

**Aerial Line Transect Surveys for
Moose (*Alces alces*) Abundance on the
Alaska Peninsula/Becharof NWR, Alaska**

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Introduction

During the winters of 2003-04, 2004-05, and 2005-06, aerial line transect surveys were conducted to estimate moose (*Alces alces*) abundance on Alaska Peninsula/Becharof National Wildlife Refuge (APBNWR) and surrounding lands. This report describes the methods and results of these surveys. In addition, this report contains a comparison of moose abundance in the winter of 2004-05 versus 1982-83 within a small portion of the study area.

Methods

Field Surveys

Prior to the 2003-04 survey, a spatially distributed sample of transect lines was developed by the APBNWR. The study area, which contains all of the Alaska Peninsula/ Becharof National Wildlife Refuge minus large lakes and higher elevations, as well as adjacent federal, state and private lands, was divided into two strata based on the perceived quality of winter moose habitat and thus relative moose densities; “medium/high” and “low”. Grids of evenly spaced transect lines were randomly placed in each stratum with transects running parallel to the major habitat/landscape gradient (gradient running NW → SE), with a few exceptions (Figure 1). Transects were spaced 3.2 km (2 miles) apart in the medium/high stratum and 12.8 km (8 miles) apart in the low stratum. Transect spacing was chosen to optimize the safety, efficiency, and cost-effectiveness of the survey while providing reliable, unbiased estimates of moose abundance. The goal for this study was to obtain a reliable estimate of moose abundance with 90% confidence interval half-width of $\pm 25\%$ or less of the estimate.

The total areas surveyed in the three winters using a double-observer modification to standard line transect methodology covered 7457 km² (Figure 2). In the 2003-04 winter, surveys were conducted on December 16-17, January 14-20, 22, 29, and February 2. The 2003-04 survey covered a 3215 km² region between Katmai National Park and Lower Ugashik Lake (Figure 3) (Nielson et al. 2004a). Approximately 1,114 km of transects

was flown during the 2003-04 surveys, of which 918 km were medium/high transects (84) and 196 km were low transects (12). Early on during the 2003-04 survey it was decided that only medium/high stratum transects would be flown during remaining surveys due to budget and logistical constraints.

Late in the 2004-05 winter, surveys were conducted in a 2135 km² region between Lower Ugashik Lake and Aniakchak Crater (Figure 4) (Nielson and Bourassa-Stahl 2005). These surveys were not flown until late March (March 26, 27, 29, 30 and April 3) due to poor snow cover across much of the peninsula. A total of 700 km of transects (48) were flown in the medium/high density stratum in 2004-05.

In 2005-06 winter, surveys were conducted in a 2107 km² region between Aniakchak Crater and Mount Veniaminof (Figure 5). A total of 529 km of transects (48) were flown in the medium/high density stratum on February 2 and March 2-4.

Bell 206 helicopters with bubble or wedge windows were used to survey all transects. The pilot attempted to maintain an altitude of approximately 122 m (400 ft) above ground level (AGL) during the surveys. This above ground height has been found to provide good visibility of moose close to the transect line in most habitat while not disturbing moose ahead of the aircraft (Nielson et al. 2006). Airspeed was approximately 48-64 kmph (30-40 mph) over rougher terrain with some vegetative cover and 129-161 kmph (80-100 mph) over more open, flat terrain. The medium/high stratum was a mosaic of open country and shrub lands, especially along watercourses. Scattered spruce trees and occasional stands of poplar were present in some areas. Hills, ridges, and steep valleys were common on many transects, as the southern ends of transect lines tended to be near the base of the Aleutian Range.

During the surveys two observers sat in the rear seats of the helicopter, one on each side. These observers were responsible for sighting moose groups, counting the number of moose in each group detected, and measuring the perpendicular distance from the transect line to each moose group detected. A third crewmember sat in the front left seat

of the helicopter on all surveys. This third observer acted as a double-observer (Manly et al. 1996, Nielson et al. 2006) on one side of the aircraft to test the assumption that detection on or near transect line was 100%. This double-observer modification to standard line transect methodology was used because perfect detection of individuals on the transect line is a primary assumption of line transect sampling and analysis procedures, although in many cases detection of animals on or near the line is not certain and usually less than 100% (Manly et al. 1996, Buckland et al. 2001, Borchers et al. 2002). In addition to acting as a double-observer, the front seat observer was responsible for recording moose group locations into the computer, including the flight path and GPS locations of moose groups, and directing the pilot to transect waypoints.

When flying a transect line during the surveys, the recorder concentrated on detecting moose at the inside edge of the survey strip, although all observations less than 600 m from the transect line were recorded. Double-count data collection procedures on the double-observer side of the aircraft allow for estimation of detection rates on or near the transect line by the rear seat observer, which are then used in the analysis to correct for individuals missed during the surveys. The double-count sampling method required that the observers on the left-hand side of the aircraft operated independently of each other, and that observers correctly recorded moose detected by both observers and moose detected by the front seat observer and not the rear seat observer. Rear seat observers rotated sides of the aircraft daily to ensure that all rear seat observers were represented in the estimates of detection rates.

Perpendicular distances (meters) of observed moose groups from the transect line were measured by the rear seat observers using Impulse XL laser range finders (Laser Technology, Inc., 7070 S. Tucson Way, Englewood, CO, 80112-3921). Observers aimed the laser range finders at the ground in the center of each moose group to prevent overshooting their target and thus overestimating distances. In similar surveys where laser range finders were not available (Nielson et al. 2006), distance bands marked on helicopter windows have been used to determine distance groupings for detected animals groups because it can be difficult to visually estimate perpendicular distances. The laser

range finders used in the APBNWR surveys contained built-in clinometers, which allowed for accurate measurement of horizontal distances of moose groups perpendicular to the transect line, regardless of the AGL or surrounding landscape. As a precaution, distance bands were marked on the windows of the helicopter (Figure 6, Table 1) for the all surveys and served as a backup if the laser range finders failed.

In addition to recording moose group size, number of calves, and perpendicular distance from the transect line, the rear seat observers estimated percent cover within a 50 m radius of each observed moose group. Percent cover was recorded because it could be used as an analysis covariate and in future habitat selection analyses based on the survey data.

Statistical Analysis

Habitat types, field data collection protocol, and observers were fairly constant during the surveys, so we combined moose observations from all surveys to estimate detection probabilities. Visual inspection of histograms of observed perpendicular distances from 2003-04 and 2004-05 winter surveys indicated detection probabilities out to a distance of 357 m were similar across these two years (Figure 7). The histogram of observed perpendicular distances for the 2005-06 survey was somewhat unusual, but the small sample size ($n = 26$), precluded fitting a separate detection function and so all data were combined for estimating detection probabilities. After estimating detection probabilities based on the pooled data, we then estimated average group sizes and moose densities for each area surveyed separately (i.e., 2003-04, 2004-05, and 2005-06 areas).

Survey protocol required that the helicopter flew at 122 m AGL on all transects. This resulted in a swath of approximately 45 m under the aircraft on either side that could not be viewed, so the minimum available sighting distance, W_1 , was set to 45 m for the analysis. This distance was measured using laser range finders and was consistent with calculations based on clinometer readings used to measure the maximum downward sighting angle from the horizon from the rear seat.

After defining the effective search strip width of the surveys to be $W_2 - W_1 = 312$ m (i.e., $357 - 45 = 312$), we used the following estimator for moose density within each area surveyed:

$$\hat{D} = \frac{nE(s)}{\hat{g}(W_1)\hat{P}A}, \quad (1)$$

where n was the number of moose groups detected, $E(s)$ was the expected moose group size, A was the total area searched ($A = \text{total length of transects} \times 2[W_2 - W_1]$), $\hat{g}(W_1)$ was the estimated probability of detection at W_1 by the rear seat observers based on the double-count trials, and $\hat{P}$ was the estimated average probability of detection of moose groups within the search area, given detection at W_1 . This modification to the density formula for standard line transect analysis (Buckland et al. 2001) has been used in previous analyses of line transect data (McDonald et al. 1999, Good et al. 2007, Nielson et al. 2004a and 2004b, Nielson and Bourassa-Stahl 2005, Nielson et al. 2006) to correct for individuals missed on/near the transect line.

Standard line transect analysis assumes 100% detection of groups at or near the minimum available sighting distance, W_1 , or $\hat{g}(W_1) = 1.00$ in equation (1) (Buckland et al. 2001, Borchers et al. 2002). We estimated visibility bias, or probability of detection at the minimum available sighting distance using logistic regression and all observations within 357 m of the aircraft by the front left observer on the double-observer side of the aircraft. The logistic regression function estimated the probability of detection by the rear left observer given the moose group was first detected by the front seat observer.

We fit two logistic regression models (McCullagh and Nelder 1989) for the probability of detection at $W_1 = 45$ m for the rear seat observer using SAS Proc Genmod (SAS Institute 2000). Given minimum and maximum available sighting distances of W_1 and W_2 respectively, we assumed that the probability of a detection by a rear seat observer of a moose group of size s at a perpendicular distance x from the transect line could be approximated by one of the following two logistic functions:

$$g(x, s) = \exp(\beta_0 + \beta_1 x + \beta_2 s) / \{1 + \exp(\beta_0 + \beta_1 x + \beta_2 s)\}, \quad (2)$$

or

$$g(x) = \exp(\beta_0 + \beta_1 x) / \{1 + \exp(\beta_0 + \beta_1 x)\}, \quad (3)$$

where β_0 , β_1 , and β_2 are unknown coefficients, and $W_1 \leq x \leq W_2$. We fit both logistic regression models to the double-count data and chose the model with the lowest value of the second-order variant of Akaike's Information Criterion (AICc) (Burnham and Anderson 2002) as our final model. AICc for each model was calculated as

$$AICc = -2\ln(Likelihood) + 2kn/(n - k - 1), \quad (4)$$

where k was the number of parameters in the model (including intercept term), n was the number of observations in the sample, *Likelihood* was the value of the logistic likelihood evaluated at the maximum likelihood estimates, and 'ln' was the natural logarithm. This model selection criterion is favored over AIC and the Bayesian Information Criterion for small samples (Burnham and Anderson 2002). Using the final logistic regression model for the rear seat observer, we estimated the probability of detection at $W_1 = 45$ m and calculated a 95% confidence interval for this prediction.

Standard line transect analysis (Buckland et al. 2001) involves fitting a detection function to the distance data, integrating this function over the effective search width (W_1 to W_2), and then dividing by the search width to obtain an estimate of the average probability of detection, $\hat{P}$, given detection at W_1 is some known or estimated value less than or equal to 100%. This estimate of the average detection probability is then used to inflate the number of groups detected to account for the groups missed within the survey strip (equation [1]).

The program DISTANCE (Thomas et al. 2005) was used to estimate $\hat{P}$ based on all observations of moose groups by the rear seat observers within the effective search strip width. The following three detection functions were fit to the survey data in DISTANCE: uniform key function with cosine expansions; uniform key function with simple polynomial expansions; and half-normal key function with hermite polynomial expansions. The number of expansion terms (0 to 5) in each model was determined by a stepwise model building process that used model AICc values to determine the most

parsimonious model (Burnham and Anderson 2002). These three semi-parametric functions were chosen because they are considered sufficiently flexible, can yield model robust estimation, and can satisfy the shape criterion described by Buckland et al. (2001).

Model averaging based on the AICc weights (Burnham and Anderson 2002) for each of the three detection functions was used for the final estimate of $\hat{P}$. The AICc weight for model i was calculated as

$$w_i = \frac{\exp(-\frac{1}{2}\Delta_i)}{\sum_{i=1}^3 \exp(-\frac{1}{2}\Delta_i)}, \quad (5)$$

where Δ_i was the AICc difference calculated using

$$\Delta_i = AICc_i - AICc_{\min}. \quad (6)$$

An AICc weight is considered as the weight of evidence in favor of model i being the “best” model for the data given that the actual “best” model is one of the models fit (Burnham and Anderson 2002). The weighted model average estimate of $\hat{P}$ was

$$\hat{\bar{P}} = \sum_{i=1}^3 w_i \hat{P}_i. \quad (7)$$

Truncation (Buckland et al. 2001) was used to estimate the average, or expected, group size, $\hat{E}(s)$, for each winter. Observations by any of the three observers within 145 m of the transect line were used to estimate the expected group sizes ($E[s]$ in eqn.1). Using moose groups seen within 145 m of the helicopter to estimate average group size limits the effect of size bias (i.e., larger groups may be detectable at greater distances than smaller groups) in the estimates.

We bootstrapped (Manly 1997) the survey data to estimate the variance and bias of estimates of moose abundance. This process involved taking 750 simple random samples with replacement of transects flown in each stratum, and re-running the analysis to obtain new estimates of moose densities and totals for each sample. The bootstrap process included estimation of $\hat{g}(W_1)$, and AICc stepwise model building using the three

detection functions fit in the program DISTANCE, along with the weighted model average of $\hat{P}$. Bootstrap sample sizes for the number of transects were the same as the original number of transects flown across years. The standard deviation of the 750 bootstrap samples was used as the estimated standard error for moose densities and totals. If the distribution of bootstrap densities and totals were found to be approximately normally distributed, then an approximate 90% confidence interval of the form

$$\text{Estimate} \pm 1.64(\text{Bootstrap Standard Deviation}) \quad (8)$$

was calculated. If the bootstrap distribution of an estimate was quite different from normal, percentile based 90% confidence intervals were calculated (Manly 1997). The percentile method uses the value at the 5th and 95th percentiles of the bootstrap estimates as the lower and upper confidence interval endpoints, respectively. Bias of a moose density estimator was calculated as

$$\text{Bias}(\hat{D}) \approx \text{Mean}(\hat{D}_B) - \hat{D}, \quad (9)$$

where $\text{Mean}(\hat{D}_B)$ was the mean of the bootstrap estimates from the 750 samples.

Comparing Moose Abundance in 2005 to 1983

During February 9-12, 1983 a “Gasaway” type aerial survey (Appendix I: Sellers 1983, Gasaway et al. 1986) was conducted to estimate the total number of moose inside 1,314 square miles of land in the Bristol Bay drainages from Ugashik River/Lower Ugashik Lake south to Cinder River (Figure 8). During March 27 to April 3, 2005 aerial line transect, or “Distance” sampling (Buckland et al. 2001), was used to estimate moose abundance within the larger region containing the 1983 Gasaway survey area (Figure 8). To assist in the management of the moose population in the region, we compared estimates of moose abundance in 1983 to 2005 for the common area surveyed. However, we must caution that we are not aware that any formal comparison has been made between these two surveys and analysis methods, and thus we cannot be sure that our comparison produced an unbiased estimate of the difference in moose abundance.

Prior to analysis of moose abundances in 1983 and 2005, we identified three potential problems that could bias the comparison. First, we did not have information about the

location or extent of the 1983 survey units in the southern most portion of the Gasaway area (Figure 9). Second, the 2004-05 survey consisted of flying transects that crossed medium, high, and low-density strata in the 1983 survey (assuming all remaining area within the Gasaway survey boundary not classified as high or medium density was classified as low density) (Figures 8, 9, and 10). Third, the low density areas surveyed in 2005 were adjacent to and surrounded by medium and high density areas and thus not representative of the entire low density stratum surveyed in 1983. To work around these issues and avoid any resulting bias, we limited our comparison to the 528.5 square mile area (1368.9 km²) consisting of the medium and high density strata survey units in 1983, excluding those in the southern most portion of the Gasaway area (Figure 9). We identified the lengths of transect flown in 2005 that fell within this identified “comparison area”, and which observations of moose groups from the 2005 survey fell within the boundaries of this region.

Given the limited historical data from the 1983 Gasaway survey (Appendix I), we used the total number of moose observed in the medium and high-density strata survey units to obtain an estimated density and total number of moose within the comparison area. We then applied the sightability correction factor (SCF) of 1.07 given in the description of the 1983 Gasaway survey (Appendix I) to obtain a final estimate of moose abundance. As mentioned above, the size of the units surveyed in 1983 was not available for this comparison, so we could not estimate a variance for the estimate of moose abundance using standard methods (Gasaway et al. 1986). The 90% confidence interval half-width of 16%, reported for the entire Gasaway area in 1983 (Appendix 1), was used to get a confidence interval for moose abundance in the comparison area in 1983. We believe the size of this confidence interval is smaller than a confidence interval based on standard methods (i.e., if all historic data were available), because stratification usually results in higher precision for the survey area as a whole compared to individual survey strata.

Statistical analysis of 2004-05 survey data for this comparison involved using the estimated probabilities of detection based on pooling observed distances in 2003-04, 2004-05, and 2005-06 to estimate probabilities of detection (described above), and

applying the estimated correction factors to those groups seen within the comparison area in 2005. Because of the potential for moose group sizes to be different within the comparison area compared to the entire region surveyed in 2004-05, we estimated average moose group size using only those groups observed within 45 to 357 m of transect line within the comparison area. Bootstrapping (described above) was used to estimate a variance for the estimated total number of moose in the comparison area in 2005.

Results

A total of 284 moose in 130 groups were sighted by the survey crew (excluding pilot) on transect during the surveys (Table 2). The number of calves identified during the three surveys was extremely low (total calves = 12). There were a total of 43 double-count observations from all three surveys available for fitting logistic regression models to estimate the probability that a moose group was detected by the rear seat observer, given the front seat observer detected the group. Of these 43 double-count trials, the rear left observer missed only 6 of the moose groups detected by the front seat observer (Table 3).

The logistic regression model containing the variable *distance* was selected based on the AICc value (AICc = 33.69 compared to 35.97) (Table 4). The final logistic regression model for the probability of detection of moose groups by the rear seat observers (Figure 11) was

$$\hat{g}(x) = \exp(4.1952 - 0.0122x) / \{1 + \exp(4.1952 - 0.0122x)\}.$$

Based on this model, the estimated probability of detection for the rear seat observers at the minimum available sighting distance was $\hat{g}(45) = 0.974$ (95% CI: 0.835 to 0.996).

There were a total of 110 observations of moose groups by the rear seat observers within 357 m from the transect line for estimating $\hat{P}$. The top 2 models for detection of moose groups, relative to detection at the minimum available sighting distance, had a combined weight of 0.81 (Table 5, Figure 12). A uniform model with one cosine expansion term

was the best model (AICc weight = 0.44), and the half-normal model was second best (AIC weight = 0.37). The weighted model average of $\hat{P}$ was $\hat{\hat{P}} = 0.631$ (Table 5).

The estimated average group size in the medium/high stratum in the 2003-04 survey area was 2.42 moose ($n \leq 145 \text{ m} = 24$, standard error = 0.342). Moose density in the 2003-04 survey region (Figure 3) was estimated to be 0.323 moose/km² (Table 6). The distributions of bootstrap estimates were approximately normal, so standard 90% bootstrap confidence intervals were calculated. A 90% confidence interval for this estimate was 0.233 to 0.413. No appreciable bias was found for this density estimate (bias < 0.01 moose/km²). The estimated total number of moose in the 2003-04 survey area (medium/high stratum) was 1039 (90% confidence interval: 744 to 1334).

The estimated average group size in the 2004-05 survey area was 2.00 ($n \leq 145 \text{ m} = 19$, standard error = 0.219). Moose density in the area in 2004-05 winter (Figure 4) was estimated to be 0.266 moose/km² (Table 6) (90% confidence interval from 0.184 to 0.348). Again, no appreciable bias was found for the estimate of moose density (bias < 0.01 moose/km²). The estimated total number of moose in the 2004-05 survey area was 570 (90% confidence interval from 395 to 745).

The estimated average group size in the 2005-06 survey area was 1.80 ($n \leq 145 \text{ m} = 10$, standard error = 0.54). Moose density in the area in 2005-06 winter (Figure 5) was estimated to be 0.227 moose/km² (Table 6) (90% confidence interval from 0.122 to 0.332). Again, no appreciable bias was found for the estimate of moose density (bias < 0.01 moose/km²). The estimated total number of moose in the 2005-06 survey area was 479 (90% confidence interval from 259 to 699).

Standard errors and 90% confidence intervals adjusted using a finite population correction factor (Cochran 1977, Buckland et al. 2001) are also available in Table 6.

Comparison to 1983 Census Results

We estimated a total of 955 moose (1.807 moose per mile², or 0.698 moose per km²) within the comparison area in 1983 (90% confidence interval using a half-width of 16% was 803 to 1108 total moose), and a total of 558 moose (1.077 moose per mile², or 0.407 moose per km²) within the area in 2005 (90% confidence interval from 362 to 753 total moose).

Discussion

Weather, time and money often limit the amount of survey effort for a given year, and several years are frequently needed to complete a survey for a large study area. It is often desirable to combine survey data across such survey occasions to increase precision. Pooling of data can be justified if survey crew, flight and field data collection protocol, and survey conditions are similar. Although survey conditions were similar between 2003-04, 2004-05, and 2005-06 winters, with the exception of slightly less snow cover in the 2004-05 survey, we carefully examined several histograms of observed distances to help determine if pooling was justified. Although a good portion of the histograms for all observed distances in the three years appeared alike, it was obvious the effective search strip width was larger in 2003-04, possibly due to the greater snow cover during that winter. In addition, detection closer to the aircraft seemed lower in 2005-06, but the small sample size for this year didn't allow for robust comparisons or a separate analysis. Although the methods used for estimating moose abundance across the study area are believed to be pooling robust (Buckland et al. 2001), stratum, or year, specific estimates could contain a small bias due to heterogeneity (Buckland et al. 2001).

Most statistical analyses, including line transect analysis, mistakenly do not take variation due to model selection into account. We believe that high model selection uncertainty for the detection functions can be responsible for a large portion of the bootstrap estimated variances. Thus, ignoring model selection uncertainty in the analysis can result in tighter confidence intervals and can inappropriately underestimate variance. Bootstrapping did include re-estimation of $\hat{g}(45)$ based on the re-sampled data, but only model (3) was fit

because models (2) and (3) had a difference in AICc values > 2.0 , and when plotted, probabilities of detection predicted by model (2) did not look reasonable.

Previous analyses (Nielson et al. 2004(a) and Nielson and Bourassa-Stahl 2005) estimated $\hat{g}(45)$ to >0.99 , and so detection at the minimum available sighting distance was set to 100%. Inclusion of the 2005-06 double-observer data into the analysis lowered $\hat{g}(45)$ slightly to 0.974. Although we expect probability of detection of moose groups at the minimum available sighting distance to be very high in the regions surveyed due to low and sparse canopy cover, good snow cover, and observer experience, 97.4% detection at the minimum available sighting distance seems more reasonable than 100%.

The use of a finite population correction factor to reduce estimated variances is limited to situations in which you can consider the population of animals to be finite during the course of the survey, individuals are not likely to be counted >1 time during the survey, and no animals are entering or leaving the region surveyed.

Because it took three years to survey a large portion of the study area, the original goal of a total estimate with a percent confidence interval half-width $\leq 25\%$ was not attainable. A total estimate for the number of moose in the regions surveyed during the three years represented in this analysis is only appropriate if we can assume that during the three year survey period no moose died, there was no recruitment (or deaths were equal to recruitment), and distributions remained static (i.e., no major movements between the three regions surveyed). If these assumptions could be met, which is not likely, a realized percent confidence interval half-width for total moose abundance across the areas surveyed may satisfy the goal of a half-width $\leq 25\%$. Unfortunately, higher precision in regions similar in size to the areas surveyed in 2003-04, 2004-05, and 2005-06 may be elusive for future surveys if the number of moose observations remains low and there continues to be substantial variation between transects.

Estimates were corrected for perception, or visibility, bias (moose in the survey strip at the time of flight that were potentially visible to the observers but were not seen) but not

for availability bias at the minimum available sighting distance (moose that were close to the minimum available sighting distance at the time of flight but were totally concealed by obstacles such as downed trees or heavy canopy cover), so final estimates should be considered conservative. Under the double-count methodology, the estimate of the probability of detection at the minimum available sighting distance by the rear seat observer is based on the assumption that moose groups detected by the front left seat observer are a random sample of moose available to be seen. If this assumption is not met, then estimates should be viewed with caution. However, given consistency in survey methods and areas surveyed, even biased estimates can be used to accurately estimate changes over time and detect trends with high statistical power.

Although the 90% confidence intervals for the 1983 and 2005 estimates of moose abundance within the comparison area do not overlap, indicating that there is a statistically significant difference at the $\alpha = 0.1$ level, we believe the 90% confidence interval for the 1983 estimate is probably too small. If we used the confidence interval half-width for the 2005 estimate (35%) and applied it to the 1983 estimate, the confidence intervals would overlap (1983 confidence interval from 620 to 1289), indicating there is not a statistically significant difference. This underscores the uncertainty in our comparison due to the lack of historical data and thus our inability to calculate a standard confidence interval based on the Gasaway protocol (Gasaway et al. 1986), and the arbitrariness of an *a priori* significance level. Note that if the sizes of each Gasaway survey unit were known or could be estimated, this would allow us to calculate a 90% confidence interval using standard methods.

The Gasaway technique (Gasaway et al. 1986) and other plot-based methods such as strip counts have been used for estimating abundance of moose and other large mammals. These methods may be more appropriate than line transect sampling for dense populations in smaller study areas (Buckland et al. 2001). However, these methods are known to be expensive and time consuming when the population is sparsely distributed over a large area (Ward et al. 2000, Borchers et al. 2002). The key to obtaining unbiased estimates of animal abundance using plot sampling involves the assumption that all

animals within the plot or strip are detected, or that a sightability correction factor (SCF) can be estimated without bias. Under the Gasaway protocol (Gasaway et al. 1986), a sightability correction factor is estimated by intensively sampling some areas just previously sampled using the standard protocol, and using the ratio of counts from the intensive effort over the standard effort as the SCF. Search effort and observer skill in plot-based surveys largely determines sightability, so if multiple observers are used on a Gasaway type survey, each observer should be used to estimate one or several SCFs, as there can be large differences in observer skill and experience. However, it is not clear how the reported SCF of 1.07 was obtained. This SCF may simply be an average seen over several surveys in other regions. If this SCF is biased low, there could be a larger difference in moose abundance between 1983 and 2005 within the comparison area.

There remains 1,977 km² of the medium/high density stratum yet to be surveyed (Figure 13). In the event this region is surveyed for moose, we recommend using the same protocol and observers used in past surveys for consistency and to allow pooling of data for estimating detection probabilities. If APBNWR wishes to monitor moose abundance for trend, the same transects flown in 2003-04 through 2005-06 winters should be re-flown following the same protocol to ensure adequate statistical power to detect trends over time.

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Table 1. Angles corresponding to distance zones to the nearest 1/2 degree, for above ground level flight of 400 feet.

Zone	Distance Zone	Midpoint	Angle Ranges
0	0 - 45 m	22.5	70.0 – 90.0
1	46 - 100 m	73	50.5 – 70.0
2	101 - 165 m	133	36.5 – 50.5
3	166 - 240 m	203	27.0 – 36.5
4	241 - 320 m	280.5	20.0 – 27.0
5	321 - 400 m	360.5	17.0 – 20.0
6	> 400 m	na	< 17.0

Table 2. Number of moose groups, total moose, and total calves observed by at least 1 of the 3 observers while surveying medium/high density transects in each of the winter surveys.

Year	# Groups	Total Moose	Total Calves
2003-04	61	135	5
2004-05	39	92	1
2005-06	30	57	6
<i>Total</i>	130	284	12

Table 3. Number of moose groups seen by the front left observer (recorder) and that were seen by the rear left observer within 357 m of the transect line, along with the percent of these detections by the rear left observer.

Distance (m)	Recorder	Rear Left	% Rear Left
45 - 90	10	10	100%
91 - 150	14	13	93%
151 - 250	14	13	93%
251 - 357	5	1	20%
total	43	37	86%

Table 4. AICc values of logistic regression models estimating detection of moose groups on or near the transect line by the rear seat observer.

Model	-2log(L)	k	n	AICc
<i>distance</i>	29.41	2	45	33.69
<i>distance + group size</i>	28.78	3	45	35.97

Table 5. AICc values for each detection function fit using the program DISTANCE, along with AICc weights and estimates of $\hat{P}$.

Key Function	Expansion	# Expansion Terms (AICc Stepwise Selection)	AICc	AICc Weight	P
Uniform	Cosine	1	1245.14	0.440	0.622
Half-normal	Hermite Polynomial	0	1245.48	0.371	0.644
Uniform	Simple Polynomial	2	1246.83	0.189	0.625
weighted average					0.631

Table 6. Estimates, standard errors (SE), and 90% confidence intervals

for moose density and the total number of moose in the medium/high stratum for each area surveyed.

	Estimate		
	2003-04 area	2004-05 area	2005-06 area
<u>Values without FPC</u>			
Moose density (#/km ²)	0.323	0.266	0.227
SE(density)	0.055	0.050	0.064
90% CI Lower Limit (density)	0.233	0.184	0.122
90% CI Upper Limit (density)	0.413	0.348	0.332
% Relative Half-width	28%	31%	46%
Total Moose	1039	570	479
SE(total)	180	107	134
90% CI Lower Limit (total)	744	395	259
90% CI Upper Limit (total)	1334	745	699
% Relative Half-width	28%	31%	46%
<u>Values with FPC</u>			
Moose density (#/km ²)	0.323	0.266	0.227
SE(density)	0.050	0.045	0.059
90% CI Lower Limit (density)	0.241	0.193	0.131
90% CI Upper Limit (density)	0.405	0.339	0.323
% Relative Half-width	25%	27%	42%
Total Moose	1039	570	479
SE(total)	163	95	123
90% CI Lower Limit (total)	771	414	277
90% CI Upper Limit (total)	1307	726	681
% Relative Half-width	26%	27%	42%

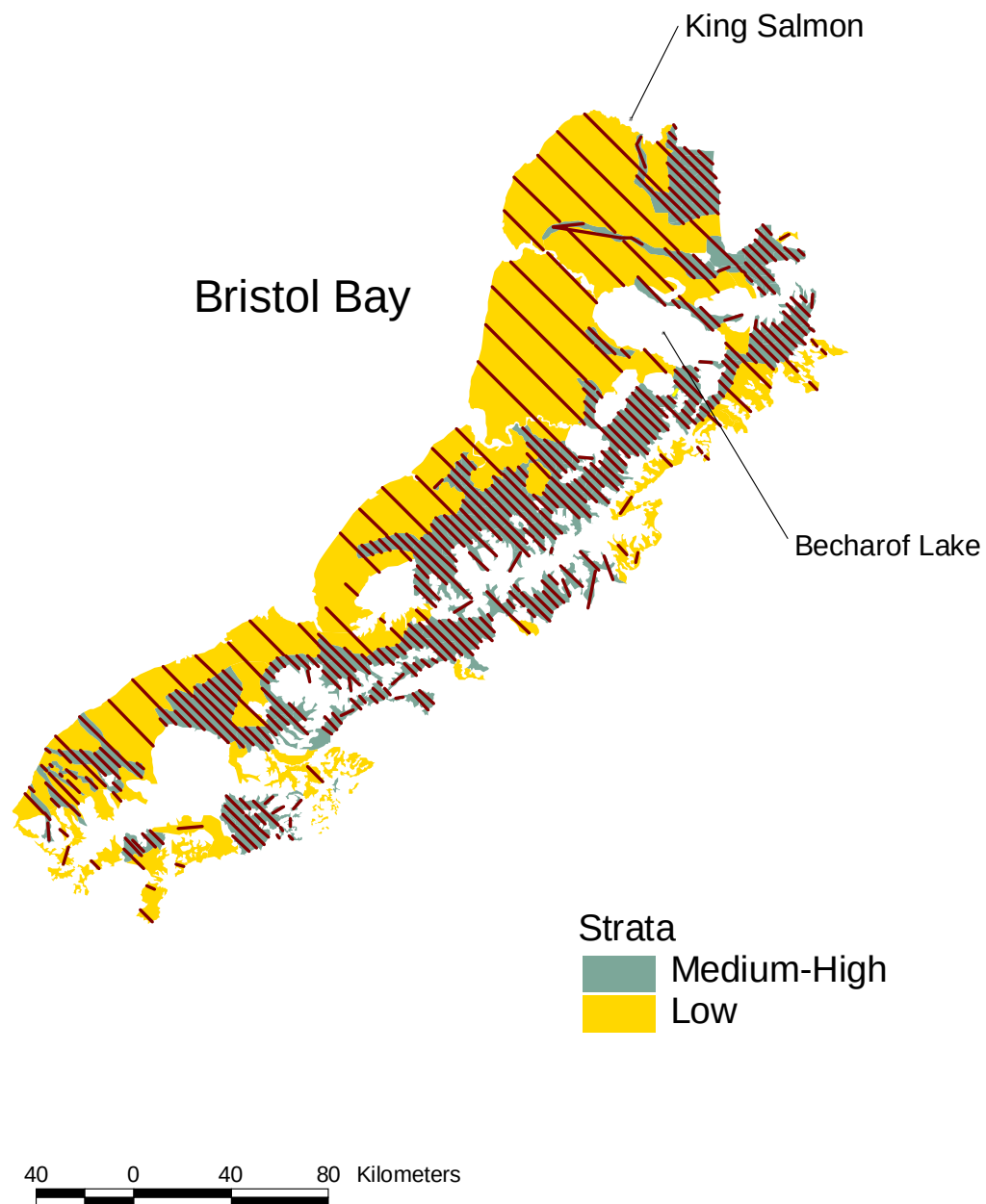


Figure 1. Initial study area containing most Alaska Peninsula/Becharof National Wildlife Refuges and adjacent state owned lands, including strata boundaries and proposed transects.

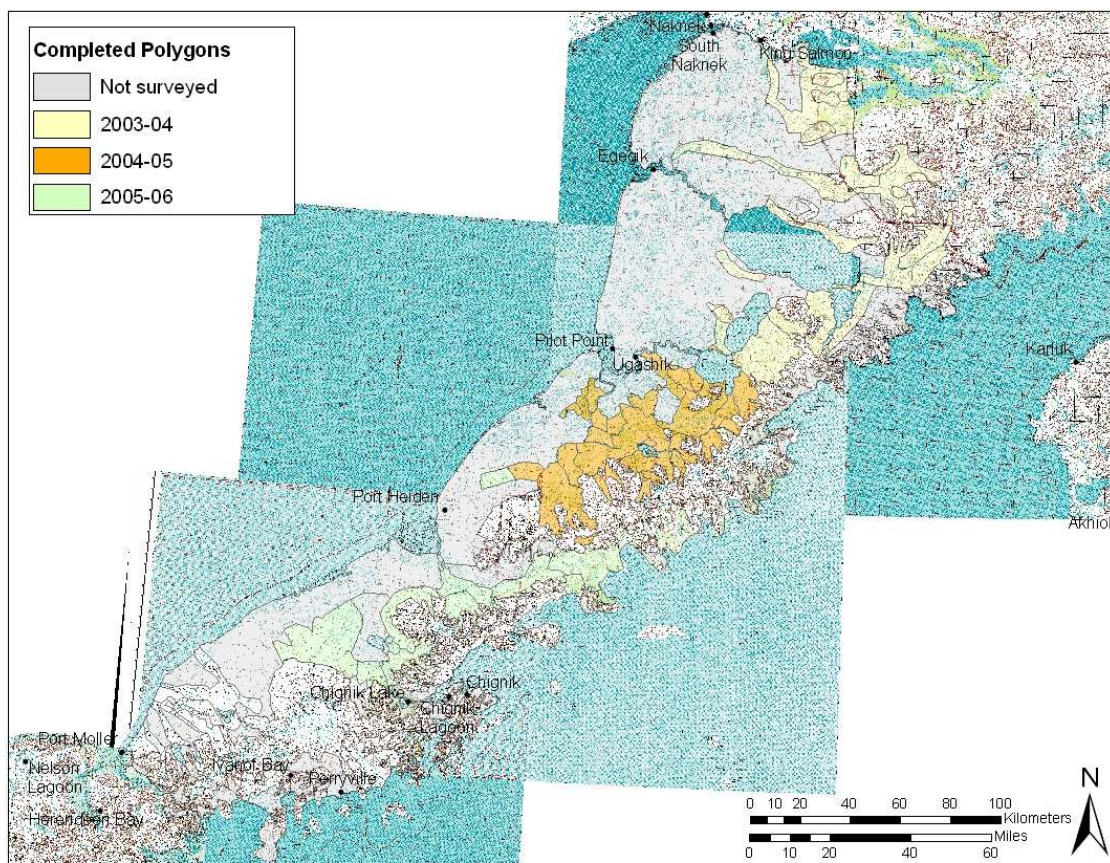


Figure 2. Areas surveyed in 2003-04, 2004-05, and 2005-06 winters.

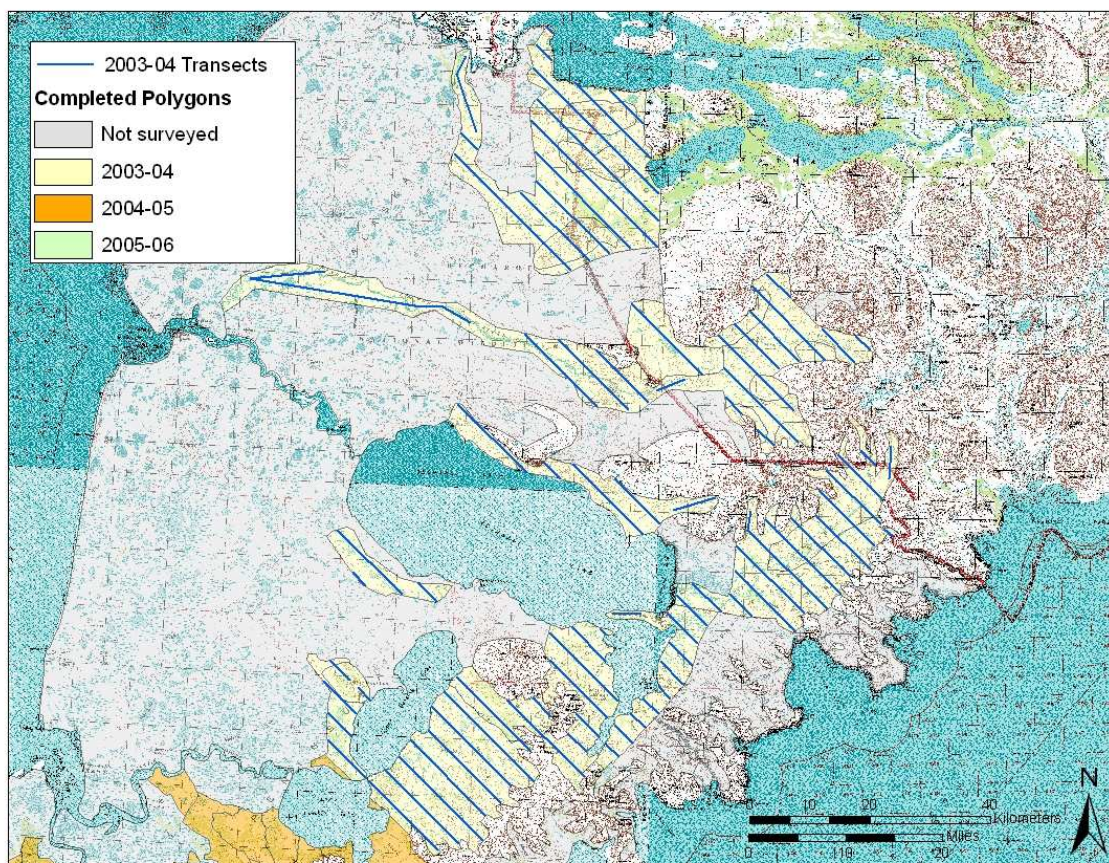


Figure 3. Transects flown in Medium/High density stratum in 2003-04.

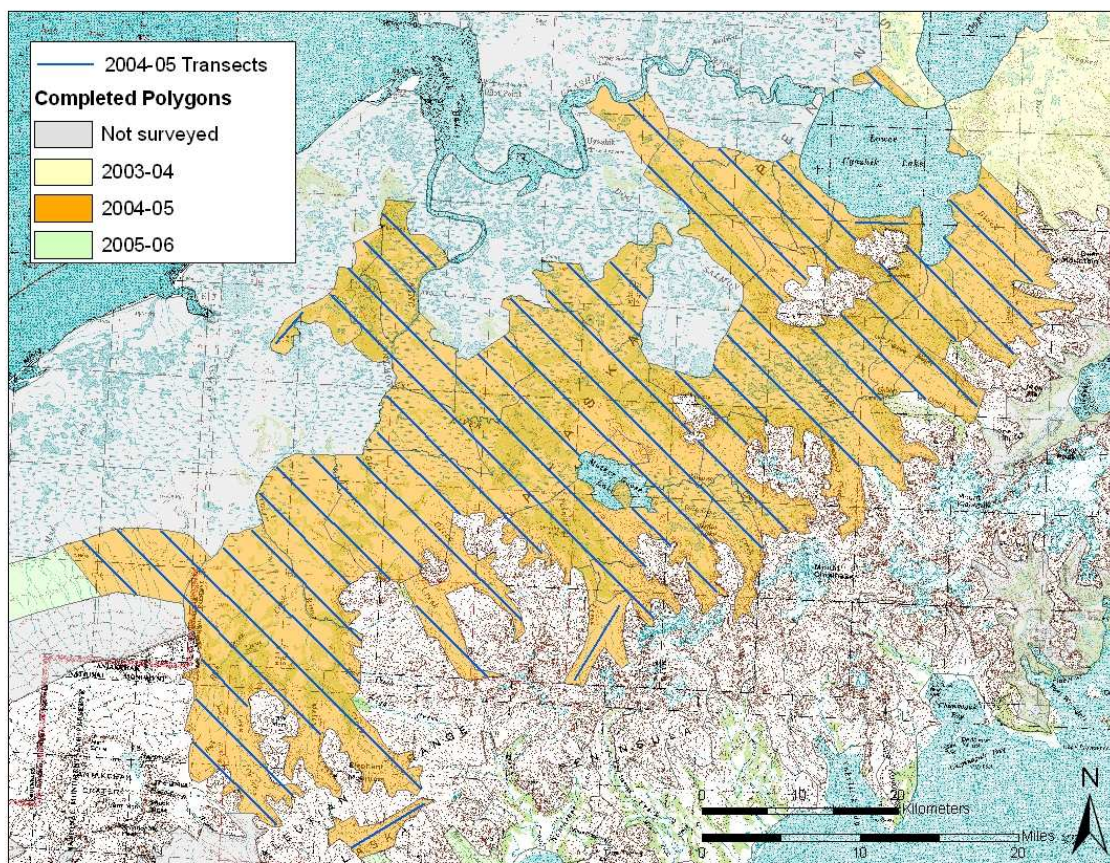


Figure 4. Transects flown in Medium/High density stratum in 2004-05.

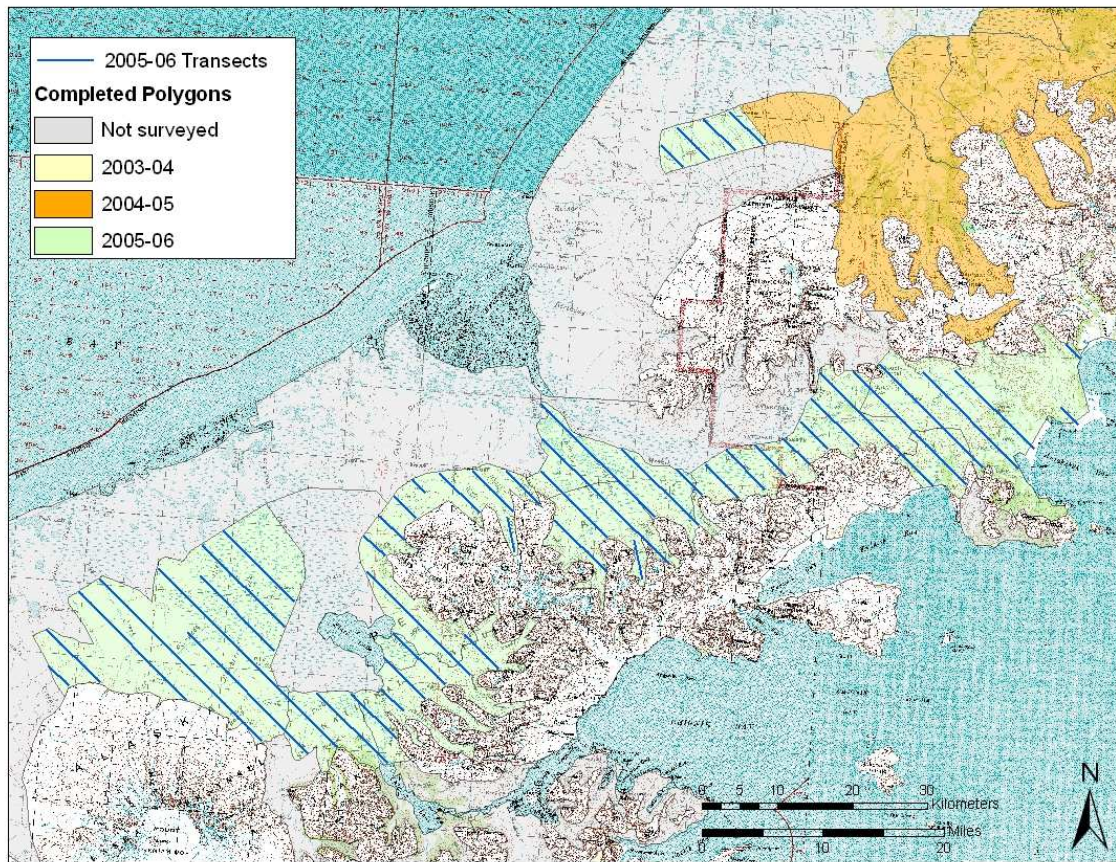


Figure 5. Transects flown in Medium/High density stratum in 2005-06.

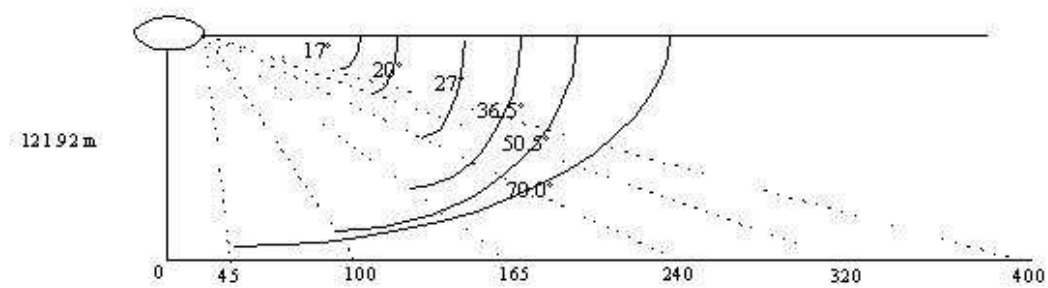


Figure 6. Distance bands marked on window for backup in case the laser range finders failed, and for estimating the minimum available sighting distance.

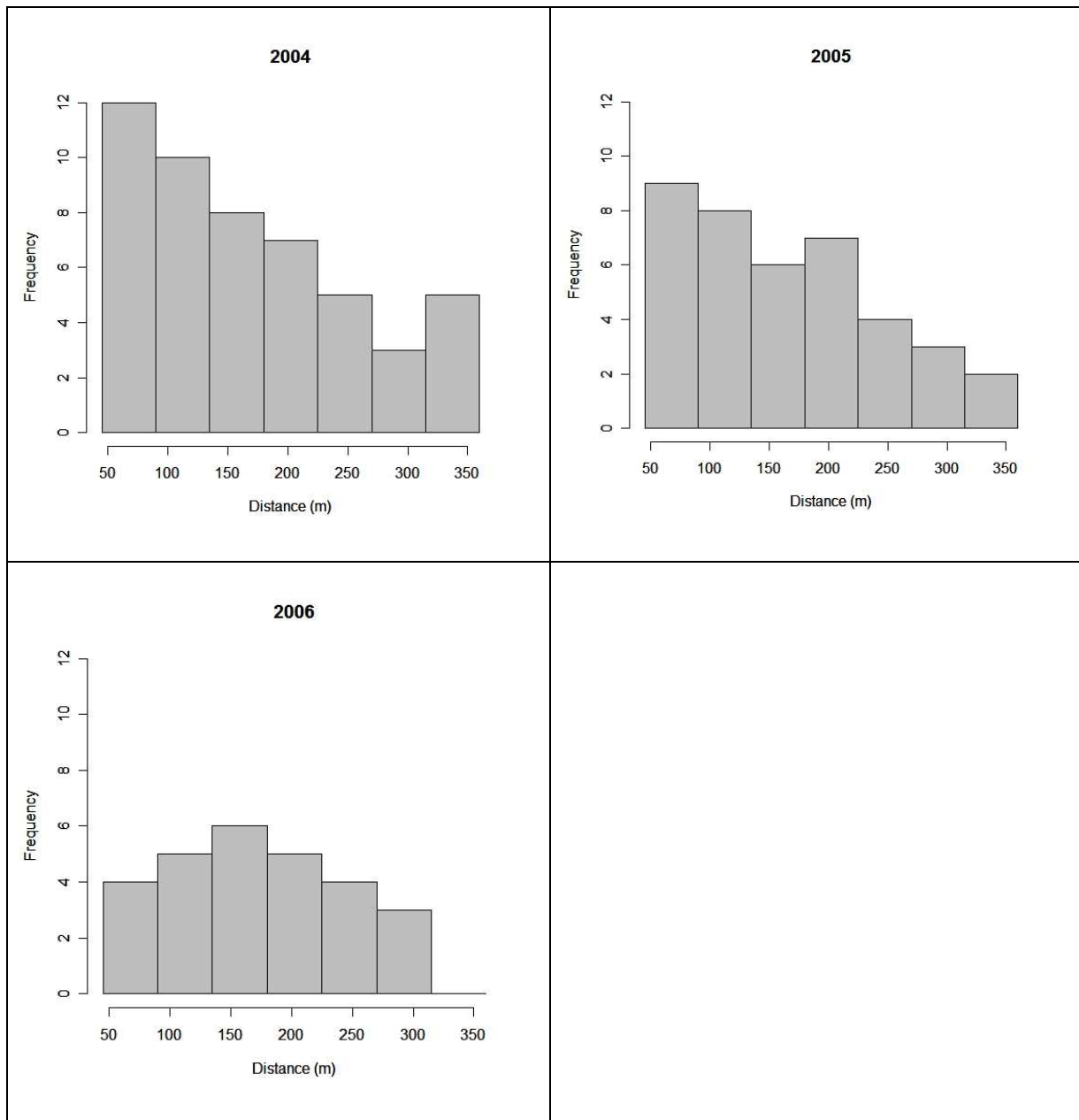


Figure 7. Histogram of perpendicular distances of observed moose groups from the transect line within 357 m of the transect during each winter.

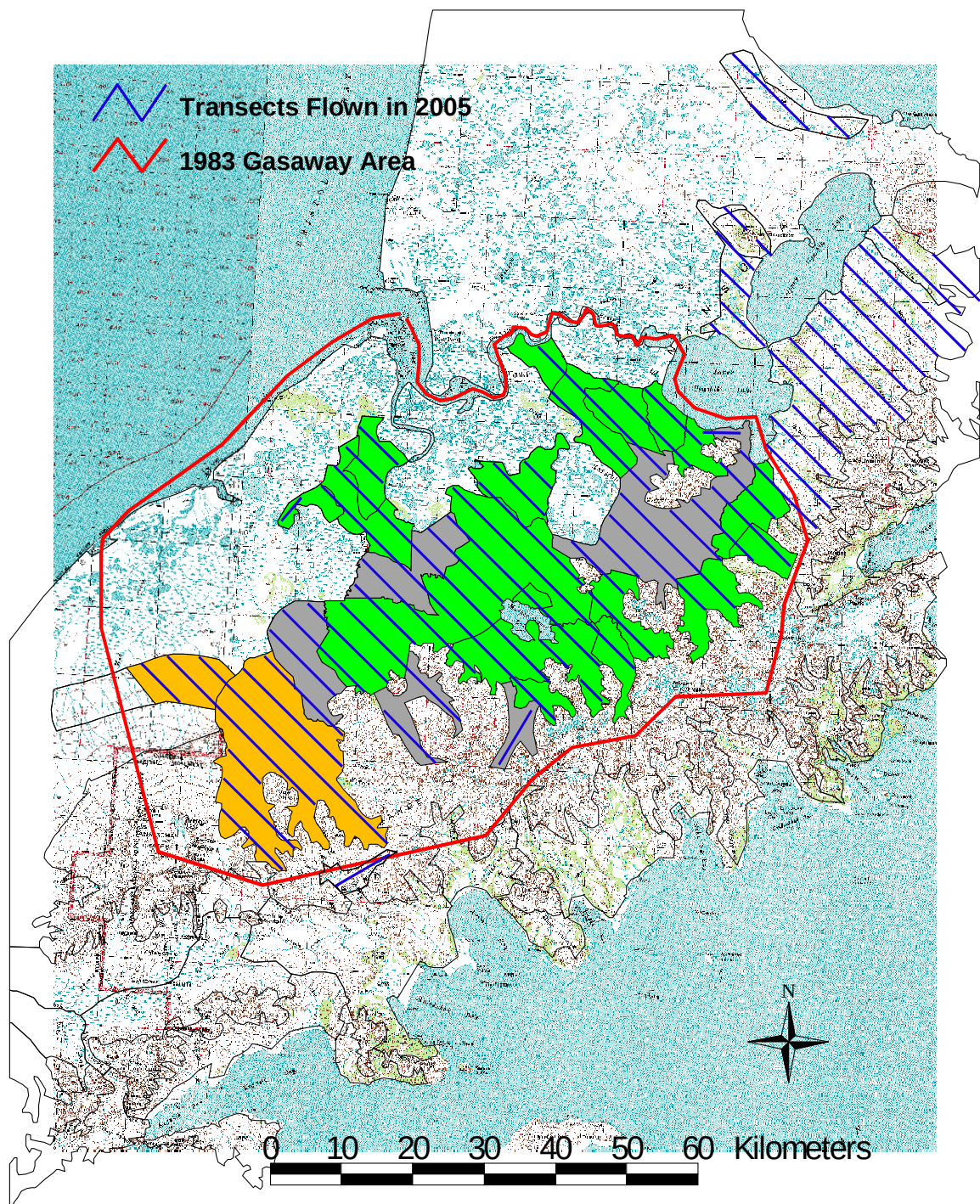


Figure 8. Boundary for 1983 Gasaway survey (red line), and areas surveyed in 2005 that were in the 1983 Gasaway Medium and high density survey units (green), low density survey units (gray), and unknown (orange).

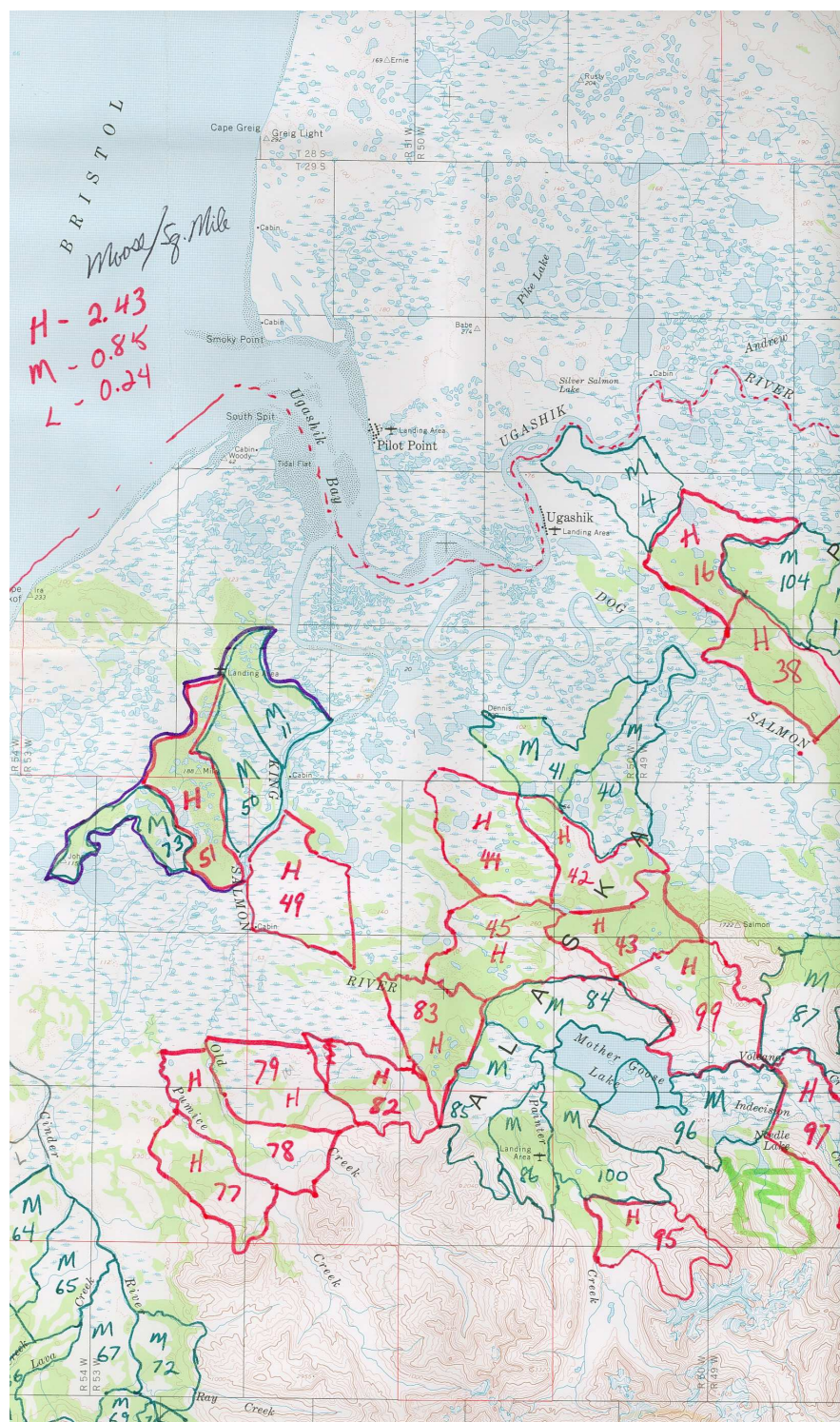


Figure 9. Medium and high strata survey units from the 1983 Gasaway survey.

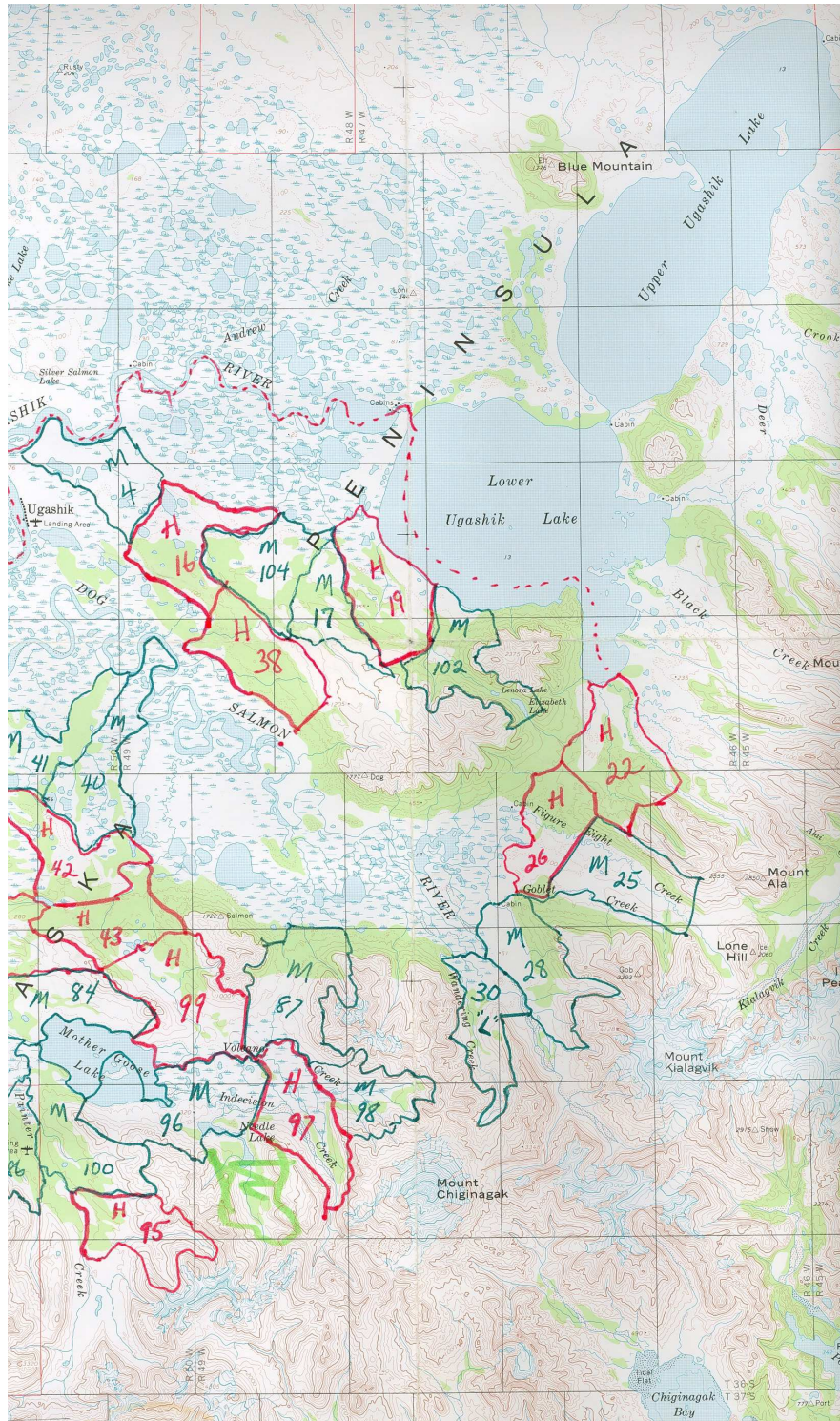


Figure 10. Medium and high strata survey units from the 1983 Gasaway survey.

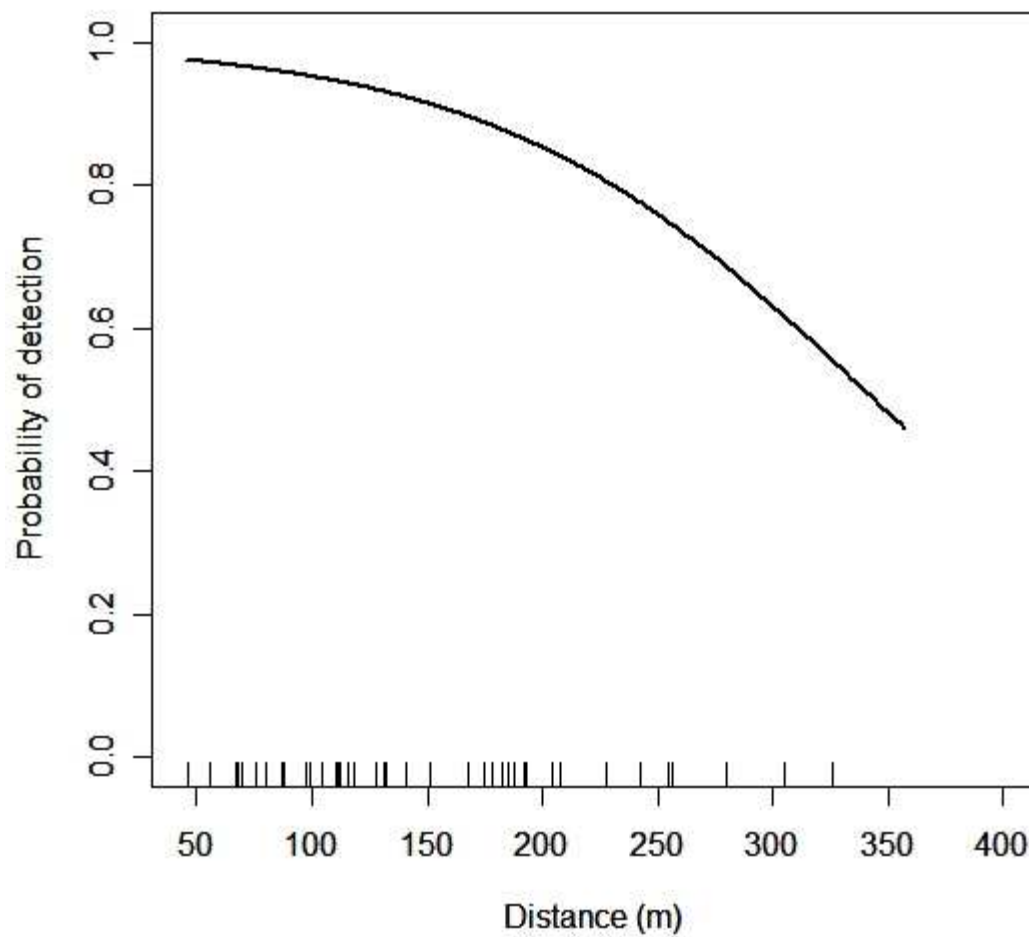


Figure 11. Probability of detection by the rear left seat observer, given detection by the front left seat observer, based on double-observer trails. Tick marks on top of the x-axis represent observations. The estimated probability of detection at 45 m = $\hat{g}(45) = 0.974$.

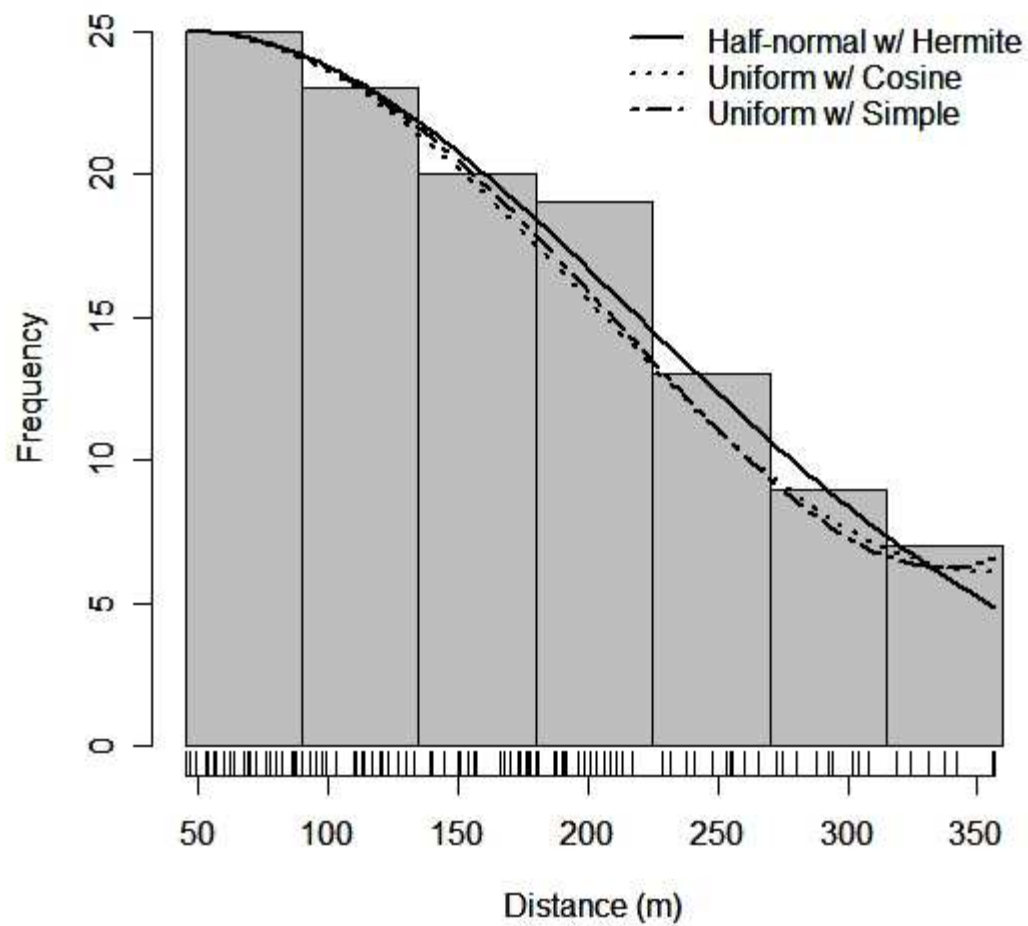


Figure 12. Detection functions fit using the program DISTANCE, assuming probability of detection at the minimum available sighting distance is known. Tick marks on top of the x-axis represent observations.

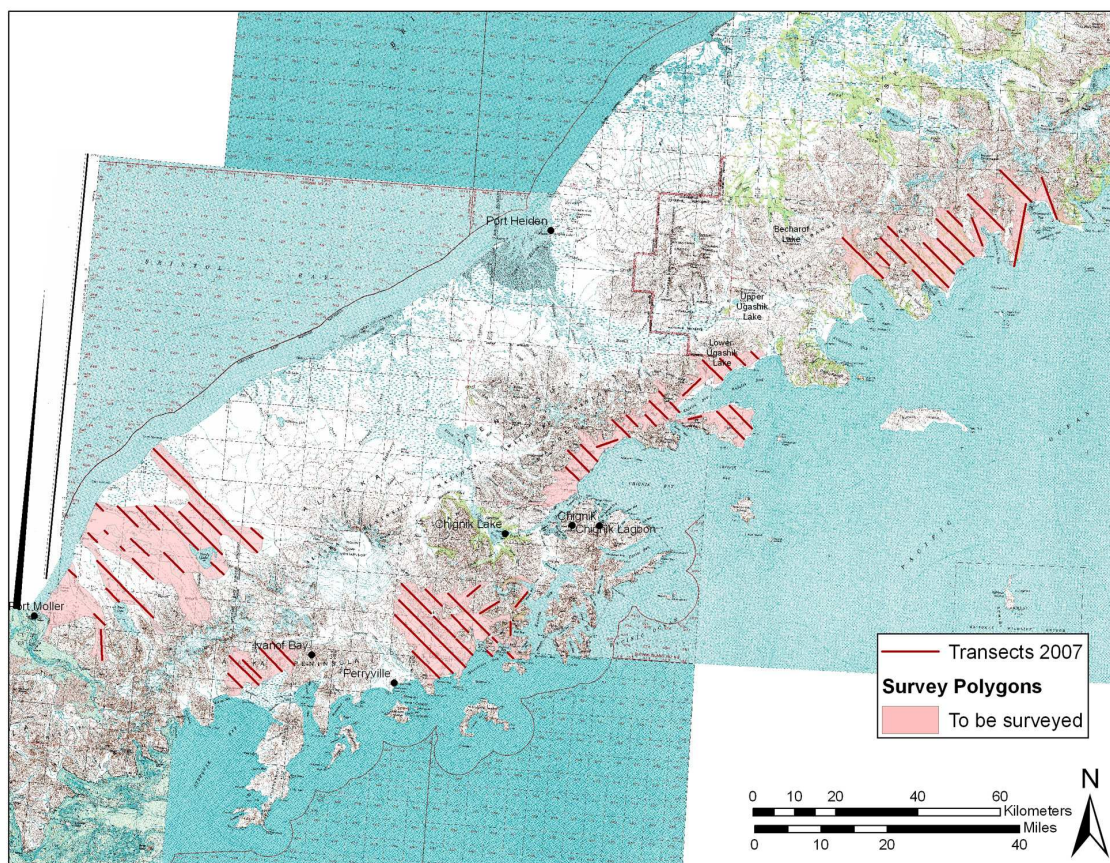


Figure 13. Line transects yet to be surveyed in the medium/high density stratum.