USING DISTANCE SAMPLING TO ESTIMATE MUSKOXEN ABUNDANCE ON THE SEWARD PENINSULA, ALASKA

Joshua H. Schmidt
Central Alaska Network
National Park Service
4175 Geist Road
Fairbanks, AK 99709
Joshua_schmidt@nps.gov

Tony S. Gorn
Alaska Department of Fish and Game
Pouch 1148
Nome, AK 99762
tony.gorn@alaska.gov

Charlotte Westing
Alaska Department of Fish and Game
Pouch 689
Kotzebue, AK 99752
charlotte.westing@alaska.gov

<u>Prepared for</u>:
2010 Seward Peninsula Muskox Census Participants
Steve Machida- ADF&G Anchorage, AK
Peter Bente- ADF&G Nome, AK
Letty Hughes- ADF&G Nome, AK
Gay Sheffield- ADF&G Nome, AK
Jim Dau- ADF&G Kotzebue, AK
Lincoln Parrett- ADF&G Fairbanks, AK
Geoff Byersdorf- BLM Anchorage, AK
Brad Shults- NPS Fairbanks, AK
Marci Johnson- NPS Kotzebue, AK
Brandon Saito- FWS Kotzebue, AK
Eric Sieh- FWS Kotzebue, AK
Brad Scotton- FWS Galena, AK
Nate Olson- FWS Galena, AK
Kate Persons Nome, AK

April 27, 2010

INTRODUCTION

Historically, muskoxen populations have been monitored on the Seward Peninsula using total coverage/minimum count methods (Gorn 2007). The most recent survey using these methods was conducted in the spring of 2007 when 2766 individuals were counted in two survey areas. During this survey, 2688 muskox were found in the main portion of the survey area (west of the Buckland River), and an additional 78 muskox were located in survey units located east of the Buckland River in GMU23 (T. Gorn *pers.comm.*). In 2010, a sample survey approach was designed in conjunction with the National Park Service (NPS) to provide both a minimum count and an estimate of the total population within the survey area. The goal was to obtain a minimum count comparable to past surveys, while testing distance sampling methods as an alternative monitoring tool for this population (Gorn 2010).

Distance sampling methods have been used extensively to sample and estimate the abundance of wildlife populations (Buckland et al. 2001, 2004), although these methods have not previously been applied to muskoxen in Alaska. These methods utilize the declining relationship between distance and detection probability to estimate the density of individuals in the population, including those that were not detected during the survey. During analysis, a 'detection function' describing this decline is fit to the observed distance data and is used to estimate the portion of the population that was not detected during the survey. The density of animals estimated for the surveyed area can then be extrapolated to the entire region to provide estimates of total abundance.

There are several critical assumptions associated with distance sampling that must be met for proper inference (Buckland et al. 2001):

1) All individuals on the line (or at a specified distance from the line in the case of aerial surveys) are detected with certainty.
2) Objects are detected at their initial location.
3) Measurements are exact.
4) Detections are independent.

For aerial surveys, the assumption of perfect detection on the line is not valid because the area directly beneath the aircraft is not visible and cannot be completely surveyed. However, a distance near the transect center can often be identified where detection probability is 1, and the data can then be left-truncated to eliminate the area with incomplete detection probability. Assumptions 2 and 3 are not likely to be a problem for muskoxen surveys because this species moves little in response to aircraft, and the use of GPS greatly reduces error in distance measurements. The final assumption can be problematic if additional groups are detected while off-transect because this introduces dependence among detections. If included in analyses, this can bias estimates of detection probability high and thereby bias abundance estimates low. Clear instructions for pilots/observers to look ahead for additional groups before leaving the transect to mark a group can minimize this potential problem.

METHODS

Surveys

Surveys for muskoxen have historically covered the entire Seward Peninsula to provide a minimum count of the entire population. In 2010, additional areas including the eastern portions of GMU's 23, western 21D, and northern 22A were added in response to an expansion of the population into previously unoccupied habitat further inland. The area was divided into 17 survey units based on past survey protocols and topography. Survey units 1 through 13 corresponded to historically surveyed areas, while 14 through 17 were added in 2010 (Fig. 1). Parallel transects were drawn at 3 mile (4.8km) intervals throughout each survey unit to provide complete coverage of the entire survey area. This resulted in 341 total transects, all of which were surveyed by one of six pilot/observer teams using one of 4 types of aircraft: PA-12, PA-18, C185, and Found Bush Hawk. Pilots were instructed to maintain 1000'AGL while on transect, although this altitude did vary in more mountainous terrain and during inclement weather. The survey aircraft followed each transect using GPS equipment until a group of muskoxen was detected. After scanning ahead to check for additional groups, the aircraft left the line to mark the location of the group and count the number of individuals present. Groups first detected while off-transect were excluded from the analysis to prevent negative bias in abundance estimates. Observers were instructed to concentrate on the area in closest proximity to the aircraft to ensure detection probability approached 1.0 near the centerline. Because transects were 4.8km apart, observers generally only recorded groups observed within ~2.4km. Groups observed at distances >2.4km were recorded on the next transect, unless they had already been missed during a previous pass on that transect.

Aircraft and observer teams collected data from January 31- March 25 with most data collection occurring March 1- 25. Careful attention was placed on completing transect lines to prevent double counting groups due to small scale winter movements for the minimum count component of the survey. Snow conditions during the survey were classified as complete, excluding the last flight on March 25 when southern facing mountain slopes were incompletely covered due to spring melt. Post survey radio tracking flights occurred April 1-5 and found two groups of muskox in eastern Unit 22B missed during the survey.

Analysis

Distances to each observed group were measured using ArcMap 9.3.1. Appropriate detection functions for these data were then identified using program Distance 6.0 (Thomas et al. 2009) which allows the user to compare several detection functions using Akaike's Information Criterion (AIC) and select the best approximating model for the detection process. Histograms of the observed data produced in Distance can also be used to assess the validity of critical assumptions. Because the width of the obstructed strip beneath the aircraft was unknown, we used these tools to select a left-truncation distance to eliminate the portion of the transect where detection probability was <1.0. The data were right truncated at 2.4km because observers typically did not search past that distance and the few observations at greater distances contributed little information.

We re-fit the best approximating model (identified using program Distance) in a Bayesian framework using R (R Development Core Team 2009) and WinBUGS (Spiegelhalter et al. 2004), which also allowed us to include spatially autocorrelated random effects on the probability of presence on each transect. The inclusion of this term helped to account for variables such as habitat suitability and quality that were not available for the entire survey area, and using the autocorrelation among adjacent transects helped estimate local abundances more accurately. We also included transect length as a covariate based on the assumption that longer transects would have a higher probability of muskoxen presence due to the additional area surveyed. We did not include covariates for detection probability (e.g. weather, snow cover, pilot/observer), although this could be done in the future. Estimates for each GMU hunt unit (Fig. 2) were produced by weighting the abundance estimate for each individual transect by the proportion of that transect that was within the hunt unit.

RESULTS

Based on a visual inspection of a plot of the observed distances, it appeared that detection probability was <1.0 until ~500m from the transect line (Fig. 3); therefore the data were left-truncated at 500m. After both left and right truncation of the data, the best fitting detection function was the half-normal with no adjustment terms (Fig. 4). We also investigated the hazard-rate detection function, but it was not selected based on AIC (ΔAIC=1.1). Using the half-normal detection function, the Bayesian estimate of the total number of muskoxen in the survey area was 3434 (95% CI: 2937 to 4048) with 3120 (95% CI: 2669 to 3692) in the historically surveyed area and 296 (95% CI: 227 to 391) in the area east of the Peninsula. For comparison, the estimate of the total population calculated using program Distance was 3307 (95% CI: 2399 to 4558). The much smaller credible interval for the Bayesian estimate as compared to the estimate from Distance can be primarily attributed to the use of a model-based vs. the design-based variance estimator as well as accounting for spatial autocorrelation through the inclusion of a spatial covariate. Abundance estimates for individual hunt units were less precise, but CV's were ≤20% in all but one area that contained few individuals (Table 1). Estimates based on the hazard rate model were very similar, showing no indication that the selection of the half-normal detection function influenced estimates. There was also little evidence that the detection process differed between aircraft types (Fig. 5), although sample sizes for each type were relatively low.

DISCUSSION

Our results suggest that distance sampling surveys are an effective alternative for estimating muskoxen abundance on the Seward Peninsula. Point estimates for the historical survey area were approximately 18% higher than those based on the minimum count suggesting that a portion of the population is consistently missed during aerial surveys. The 95% credible interval around this estimate was very precise (CV ~8.5%) and did not include the minimum count indicating little chance that the minimum count reflects true population size. We also found that the strip under the aircraft with imperfect detection probability was much wider than expected. Based on our data it appears that a strip ~1km wide (500m on each side) beneath the aircraft is only partially observed during aerial muskoxen surveys. This may have implications for future minimum count surveys that generally assume complete detection.

We initially suspected that differences in aircraft configuration alone might explain the 500m zone of imperfect detection on each side of the transect, but plots of observation distances did not appear dramatically different between Super Cub vs. C185 aircraft. Pilots and observers generally recorded twice as many groups in each distance category >500m than they did in categories <500m regardless of aircraft type. We found this somewhat surprising because we expected the C185 to have reduced visibility compared to the Super Cub, and we suspect that several other factors may have played a larger role in reducing detections close to the transect line. First, some groups are sure to be missed because the area directly beneath the plane is not visible most of the time, so only a few groups are likely to be detected at very short distances. Also, the 1000'AGL requirement was difficult to follow in some circumstances, especially in mountainous terrain or poor survey weather. This would result in a constantly changing strip near the aircraft with lower visibility that may have extended out to 500m. Another possibility is that observers may have failed to scan the terrain closest to the plane as intensively as other areas, resulting in more detections at further distances. Taken together, these issues likely lowered detection probabilities out to 500m. We have no reason to suspect that muskoxen densities were consistently lower near the lines because transects were generated systematically throughout the survey area. Future survey improvements might include: additional training for observers, consistent aircraft type, and contour transects in mountainous terrain to help increase detection probabilities near the transect line.

We are confident that left-truncating the data at 500m was a valid solution to incomplete detection at the shortest distances because muskoxen are extremely visible at that distance and historic field data suggest that detection probability is very high (Gorn *pers. comm.*). Detection probability also remained high out to the edge of the searched strip, supporting the assumption that groups at shorter distances are highly detectable. The right truncation distance was fixed prior to the survey because the survey was designed to collect distance sampling information while completing a valid minimum count for direct comparison to historical survey data. This required a transect spacing of ≤3miles to ensure full coverage for the minimum count. The high detection probabilities out to 2500m and the slow decline in detection probability with distance suggests that muskoxen would likely be visible over much larger distances under favorable conditions (i.e. flat or rolling terrain, good lighting, complete snow cover). Based on this, we suspect that future distance sampling surveys could probably produce useful total population and individual GMU hunt unit estimates with 50-75% of the effort used for this project. In areas with high hunting pressure, additional surveys could be conducted to improve local estimates if necessary.

Even with only one year of data, abundance estimates for most hunt units were quite precise for most hunt areas (CV<20%), and we expect this to improve through time as additional data are collected. These estimates include some accounting for animals on the borders between units by attributing a portion to each unit if a transect crosses between them. For example, if 50% of a transect crossed through each of two units, and 30 muskox were estimated to be present on that line, 15 would be attributed to each unit. This aspect of the analysis partially averages estimates for adjacent units, especially those with groups observed near the borders, and likely provides more stable estimates of abundance on average. The degree to which this affects individual hunt unit estimates depends on the number of transects that overlap adjacent units and the locations of observed groups.

Future surveys and analyses could also begin to include covariates that are expected to affect detection probability. We did not attempt to include covariates in this analysis due to a relatively small sample size, but as additional data are collected it may be possible to estimate the effects of weather, snow conditions, aircraft type, observer, or other factors on detection probability. This would improve the accuracy of population estimates and would reduce the effects of annual variation caused by differences in survey conditions or observers between years. One of the benefits of the analytical approach that we used is that estimates should continue to improve through time as additional data are collected. Distance information from past years can be used to help estimate detection probability and the effect of covariates on detection. By pooling data across surveys, the amount of information available for estimating the detection function continually increases, thereby increasing the precision of smaller scale estimates, either temporally or spatially.

The introduction of a new survey technique often raises the question of how to interpret the results in relation to past surveys. Muskoxen populations have been increasing for many years, but there is some evidence that this trend is slowing (Fig. 6) and harvest success rates have recently increased (Fig. 7). The minimum count for 2010 was slightly lower than the count from 2007, although survey methods differed, perhaps explaining some of this difference. Some quick calculations can be made to help compare the new distance estimates with past minimum counts. For example, during the 2007 survey ~2700 individuals were counted on the Seward Peninsula. If 10-20% were missed, the true population would have been between 2970-3240 in 2007, right around the current population point estimate. If the population continued to grow at 5-7% annually, detection probability for the 2010 minimum count would have to have been dramatically lower than in the past for only 2409 animals to be counted. This seems highly unlikely. Although the current estimate based on distance sampling does contain uncertainty, it suggests that population growth for the Seward Peninsula portion of the population is continuing to slow, and emigration from historical Seward Peninsula muskox range is occurring in areas eastward previously unoccupied by muskox, including the Nulato Hills in Unit 22A, east of the Buckland River drainage in Unit 23SW, and western portions of Unit 21D (Fig. 8). If accurate estimates of population growth rate are desired, more frequent surveys would likely be necessary.

CONCLUSIONS/RECOMMENDATIONS

This study provided strong evidence that distance sampling methods can be effective for estimating muskoxen abundance on the Seward Peninsula. Suggestions for future improvements include: contour transects in mountainous terrain, wider spacing between lines (~4-6 miles) if parallel lines are desired, consideration of random line placement or a zig-zag transect design, and >1 observer in larger aircraft (i.e. C185 and Found Bush Hawk). These changes would increase efficiency, and depending on the level of precision necessary for management, overall costs could be decreased dramatically. This may provide the opportunity to conduct surveys at a 1-2 year vs. the current 3 year interval which would greatly improve the ability to identify population trends over shorter time periods. This may be important if the population growth rate is truly slowing.

LITERATURE CITED

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers, and L. Thomas. 2004. Advanced Distance Sampling: Estimating Abundance of Biological Populations. Oxford University Press, USA.

Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers, and L. Thomas. 2001. Introduction to Distance Sampling: Estimating Abundance of Biological Populations. Oxford University Press, USA.

Gorn, T.S. 2007. Unit 22 and southwest portion of Unit 23 muskox. Pages 12-34 *in* P. Harper, editor. Muskox management report of survey and inventory activities 1 July 2004-30 June 2006. Alaska Department of Fish and Game. Project 16.0. Juneau, Alaska, USA.

Gorn, T.S. 2010. Survey techniques for the 2010 Seward Peninsula muskox census. ADFG internal memorandum, January 19, 2010. 8p.

R Development Core Team. 2009. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: http://www.R-project.org. Accessed April 9, 2010.

Spiegelhalter, D. J., A.Thomas, N. G. Best, and D. Lunn. 2004. WinBUGS Version 1.4.1. User manual. MRC (Medical Research Council) Biostatistics Unit, Cambridge, United Kingdom.

Thomas, L., J. L. Laake, E. Rexstad, S. Strindberg, F. F. C. Marques, S. T. Buckland, D. L. Borchers, D. R. Anderson, K. P. Burnham, M. L. Burt, S. L. Hedley, J. H. Pollard, J. R. B. Bishop, and T. A. Marques. 2009. Distance 6.0. Release 2. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. <http://www.ruwpa.st-and.ac.uk/distance/>

Table 1. Muskoxen abundance estimates with coefficients of variation and 95% credible intervals for individual hunt units (GMU's) throughout the Seward Peninsula

GMU	Mean	CV	2.5%	97.5%
22A	108	19%	78	156
22B East	52	36%	30	98
22B West	456	12%	369	581
22C	480	12%	390	610
22D Remainder	532	11%	440	659
22D Kuzitrin	285	12%	229	368
22D SW	137	18%	105	199
22E	1092	10%	913	1331
23 SW	193	17%	148	270
23 Out, 24	132	18%	97	188

Fig. 1. Locations of the 17 survey units and the 341 transect lines surveyed for muskox during spring 2010.

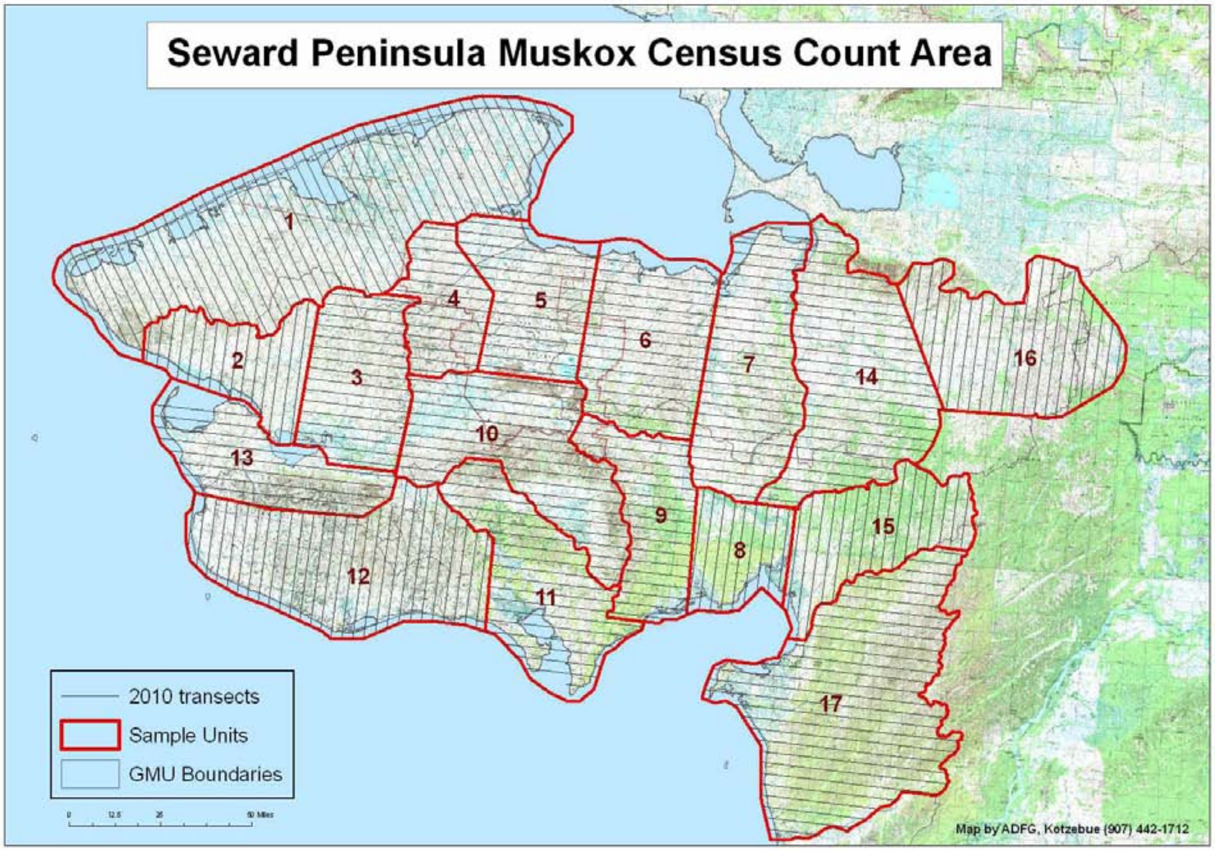


Fig. 2. Locations of the muskoxen hunt unit boundaries on the Seward Peninsula, Alaska corresponding to estimates in Table 1. There is no currently no hunting in 23 Other or 22A.

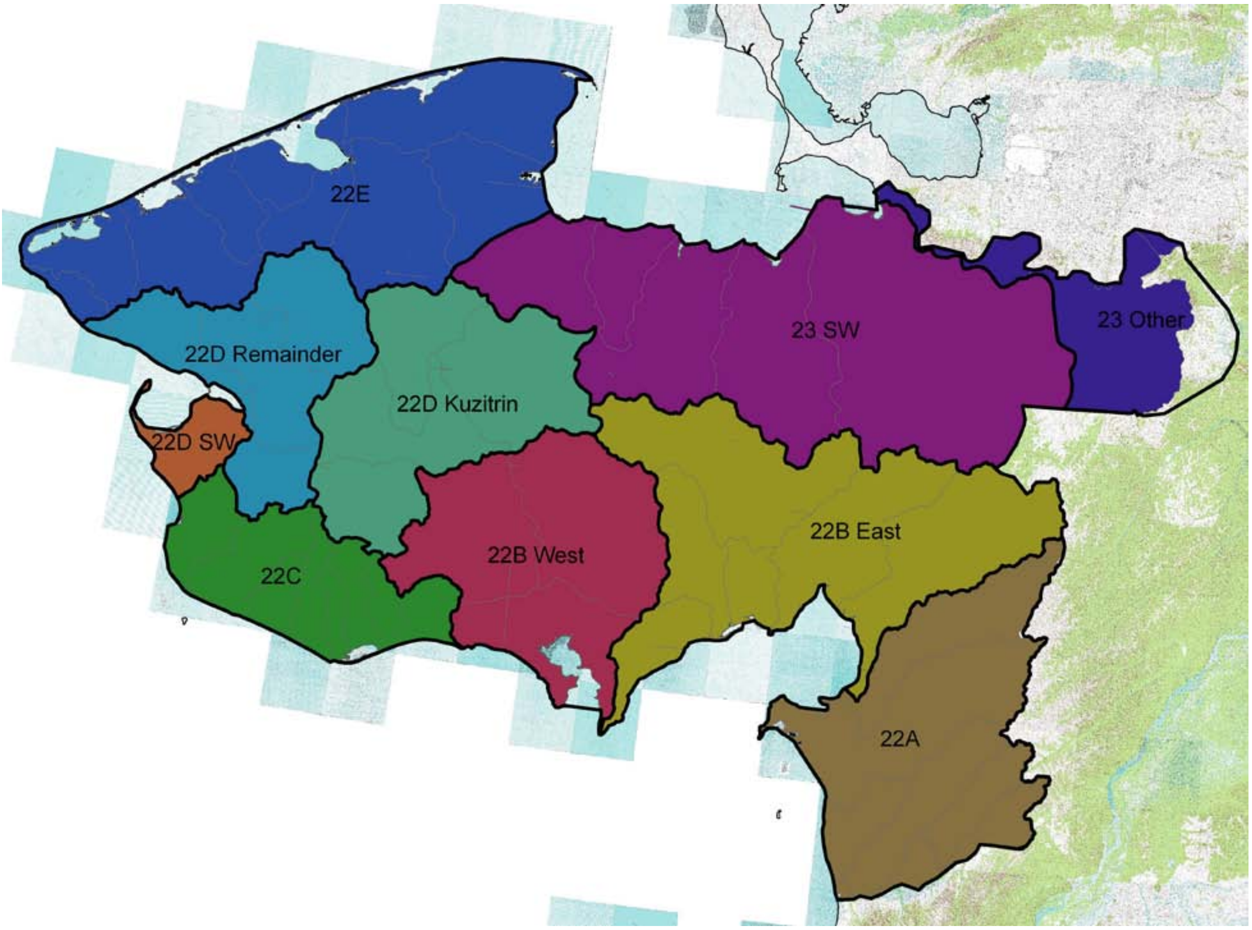


Fig. 3. Histogram of detection distances for all muskox groups observed from the transect line and recorded during the survey. Low numbers of observations at <500m indicates detection probability was likely <1.0 for these categories. Distances >2500m were rare due to proximity of adjacent transects.

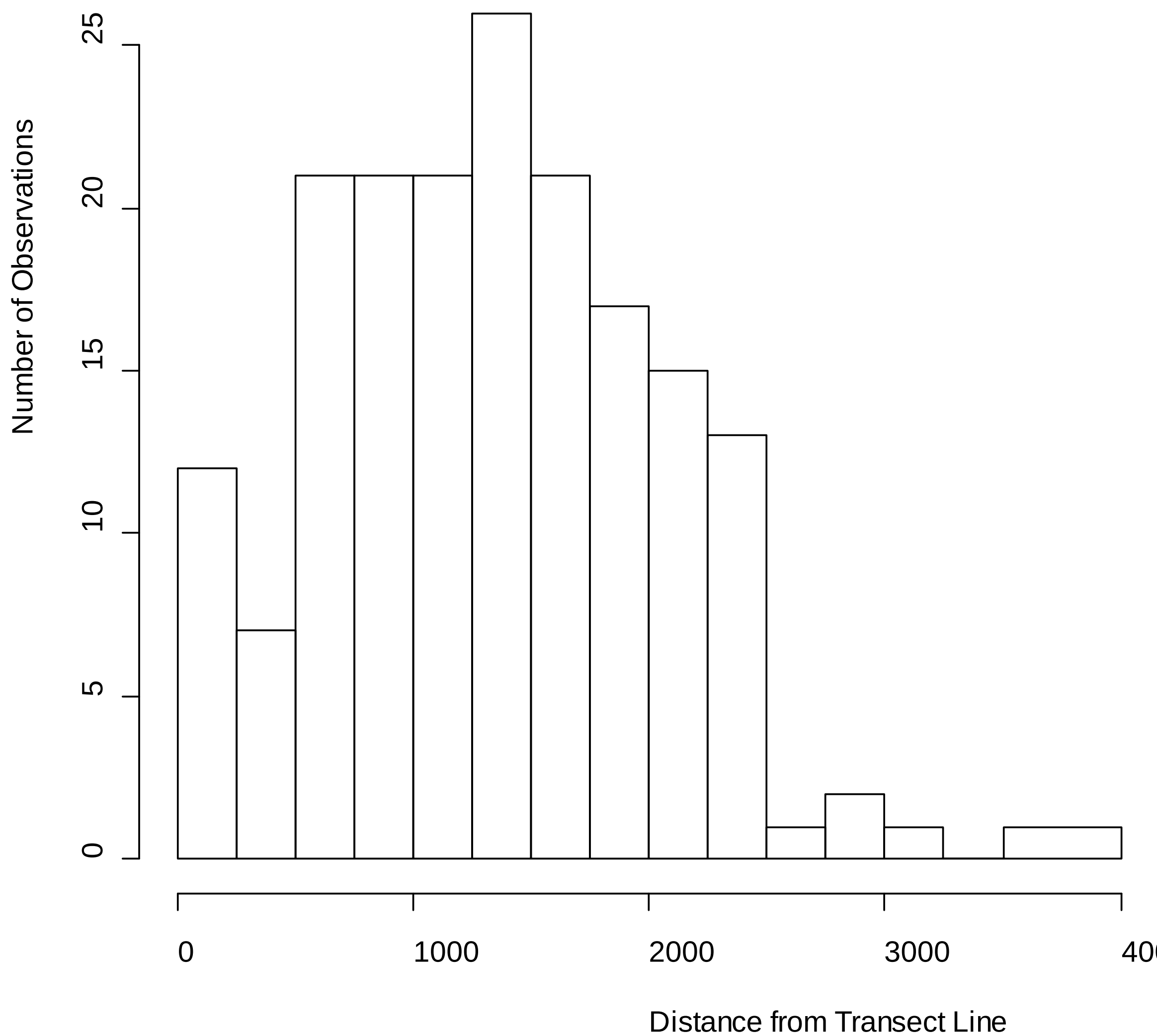


Fig. 4. Fitted half-normal detection function (red line) and the observed distance data after left-truncation at 500m and right truncation at 2500m. Distances were rescaled to the interval 0-2000m for analysis to reflect the measured distance from the point of left-truncation.

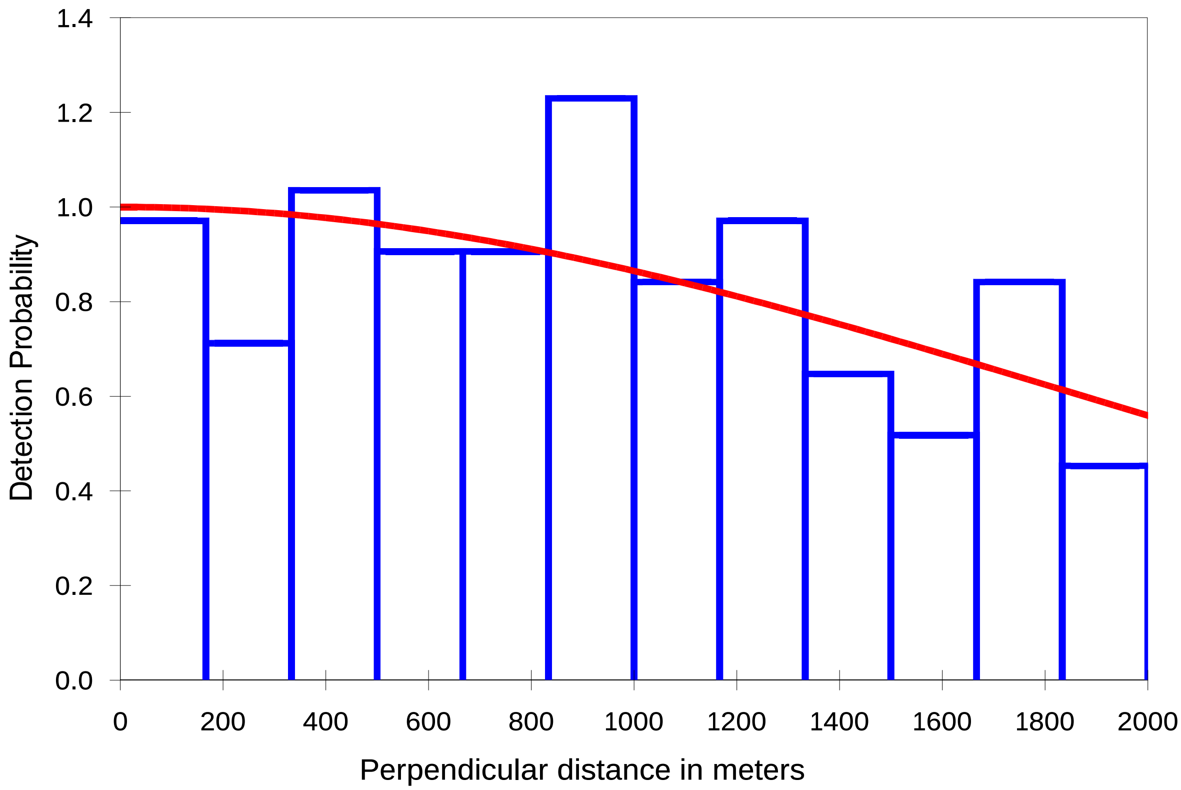


Fig. 5. Number of detections in each distance category for Super Cub (A) vs. C185 (B) aircraft.

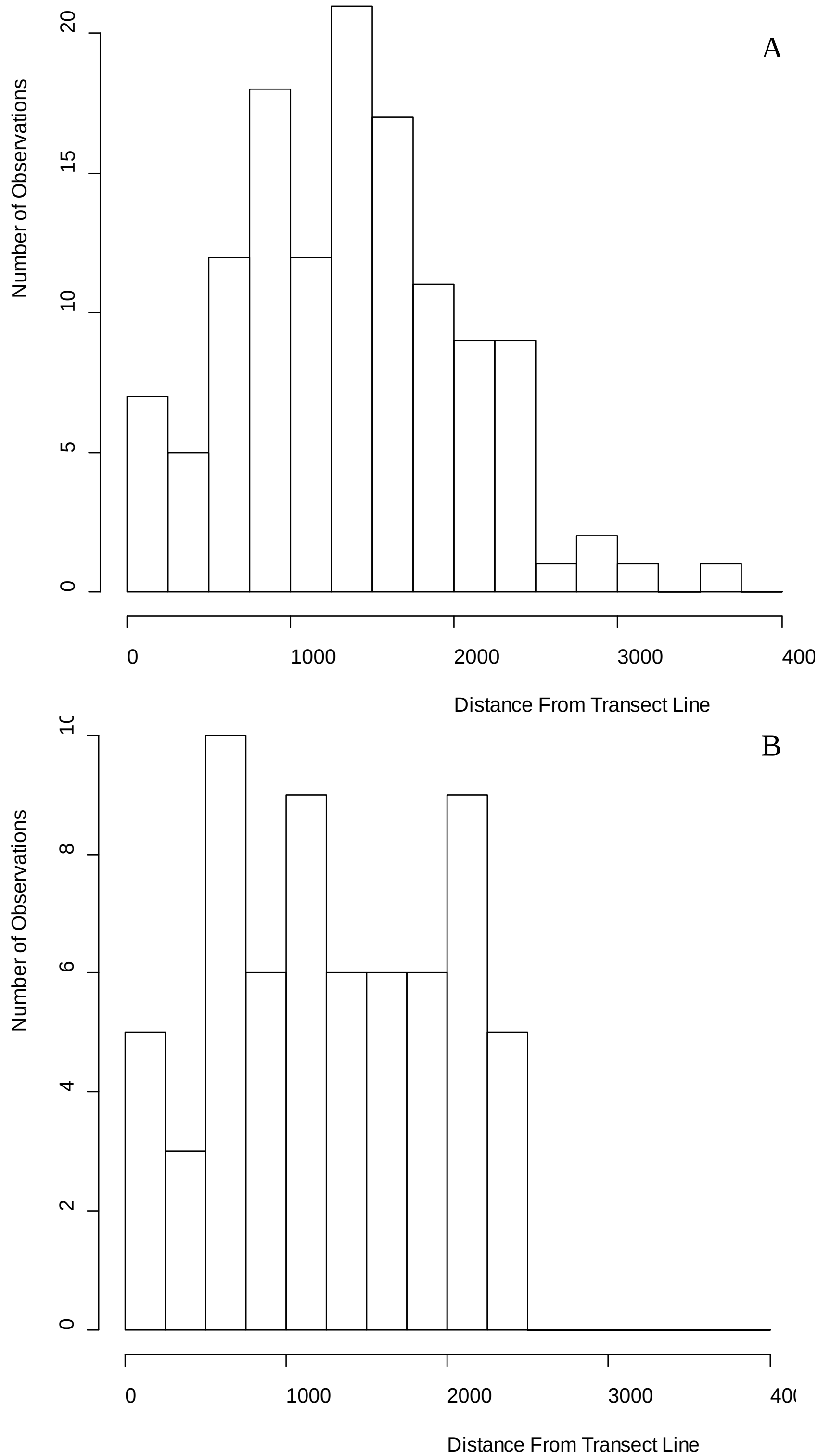


Fig. 6. Results of Seward Peninsula Muskox Counts completed from 1970-2010. Minimum count surveys found 14% annual growth from 1970-2002, and approximately 6% annual growth between 2002-2007. The 2010 count utilized a line transect distance sampling approach. Surveys completed from 1970-2007 used a direct minimum count technique with no strict protocol on data collection, however the 2010 direct minimum count technique required 3 mile spacing of line transects. For this reason, results from the 1970-2007 and 2010 minimum count surveys are not directly comparable. The transparent bar for 2010 shows the line distance sample survey approach estimate and is not directly comparable to survey efforts completed 1970-2007.

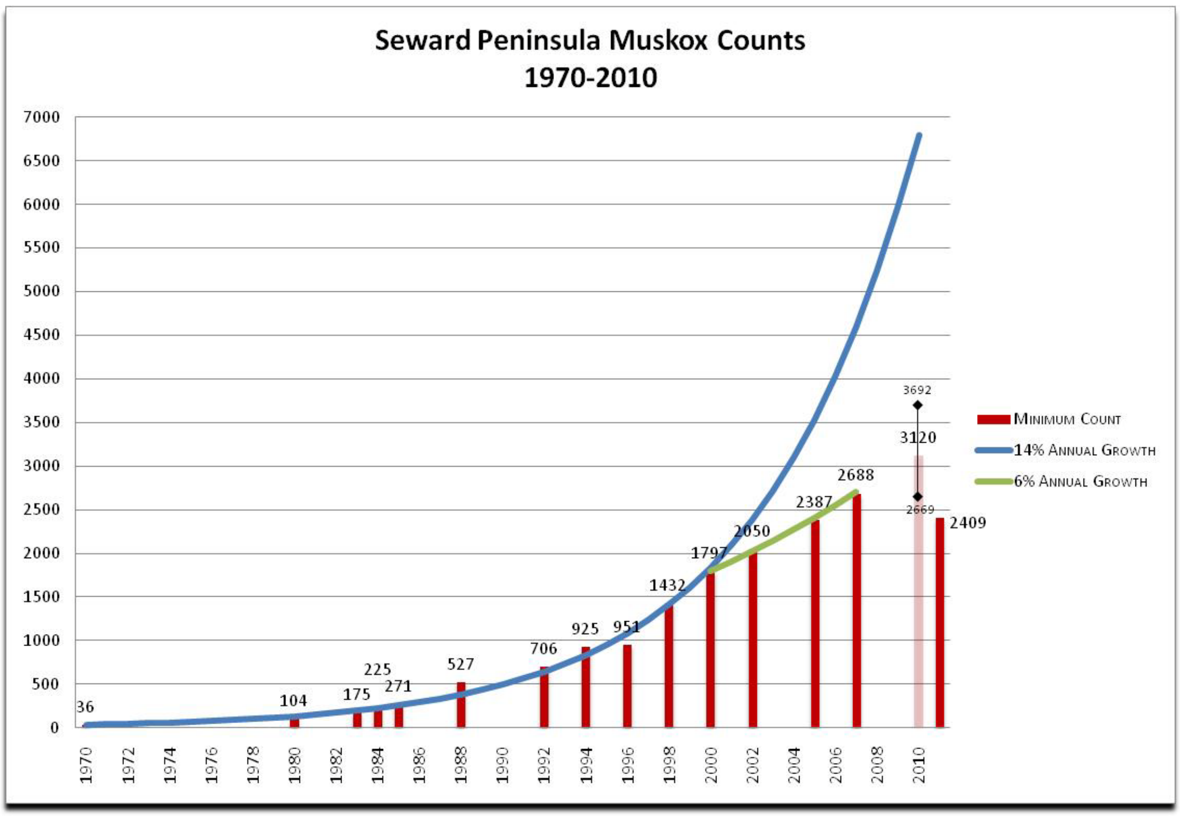


Fig. 7. Proposed hunt management harvest rates varied between 2%-8% from 2000-2009, and actual harvest rates between the same period varied between 1.6% and 5.4%.

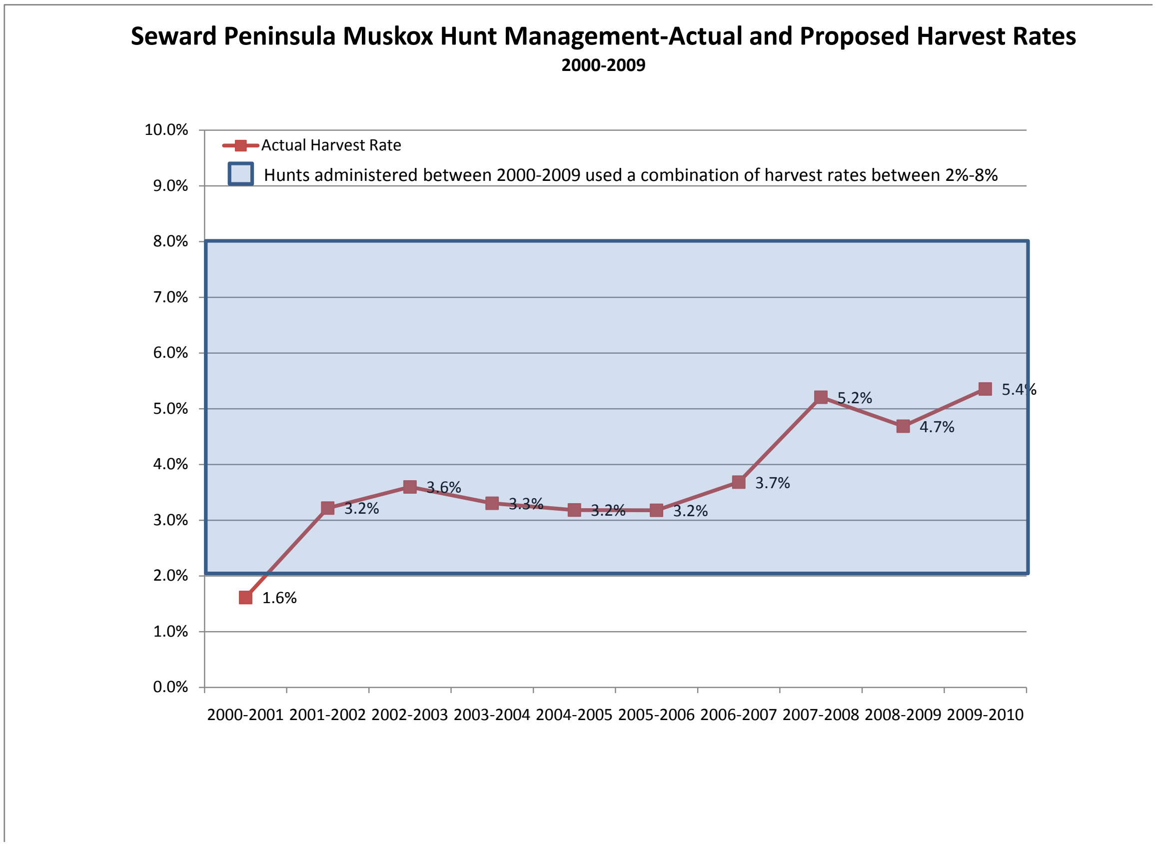
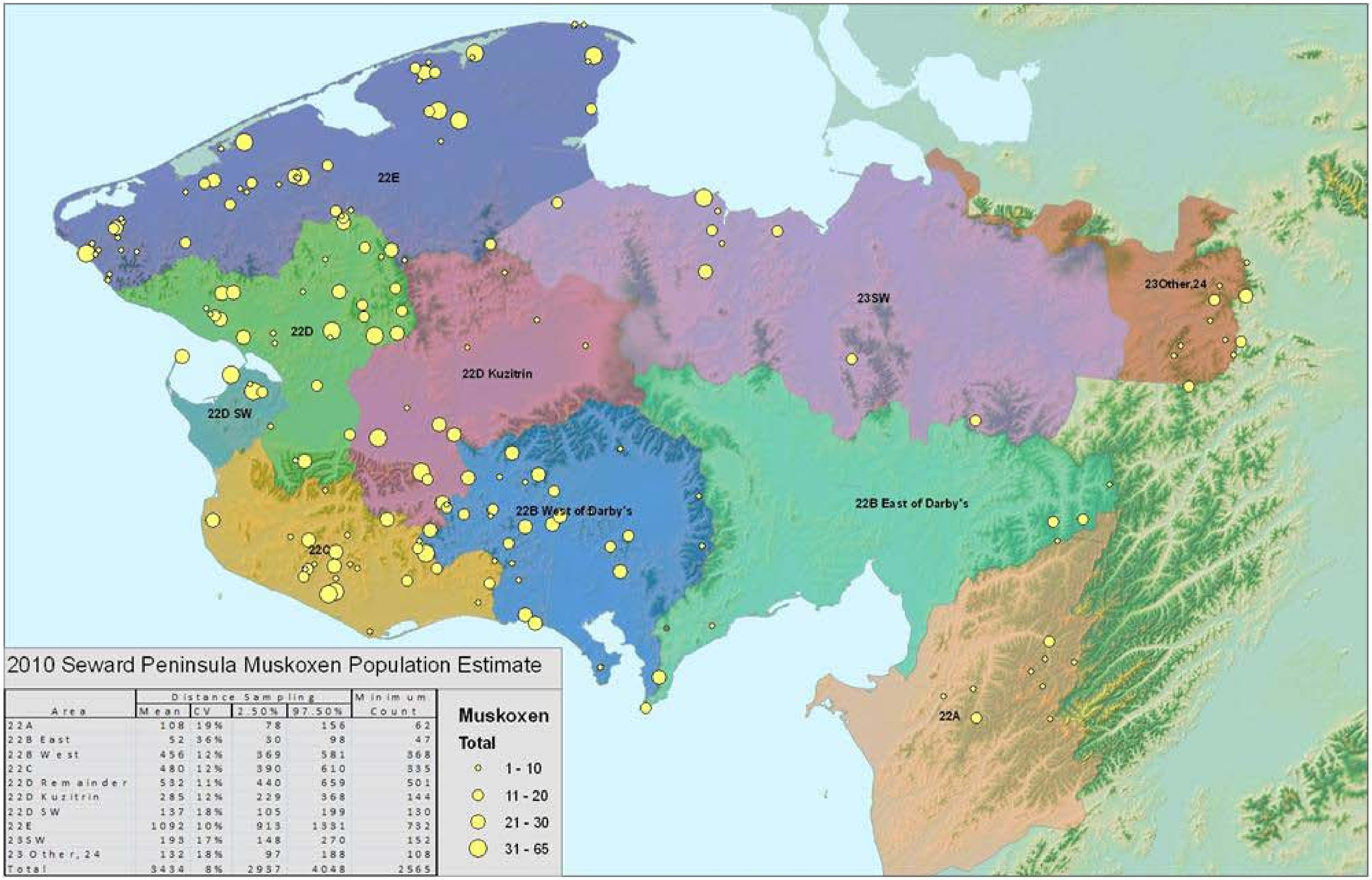


Fig. 8. Muskox group locations from the 2010 Seward Peninsula Muskox Count.



2010 Seward Peninsula Muskoxen Population Estimate

Area	Distance Sampling Mean	CV	2.50%	97.50%	Minimum Count
22A	108	19%	78	156	62
22B East	52	36%	30	98	47
22B West	456	12%	369	581	368
22C	480	12%	390	610	335
22D Remainder	532	11%	440	659	501
22D Kuzitrin	285	12%	229	368	144
22D SW	137	18%	105	199	130
22E	1092	10%	913	1331	732
23SW	193	17%	148	270	152
23 Other, 24	132	18%	97	188	108
Total	3434	8%	2937	4048	2565