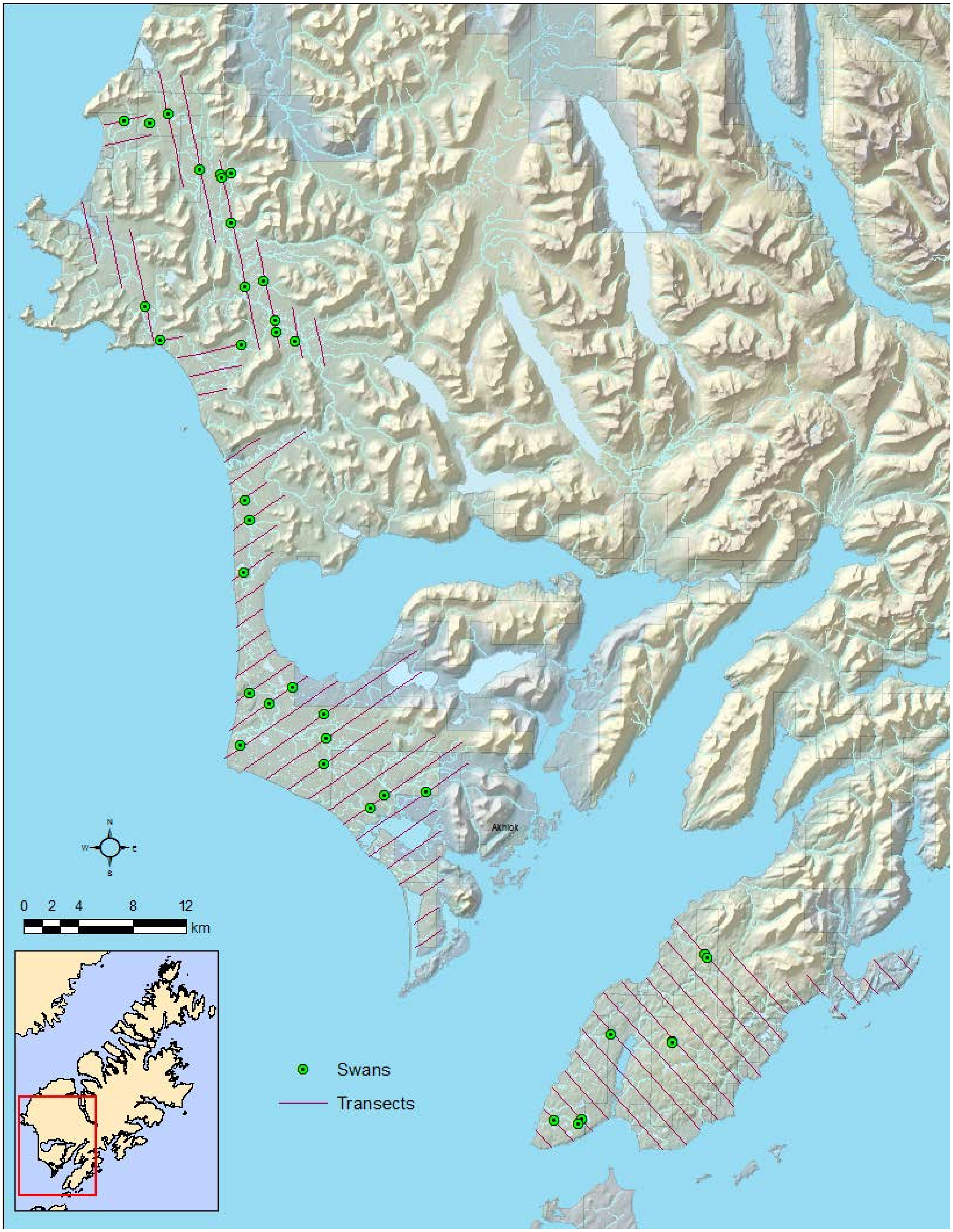
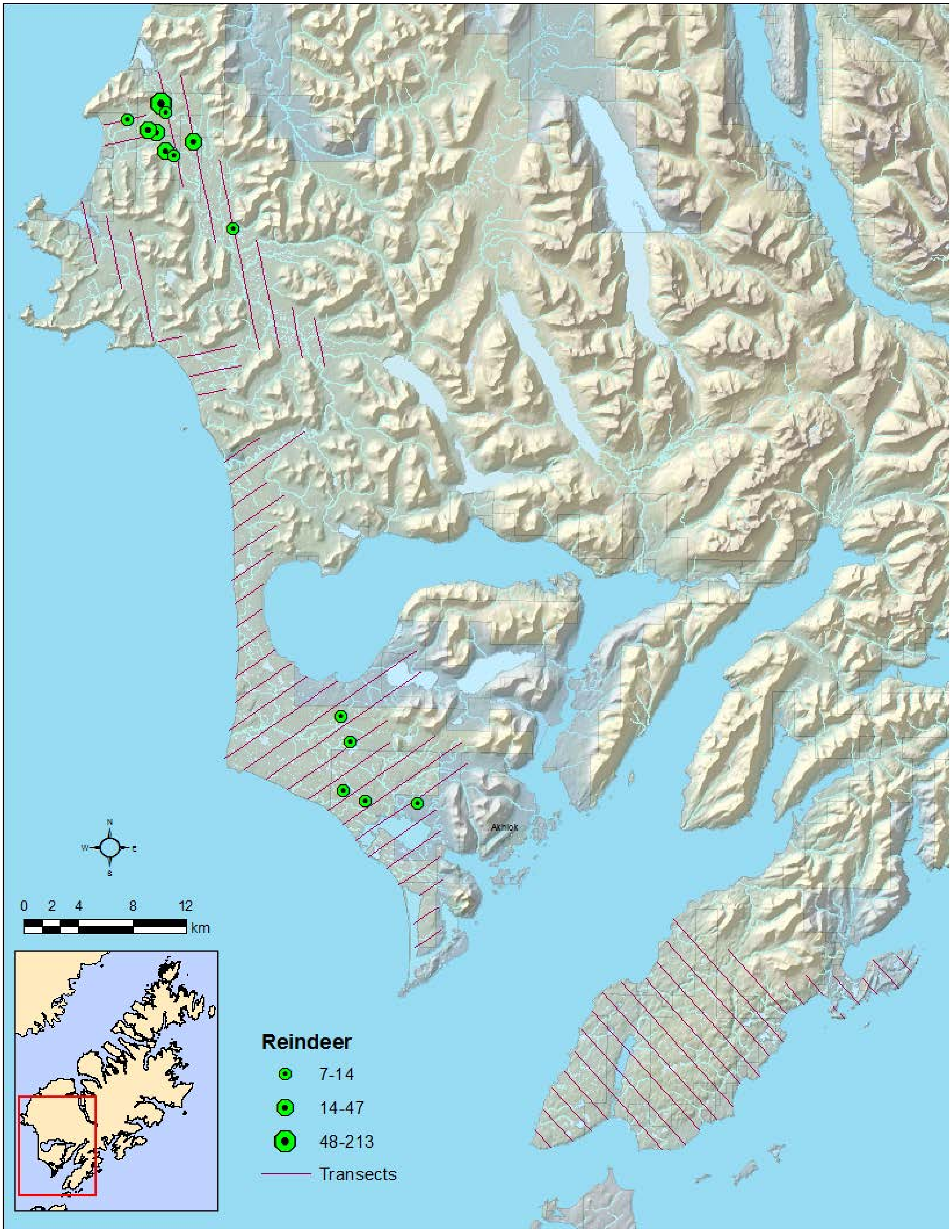
Appendix A. **Bear locations.**



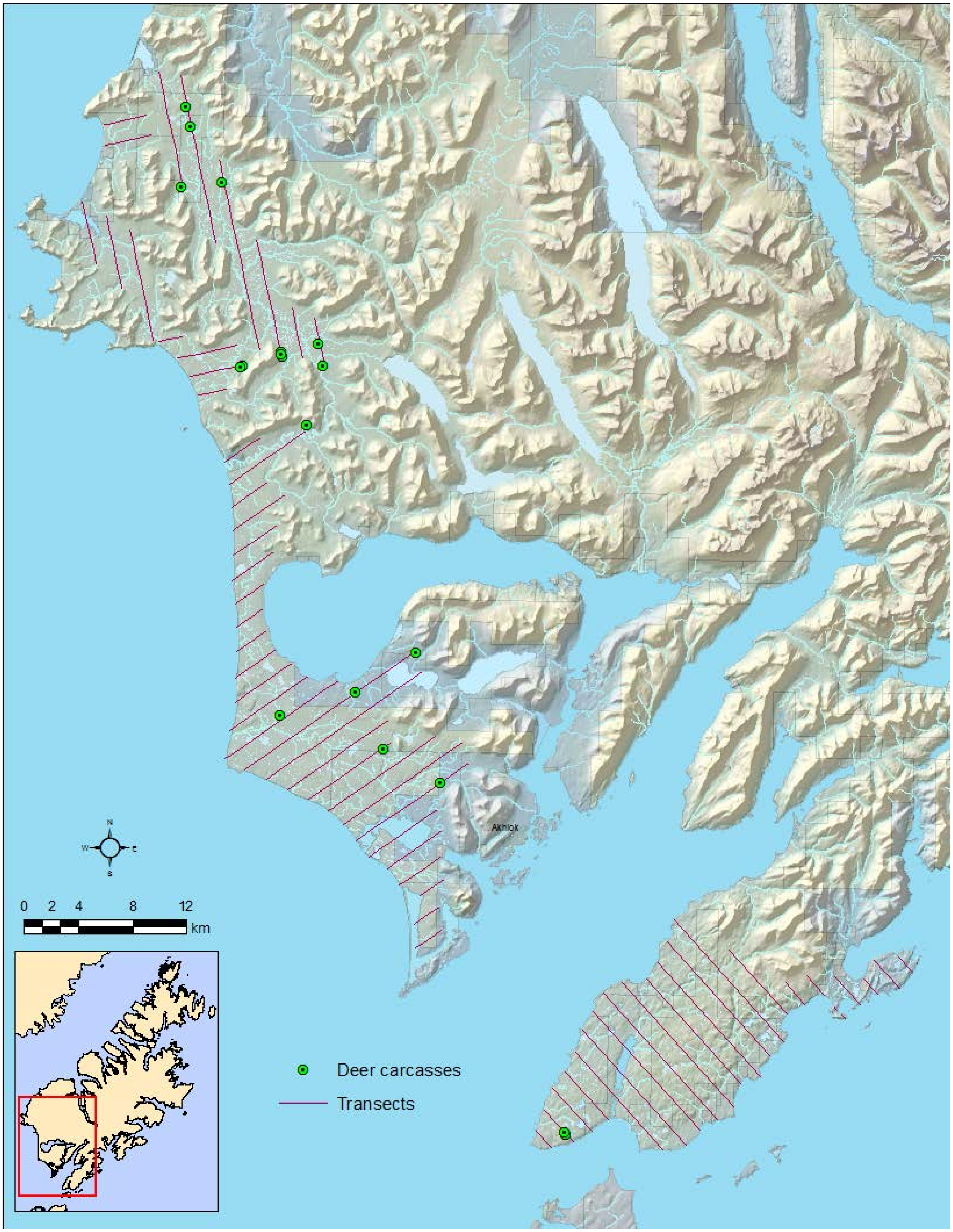
Appendix B. Swan locations.



Appendix C. Reindeer locations



Appendix D. Deer carcass locations.



Appendix E. Whale carcass location.