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Master thesis

Modeling of Sampling Designs for Peary caribou Survey in Bathurst Island Complex Canada

Photo from Canadian Geographic Magazine (Paul Loewen)

Master in Applied Ecology

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Abstract

Sustainability of wildlife resources requires effective management strategies. Unbiased estimation of wildlife populations through efficient survey methodology is therefore crucial in formulating effective wildlife management policy.

I expected intensive survey for low Peary caribou populations to produce good precision and accuracy. Also, for moderate and low survey coverage to produce useful minimum counts at medium and high Peary caribou densities.

Empirical Peary caribou data points and watershed delineations obtained from previous aerial survey carried out in the Island were used in creating resource selection model. The significant variables used in formulating the realistic habitat scenarios of the resource selection model included elevations, slope, and hill-shade. Specified low, medium and high densities of Peary caribou were simulated across the Island using the Resource Selection Function (RSF). Systematic transects placement of varying spacing (low, moderate and high survey coverage) were overlaid on the different population density scenarios, and distance estimation method used in determining the population estimates.

The detection probabilities (more than 50%) and the coefficient of variation (precision level as low as 18%) of the survey designs revealed that they were suitable for Peary caribou survey in Bathurst Island. However, the accuracy levels of each survey design, measured by the percent difference between the simulated and the estimated Peary caribou populations for each density scenarios varied greatly between the intensive survey design and the moderate/low survey coverage. For low density Peary caribou, 20% accuracy level was observed with intensive survey coverage while 75% - 96% accuracy level was observed for moderate and low survey coverage.

Low density of Peary caribou have been reported in Bathurst Island in past surveys. I would therefore recommend that moderate or low survey coverage which produced better accuracy and relatively good precision be field-tested to assess practicability.

Keywords: Survey designs, Peary caribou, GIS, simulation, Resource Selection Function, Systematic transects, distance sampling, coefficient of variation CV.

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1. Introduction

Wildlife managers rely on the combinations of data estimates on herd structure, calf recruitment, and ecology for sustainable wildlife resources management. Setting of appropriate hunting quotas, monitoring of population trend and status, and the protection and conservation strategies for wildlife populations are dependent on accurate and precise population estimates or an index consistently related to population size (Kremen et al. 1994). Therefore, it is imperative that reliable and unbiased estimates of wildlife population size are obtained through efficient survey techniques in order to formulate effective strategies in the management of wildlife resources.

Statistical precision of an estimate from a given survey can be determined directly from the survey data, and the quality of a given estimate's precision may be compared to that other surveys conducted on the same population in the past, or from similar populations in similar habitats in other areas. On the other hand, survey accuracy is rarely known, but the actual size of a given population is rarely if ever known. Usually, managers ignore this issue for more harvested populations. If the population has a substantial size, then there is some cushion before harvesting may put the population at risk due to inaccurate estimates. However, small populations of endangered species subject to large partially density-independent declines (Tews et al. 2007) could be at high risk due to inaccurate estimates, with little time or warning for adjustments in conservation strategies. When it comes to public input into conservation strategies, the public rarely questions the precision of population estimates. They mainly discuss and often disagree with the accuracy of population estimates, which surveys rarely assess.

Wildlife conservation agencies often invoke the precautionary principle in developing strategies to manage populations at risk, but the precautionary principle can be a double-edged sword. On one hand, to avoid extirpation the principle may suggest that harvesting of the population should be prohibited for many years. That conclusion however may put a critical element of an aboriginal community's culture at risk. In that case, the precautionary principle could suggest that some low level of harvesting should be allowed so that the community may maintain their resource-related aboriginal knowledge and culture. In such situations, designing surveys must emphasize high levels of accuracy.

1.1 Monitoring of wildlife populations

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) reviews the status of flora and fauna that may be a risk in Canada, based on sound scientific assessments. Government departments are responsible for monitoring and management of wildlife populations. Under the Species at Risk Act of 2002, COSEWIC's status reviews are not legally binding but they guide the decision making processes of the responsible government agencies. COSEWIC may assign species and populations to the following categories: Not At Risk (NAR), Special Concern (SC), Threatened (T), Endangered (E), and Extinct (X). The accuracy and precision of the population estimates used during the review process are therefore very important in classifying species into COSEWIC categories.

Issues of low or varying accuracy and precision become especially problematic when we survey either rare, endangered or super-abundant populations; populations with varying detectability across the population's range; inadequately delineated populations; populations that exhibit large changes in abundance either spatially or temporally; and study areas based largely on management or jurisdictional boundaries instead of population movements. With small, rare or endangered populations of large mammals widely scattered across their ranges, accurate estimates are more important for conservation, while with moderate or high abundance populations precision may be more important to managers focused on largely recreational resource use.

1.2 Large mammal survey techniques

Estimating the population size of large mammals spread across large area entails huge costs and effort, and usually the only practical survey methods involve flying aircraft over the population's range and counting the animals seen. Even though aerial surveys can effectively census large areas, there are still challenges affecting the accuracy and precision of resulting population estimates (Caughley and Goddard 1972, Caughley 1974, Caughley et al. 1976).

Large mammal aerial surveys could be carried out by either systematic or random sampling since it is rarely possible to find or census entire populations. Systematic sampling method involves randomly placing a sampling transect or quadrat within the population range, and then uniformly spacing all other transects or quadrats equal distances apart such that each transect or quadrats in the survey has a known and equal probability of being selected. On the other hand, random sampling would place all transects or quadrats randomly across the population's range. Systematic sampling technique in aerial surveying is the most common strategy because uniform spacing are usually consider more cost efficient, and is less prone to navigation problems, compared to random aerial sampling.

The precision in systematic sampling of randomly distributed populations is greater than in random sampling, but is less when populations are distributed unevenly or highly clumped (Cochran 1963). Coughley (1977) suggested that the choice of sampling method should depend on the aim of the survey. For example, systematic sampling appeared to be the appropriate choice when the aim would be both to map the distribution of animals and to estimate their total number. Random sampling may be most appropriate when mapping distribution is not an important objective.

In addition to the overall sampling design adopted for large mammal survey, the type of the sampling unit is also an important factor. Transects and quadrats are the most common sampling units used in aerial surveys. As pointed out by Coughley (1977), the choice of transect is weighed among trade-offs in safety and visibility conditions during flight time, sightability and short-term movements of animals, navigational problems, observer and pilot fatigue, and variability between unit counts. Despite a few merits of quadrats over transect (Law et al. 1975), transect sampling usually is more efficient and economical when an estimate or index of density is sought, or sightability biases in counts can be corrected (Coughley 1977).

Distance sampling using transects as sampling units involves counting animals or groups of animals as an observer or team of observers travels along each transect, as well as recording the perpendicular distance of the detected animals or groups from the transect (Buckland et al. 2001, Thomson 2010). From the measured distances from the transects, detection probabilities, which change with distance are then computed and used to estimate the abundance and density of animals or groups (i.e., clusters) that were surveyed.

An older method is strip transect sampling, and involves counting animals within a pre-determined distance from the transect, usually called a strip (Eberhardt 1978). This method assumes that the detection of animals within the strip is equal regardless of their distance from the transect. Animals counted within each strip are recorded and collated to obtain the abundance and density estimate for the whole area. Strip width and the number of strip transects required can be determined and deployed for each survey. For instance, a narrow strip width could require a large number of strip transects.

Study areas in conventional large mammal survey are often stratified into areas of differing densities, based on either assumptions or initial reconnaissance surveys. Through stratification, areas with high densities are more intensively surveyed than areas with low animal densities, because surveying low density areas contributes less to the total population estimate. Estimates from stratified surveys are usually more precise than estimates obtained from unstratified surveys using the same effort (Coughley 1977). This implies a lower coefficient of variation (CV, or ratio of standard deviation to the mean), and is generally accepted to maximise survey efficiency in terms of time, costs, and manpower as more time is spent in areas where the greatest amount of data can be obtained.

However, if low density areas are very large relative to the population's range, a significant proportion of the population may be inadequately surveyed. Another consequence of such thinking about sampling efficiencies is that when populations change by several orders of magnitude over time, managers may be unwilling to invest the same resources into estimating population size during years when it is at historical lows. It is precisely during historical lows when populations are most at risk of extinction and there is a need for more accurate and precise estimates.

Survey techniques have often been compared in terms of accuracy and precision of population estimates. Aerial survey is one of the most frequently used methods in large mammal census (Norton-Griffiths, 1978). Like any other survey method, it has inherent biases and errors which tend to create debates over acceptability of the resulting population size estimates (Hone 2008). In the past, improvements in aerial survey methods have mostly emphasised maximizing precision by combining robust survey designs, high sampling intensity, intricate stratification and powerful methods of analysis (Caughley 1974). Adequate knowledge of wildlife population distribution is very crucial in maximizing both the efficiency of sampling designs for aerial survey and the precision of the resulting estimates. However, lack of information on the exact number of animals being surveyed and their exact positions at the time of survey have greatly hampered the performance of sampling designs for aerial survey of large mammals (Caughley 1977).

The general practice of higher survey coverage using high density strata has gone largely unchallenged, and has been compared only rarely with other potential alternatives for large mammals in terrestrial ecosystems. This practice is not an issue when we are concerned about a single population in a given survey if the population is relatively abundant. However, with endangered species, occupied habitats may be widely spaced or scattered with many potentially suitable habitats having no animals, and any occupied habitats may have very low densities. As a result, finding the occupied habitats among all potential habitats may require extensive costly surveying and then finding animals within the occupied habitats may require expensive intensive sampling. Even with species that occur in high abundance in some areas and low densities in other areas, populations may be composed of specific ecotypes that are adapted to certain habitat types, especially in low density areas. As environmental condition change with climate and human impact over time, loss of ecotypes that are adapted to low density habitats may reduce the overall resilience of the species. Because we often are interested in population trends over time, loss of sub-populations adapted to low density habitats may in time lead to loss of entire populations during periods of low abundance and scattered distributions.

1.3 Peary caribou survey in Bathurst Island Complex

Peary caribou is an endemic caribou subspecies occurring in six populations across the Canadian High Arctic: eastern Queen Elizabeth Islands, western Queen Elizabeth Islands, Banks Island and North-WesternVictoria Island, Prince of Wales Island and Sommerset Island, and the Bathurst Island complex (COSEWIC, 2004). It is the only member of the deer family Cervidae that exists as genetically homogenous inter-island populations on the Queen Elizabeth Islands in the Canadian High Arctic (Banfield 1961). There is documented evidence suggesting genetic differentiation between the Peary caribou of the High Arctic and the barren-ground caribou to the south (Roed and Whitten 1986).

Peary caribou are seasonally migratory, occurring characteristically in small groups of 3-5 during winter and then aggregating to somewhat larger groups in the summer (Miller 1977a). They move between and among islands feeding on available and accessible vegetation, thereby reducing foraging pressures on the vegetation (Parker and Ross 1976, Miller et al. 1982). However, during winter (i.e., September-May) most potential forage is inaccessible under hard snow (Maher et al. 2012), leading to population-density effects even at low density (Tews et al. 2007). They are often restricted to relatively small areas of foraging habitats with minimal snow cover along bare wind-blown ridges with extensive bare ground and rocks. In some winters, autumn icing events (i.e., rain on snow) greatly reduces the accessibility of forage, resulting in acute malnutrition and high mortality rates (Parker et al. 1975, Miller et al. 1977a, Gunn et al. 1981, Tews et al. 2007).

Many of the Canadian Arctic Islands, including the Bathurst Island Complex (16 070 km^2), compose the entire range of Peary caribou (*Rangifer tarandus pearyi*), and are dispersed across them at generally low densities (Jenkins et al 2011). In most previous aerial surveys of Peary caribou on the BIC, strip transects were run in north-south direction and spaced at 6.4 km apart (Ferguson 1991). Line transects were systematically placed across the study area starting from an initial randomly placed line transect The caribou selected 60 – 300-m elevations during late winter (Miller et.al. 1977a) and 151 – 300 m elevations during summer (Miller et.al. 1977a, Ferguson 1991). Caribou were not found below 60m and above 300m during August 1981(Ferguson 1991).

Edlund et al. (1989) conducted a comprehensive study on the vegetation and climatic patterns in the Queen Elizabeth Island. Peary caribou use mesic and xeric habitats as their summer and winter foraging areas, respectively (Thomas and Edmunds 1983, 1984). They feed in the slopes of river valleys and uplands plains with woody prostrate shrubs of sedges and foliose lichens, willow, grasses, and forbs (Gunn et al. 1981).

2. Objectives

In response to issues that were raised by Inuit elders and hunters and with input from other biologists during a workshop held in 1997 and earlier, models were developed to improve survey methods for Arctic tundra caribou populations, based on expected potential population sizes, patterns of detectability and aggregation at moderate densities. This modelling was based on rather laborious paper-based simulations. The sampling design obtained from this simulation study suggested some important changes from past standard survey designs. Some elements of the revised methodology were first implemented for caribou surveys on southern Baffin Island (Ferguson and Messier 2000). After more testing in Greenland, many elements of the design were implemented for long term monitoring beginning in 2000 by the Greenland Institute of Natural Resources (Cuyler et. al 2002).

This methodology was designed and implemented mainly for populations at moderate densities, but it may not be suitable for populations at extremely low densities with widely scattered distributions for which accuracy of estimates of population size are critical for conservation purposes. To further explore and extend Ferguson and Messier’s (2000) caribou survey designs, several alternative designs should be compared to determine the most effective and efficient methodologies for large mammal surveys in various types of situations in terms of spatial differences in animal abundance and distribution. These comparisons should take into account level of sampling intensity and extent of coverage of occupied habitats, and provide precise and accurate estimates for large mammal populations with differing densities and distributions. I have explored the potential to select innovative, robust and cost-effective survey methods for surveying caribou at different spatial densities using a GIS-based modelling approach.

I hypothesized that very intensive systematic survey of the occupied habitats of a low Peary caribou density would be required to obtain precise and accurate population estimates or at least useful minimum counts, while moderate survey coverage and low survey coverage would produce precise and accurate population size estimates at medium and high Peary caribou densities respectively.

3. Method

3.1 Study area

Bathurst Island (16070 km^2) is located between latitudes 75°N and 77°N and longitudes 96ºW and 105ºW (Figure 1). The Island group lies in the Arctic vegetation region (Polunin 1951, 1960) of highly impoverished and less diverse vegetation classes (Young 1971), and it is referred to as "Complex" according to Bliss classification (Babbs & Bliss 1974, Bliss 1975, 1977). The Islands are low-lying areas with slopes, river valleys, raised beach ridges, upland plains, and hilltops with only a few exceeding 300m elevation. The terrain is sparsely vegetated with sedges, willow, grasses and forbs covering the low-lying areas and the valleys, and represented according to dominance, by three bioclimatic zones; namely: herbaceous, shrub-herb transition and the prostrate shrub (Gunn et al. 1981, Edlund and Alt 1989, Walker et al. 2005).

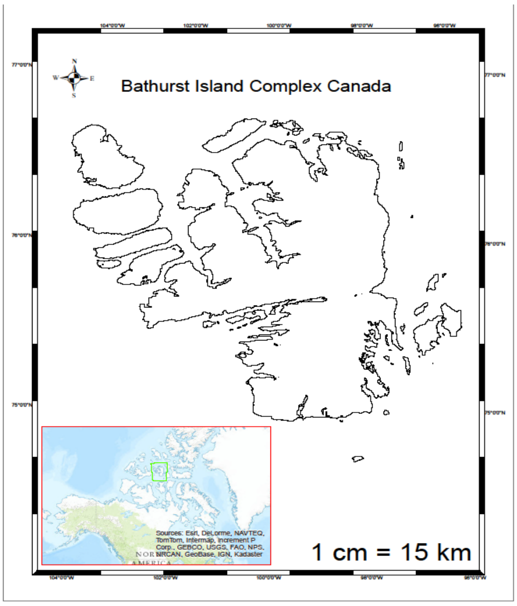

Figure 1– Bathurst Island Complex Canada

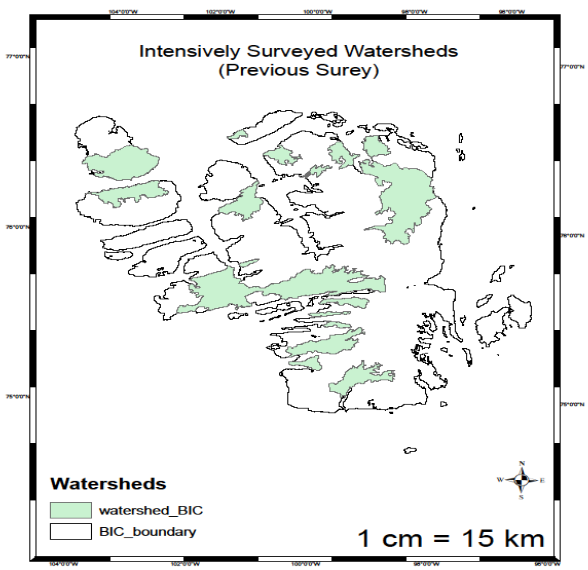

Figure 2 – Surveyed watersheds (Ferguson unpub.)

3.2 Data sources

Tiles of NAD83-processed 1:250 000 National Topographic System (NTS) containing the Canadian Digital Elevation and Land Cover Data covering the entire study area (Bathurst Island Complex - BIC) were downloaded from the Geobase website of the Canadian Council on Geomatics (http://geobase.ca). Geobase Land Cover, circa 2000 Feature Catalogue was used for the attribute classification. The topographic data containing watersheds, river systems and contour lines were also downloaded from the Natural Resources Canada website (http://geogratis.gc.ca). Empirical data for Peary caribou in the Bathurst Island Complex from an aerial survey carried out in April 2001 were used to model resource selection functions of Peary caribou within the study area.

3.3 Habitats and Survey Design Modeling

The habitat modelling, Peary caribou distribution and survey designs were summarised in the flow chart shown below (Figure 3). Using data from the April 2001 survey on the Bathurst Island Complex, boundaries of watersheds occupied by caribou were delineated after detecting the presence of animals or recent tracks. Seventeen occupied watershed areas (Figure 2) of not more than 200m elevation above sea level were all intensively surveyed. Sixty two group locations of a total of one hundred and forty nine Peary caribou were observed.

GPS coordinates of the observed Peary caribou groups were imported into ArcMap to determine the Resource Selection Function (RSF) of the Peary caribou within the surveyed watersheds. The parameters used to determine the RSF included: elevation, land cover, ruggedness index, hillshade, slope, and aspect. I determined the elevation, slope, aspect, and hillshade from the downloaded digital elevation data using the appropriate functional tools in ArcMap. I used the QGIS software to determine the ruggedness index from the digital elevation data.

The Bathurst Island land cover types were reclassified into 8 categories in ArcMap (Table 1). All the parameters were extracted for each Peary caribou presence point (i.e. Caribou group locations from the 2001 survey and randomly generated caribou points) within the watersheds using the 'Extract to Multi-value' tool in ArcMap. I ran R-Statistics on the output from the extraction process to determine the most parsimonious model by selecting the model with the least AIC value (Table 2). I used the estimates of this model in determining the resource selection function for Peary caribou within the watersheds and then extrapolated them over the entire Bathurst Island Complex (Figure 6).

I allocated random Peary caribou presence points of 50, 100, 200, 400, 800 and 1000 in accordance with the probability profile of the Peary caribou occurrence from the Resource Selection Model (RSM) using the 'generate random points' tool in the Geospatial Modelling Environment (GME) software. I placed systematic transect lines running from north to south across the entire Bathurst Island Complex at 10km, 5km, 1km and 0.5km apart using the 'Create Fishnet' tool in ArcMap (Figures 4a – d).

Table 1 – Land Cover classes of the vegetation in Bathurst Island

Classes	Land Cover Types	Composition(%)
1	No data	0.02
2	Water	0.30
3	Barren/Non vegetated	0.50
	Bare Soil with Cryptogam crust-frost boil	6.80
4	Snow/ice	1.40
5	Sparsely Vegetated bedrock	3.30
	Sparsely vegetated till-colluvium	5.10
6	Prostrate dwarf shrub	7.70
	Moist-dry non tussock graminoid/dwarf shrub tundra	20.50
	Dry graminoid prostrate dwarf shrub tundra	23.90
7	Wetland	8.70
8	Tussock graminoid tundra	10.10
	Wet sedge	11.70

3.4 Distance Estimation

Using the Spatial Analyst of the ArcGIS 10.1 software, perpendicular distances of the Peary caribou presence points to each transect line were determined. Total transect length for each survey design was also determined. For each survey design, I used distance estimation method with the Distance software (Thomas et. al 2010) software to determine the Peary caribou population estimate. I filtered the data by truncating all distances at 500m except for the 0.5-km transect lines which were truncated at 250m (see Appendix). These were suggested as realistic strip widths for animals in aerial survey (Ferguson 2014, pers. comm.). I also analysed the data using detection function model with appropriate key functions/series expansion (Buckland et al. 2001). I considered half normal, uniform and hazard rates detection functions adjusted with their respective cosine, simple polynomial and hermite polynomial expansion series before selecting the best fit model using the AIC value. From the model summary of each survey design, I obtained the detection probability of seeing Peary caribou points within the specified strip, the population density estimate and the coefficient of variation.

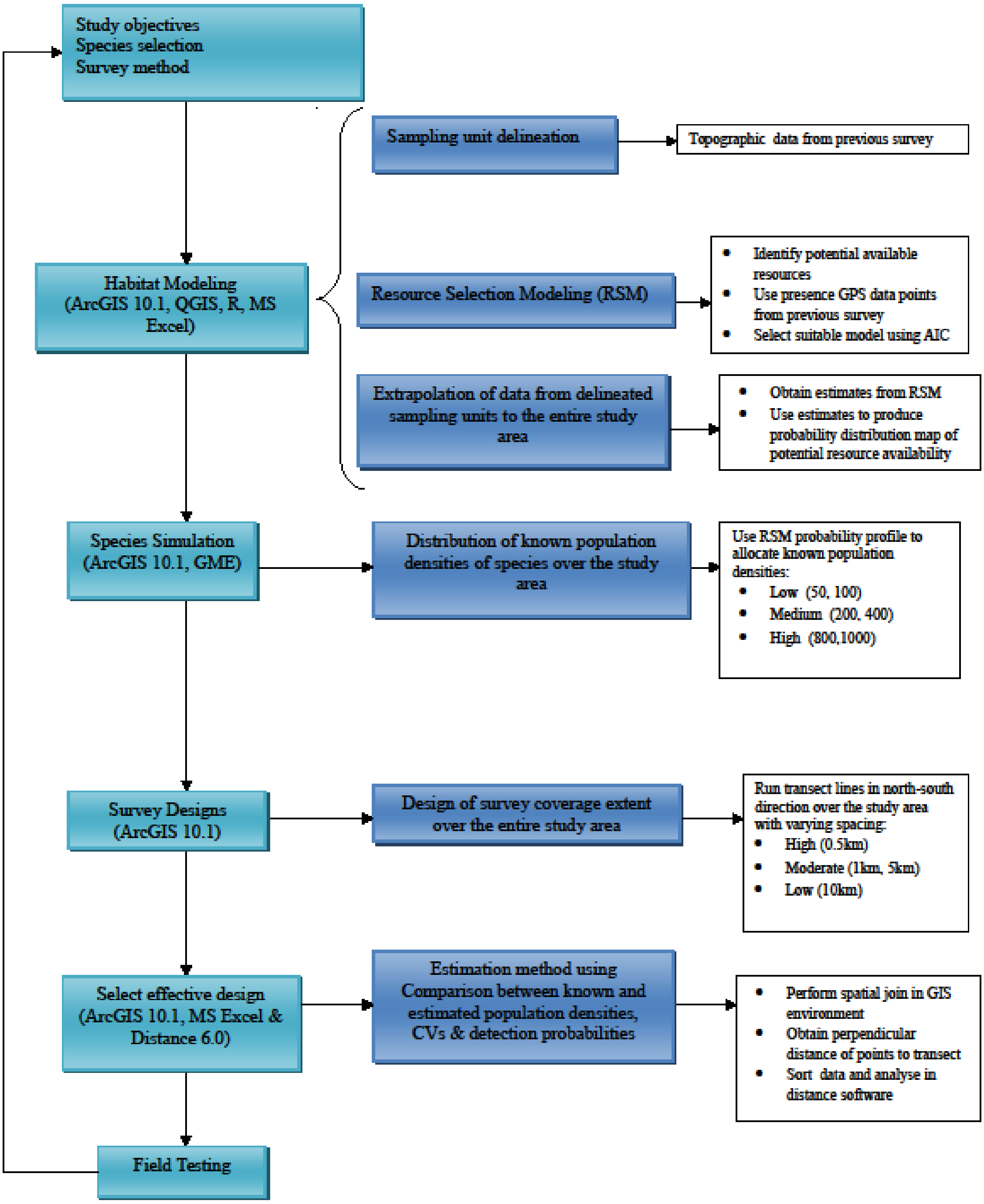

Figure 3: Flow Chart of the Habitat, Species and Survey Design Modelling

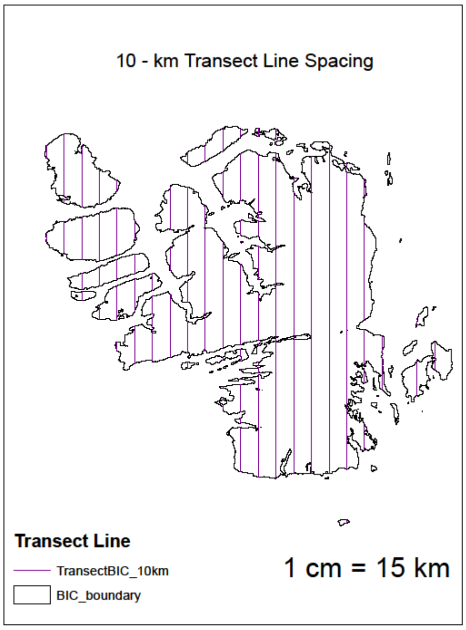

Figure 4a: 10-km Transect Spacing (T10)

Figure 4b: 5-km Transect Spacing (T5)

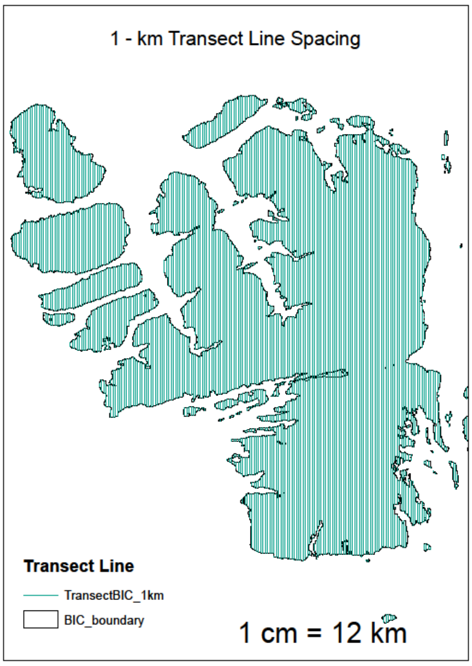

Figure 4c: 1-km Transect Spacing (T1)

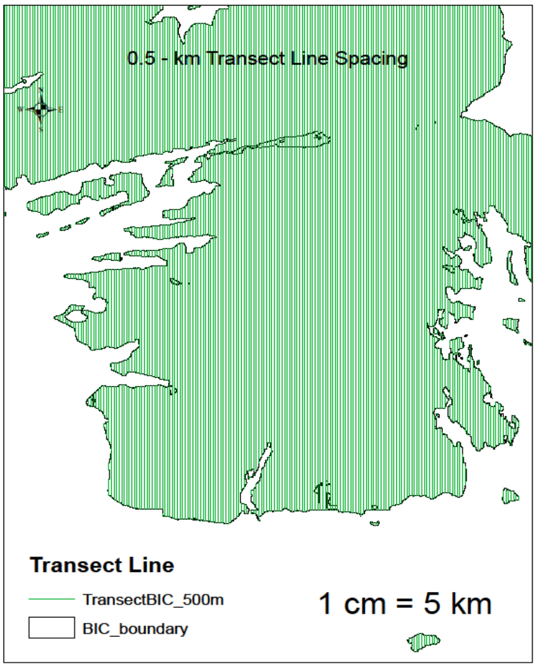

Figure 4d: 0.5-km Transect Spacing (T0_5)

4. Results and Discussion

4.1 Resource Selection Model

Table 2 shows the lists of candidate models and their corresponding AIC values. I selected the first model in the list because of its least AIC value. As obtained from the outcome from the R-statistic and in relation to the effect plots in Figure 5, the estimates of the selected model were as follow: Elevation (-0.0087), Slope^2 (-0.0462), Slope (0.4325), Hillshade (-0.0167) and Intercept (1.0555).

Table 2: Candidate model parameters and their corresponding AIC values

Model Parameters	AIC values
Elevation + Hillshade + Slope + Slope ^2	370.54
Elevation + Hillshade + Slope + Slope^2 + Hillshade^2	372.54
Elevation + Hillshade + Slope + Ruggedness Index	374.47
Elevation + Hillshade + Slope^2	374.63
Elevation + Hillshade	374.77
Elevation + Hillshade + Ruggedness Index	375.15
Elevation + Hillshade + Slope + Slope^2 + Elevation^2 + CoverType * Hillshade	375.63
Elevation + Hillshade + Slope + Ruggedness Index + CoverType	375.96
Elevation + Hillshade + Slope	376.42
Hillshade + Slope + Slope^2	378.92
Elevation + Hillshade + Slope + CoverType + Aspect	380.62
Elevation + Slope + Ruggedness Index + CoverType + Aspect	387.30

After running the R-Statistics of the resource use of Peary caribou within the watersheds and extrapolating the estimates to the entire Island, elevation, hill-shade, and slope were observed to be the most suitable resources for creating the scenarios for ideal Peary caribou population distribution within the study area – slope ($p = 0.03$), slope^2 ($p = 0.04$), hill-shade ($p < 0.001$), elevation ($p < 0.001$).

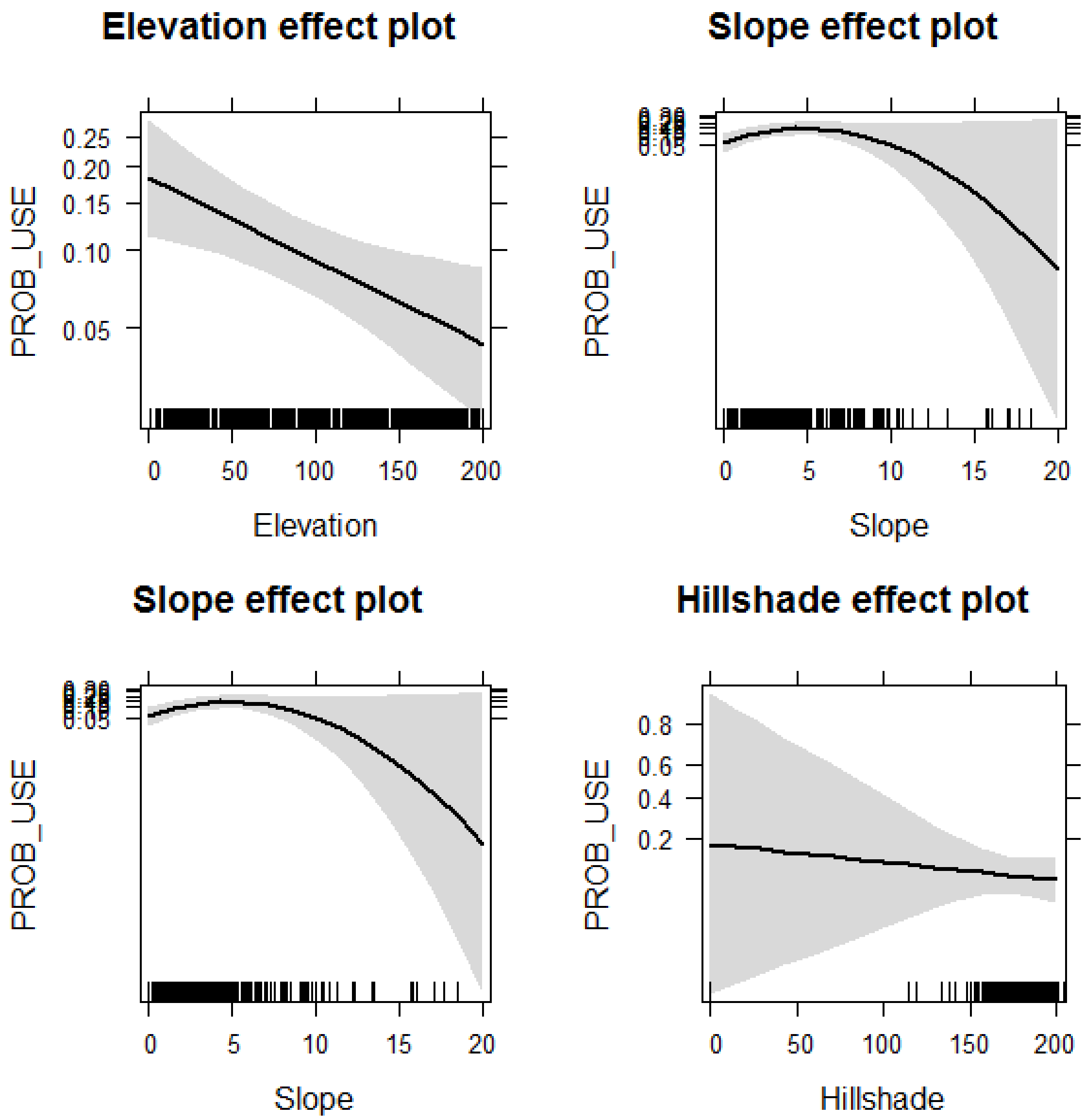

Figure 5: The effect plots of the relevant variables for the resource selection model

Equation 1: Resource Selection Function (RSF)

RSF = Exp (-0.0167*Hillshade + 0.4325*Slope + 0.0462*Slope^2 – 0.0087*Elevation)

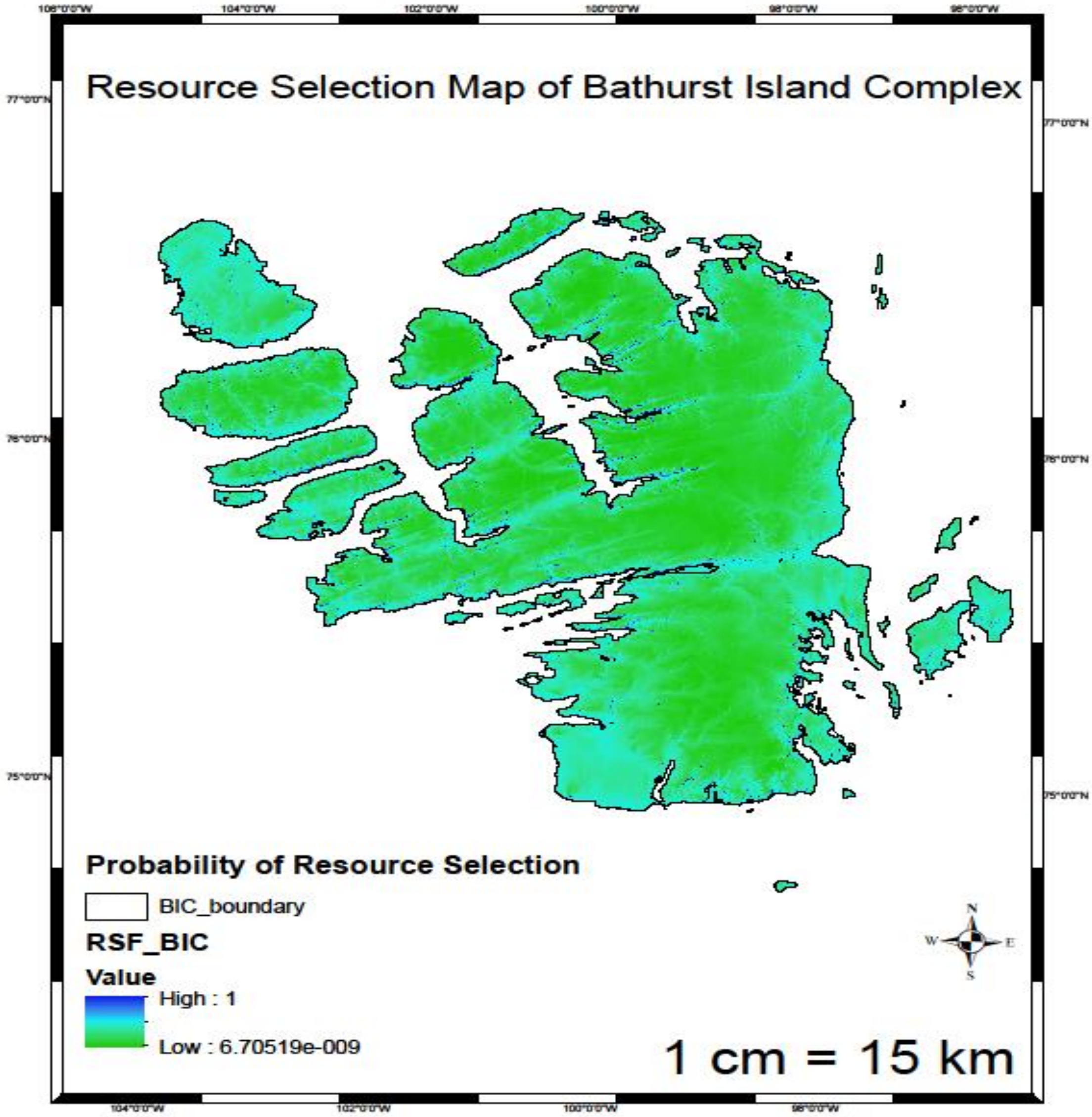

Figure 6: The Resource Selection Map of the Bathurst Island Complex

I discovered that Peary caribou resource use in the Bathurst Island was mostly influenced by elevation, slope, the gentleness of the slope and the hillshade direction. It seemed that the Peary caribou of the Bathurst Island Complex tended to show preferences for areas within the Island which were of low elevations (Ferguson, 1991), gently rising slopes and hillshade areas.

Though, Peary caribou occurred in areas of gently rising slopes but they seemed to avoid steep slopes. It would appear that most resources available to them were at low elevations, the hillshade areas and along the areas of the gently rising slopes.

Windblown ridges could create sites for shallow snow deposition thus making such areas available for Peary caribou to forage (Nellemann and Fry 1995). Hillshade may relate to the effects of wind on snow deposition. The elevation data used for the hillshade were collected in autumn when the sun was at low angle (http://geobase.ca). With the sun being at low angle, the prevailing winds from north-west dominates the stormy winds from the south-west thus creating hillshade areas which could be regarded as surrogates for windblown ridges. Windblown ridges or hillshade areas of the Island, being an indication of the direction of the prevailing wind and shallow snow deposition, would not in any way hamper the free movement or calving activities (Miller et al. 1977a, Fergusson 1991) of Peary caribou within the Island.

4.2 Population density estimates and the survey designs

Table 3 below shows the Population density estimates of specified randomly simulated Peary caribou population scenarios of High density - 1000, 800; Medium densities - 400, 200; and Low densities – 100, 50 represented by R1000, R800, R400, R200, R100, R50 with their respective transect spacing – 10km, 5km, 1km and 0.5km (T10 – Low Coverage, T5 & T1 – Moderate Coverage, T0.5 – High Coverage or Intensive survey coverage) as measured using distance estimation method.

I considered 0.5 km transect spacing (T0.5) to be an intensive survey design which covered at least 75% of the entire study area. This coverage extent meant that more transects lines were needed which obviously translated to more survey cost. Based on knowledge of past surveys from literatures, I assumed that 10km transect spacing (T10) would cover about 25% of the study area which would mean fewer transect lines and less survey cost. 5km (T5) and 1km (T1) transect spacing were regarded as moderate coverage of between 25% and 50% of the study area thus requiring moderate transect lines.

Table 3: Population Density Estimates (caribou/km^2)

		High Density		Medium Density		Low Density	
		R1000	R800	R400	R200	R100	R50
Low Coverage	T10	0.043	0.041	0.022	0.013	0.005	0.003
	T5	0.048	0.041	0.019	0.012	0.007	0.004
Moderate Coverage							
	T1	0.049	0.043	0.022	0.016	0.012	0.014
High Coverage	T0.5	0.059	0.051	0.035	0.023	0.020	0.024

4.3 Detection Probability and Coefficient of Variation

The detection probabilities for all the survey designs irrespective of the density scenarios appeared to be at least 0.5 (Figure 7). As transect spacing increased, I would expect the probability of seeing more animals to decrease due to a number of reasons expressed by Caughley (1974) in relation to strip width. The decrease in detection probability was not particularly evident between low and moderate survey coverage. However, intensive survey coverage for all density scenarios produced lower detection probabilities when compared to moderate and low survey coverage. This was probably due to the imposition 500m strip width for the survey. At least about 50% of the simulated Peary caribou populations within the specified 500m truncated distance were still observed by the Distance software. Based on the result shown in the detection probability (Figure 7), I would suggest that all the survey designs used for this modeling project were potentially capable of producing realistic estimates of Peary caribou population in the Bathurst Island. However, following the lower detection in intensive survey coverage, there should be cautious deployment of intensive coverage for Peary caribou survey in Bathurst Island irrespective of the prior knowledge of its population density.

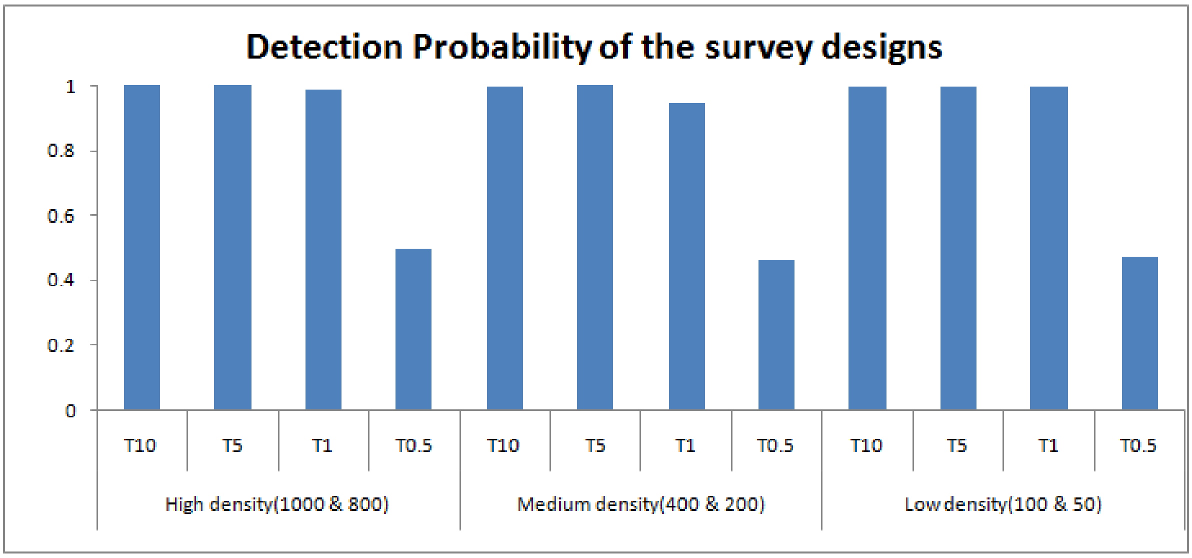

Figure 7: Detection probabilities of the survey designs

According to Figure 8, coefficients of variation (14-18%) were observed in all the survey designs for the low density Peary caribou scenario. In all the survey designs, there appeared to be a general decline from (13-14%) for medium density to about (7-10%) for high density Peary caribou populations. From this modelling project, the survey designs assessed for all the density scenarios of Peary caribou population produced relatively reasonable estimates of Peary caribou populations (Beasom 1979) but precision varied greatly. The survey designs for high density Peary caribou scenario produced better estimates than for medium and low densities. This is evident in their relatively good precision – low coefficient of variation of about 7-10% (Figure 8). I could possibly infer from this study that all the survey designs assessed in this project would be appropriate for the survey of Peary caribou if preliminary survey could establish that they were in high density. If cost of survey would be an issue, then low survey coverage would produce as much precision as moderate or intensive survey coverage for Peary caribou occurring in high density.

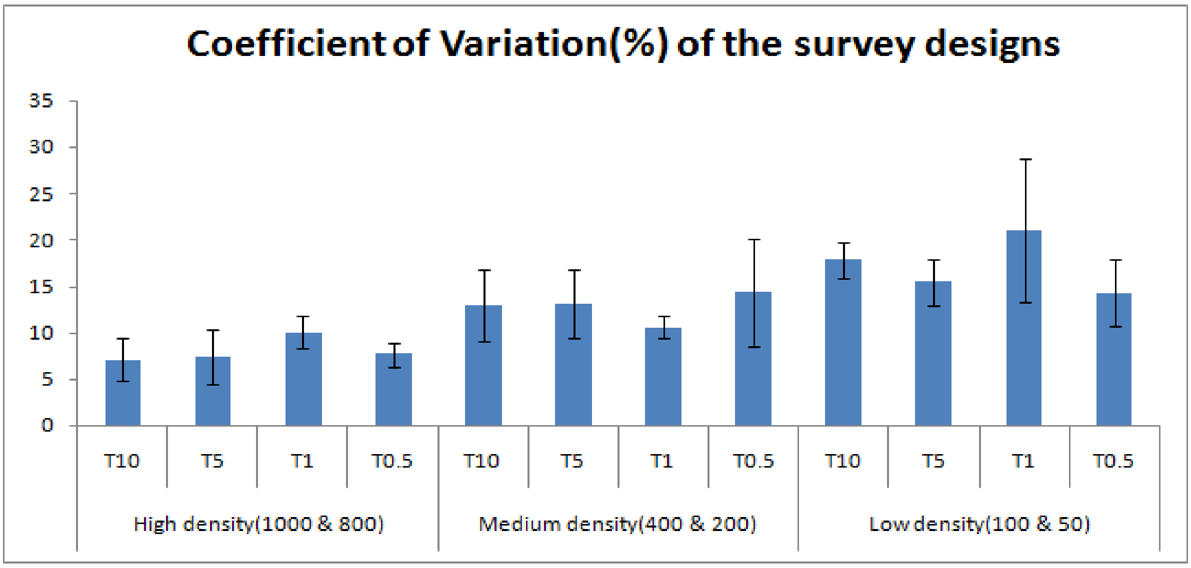

Figure 8: Coefficient of variation (%) of the survey designs

Figure 9 shows the difference (%) between the known or simulated populations of Peary caribou across the Bathurst Island and the estimated populations as obtained from the distance estimation method for each survey design. I used this approach to determine the level of accuracy of the each survey design, i.e., Accuracy (%) = (Known Population Density – Estimated Population Density)/Known Population Density.

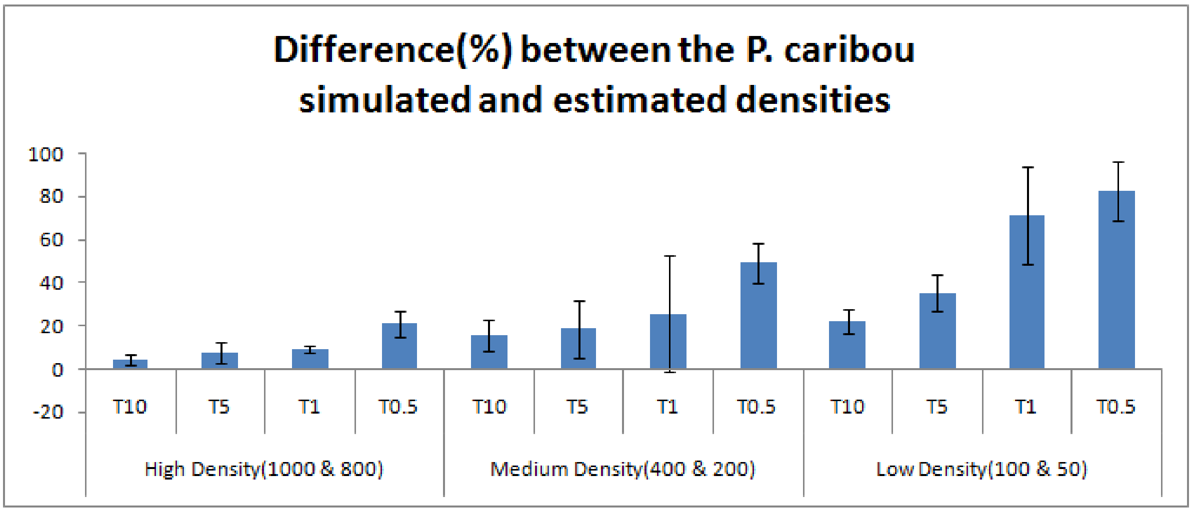

Figure 9: Difference (%) between the P. caribou simulated and estimated densities

The difference between the known and estimated Peary caribou populations appeared to increase progressively for low through moderate to high survey coverage survey for each density scenario. For low density Peary caribou, 0.5km transect spacing produced about

80% difference between the known and the estimated population densities. 70%, 35% and 20% difference in population densities were observed in 1km, 5km and 10km transect spacing respectively. 50%, 25%, 20% and 15% difference were observed in 0.5km, 1km, 5km and 10km transect spacing respectively for medium density scenario. High density scenario produced 20%, 9%, 7%, and 4% difference between the simulated and estimated Peary caribou populations for respective 0.5km, 1km, 5km and 10km transect spacing. Low difference (%) between the known and estimated Peary caribou population implies high accuracy level and vice versa. For instance, 80% difference between simulated and estimated population density means 20% accuracy level.

The effectiveness of the survey designs was evaluated on the basis of the accuracy measured as the percent difference between the known and estimated Peary caribou population densities for each survey designs validated by the detection probabilities. Precision level was assessed using the coefficients of variation. For low density Peary caribou simulation, almost 50% of Peary caribou were detected and the coefficient of variation was about 14% and at about 20% accuracy level at intensive survey coverage. Not less than 75% accuracy level and as low as 14% coefficient of variation (CV) was observed under moderate and low intensity survey coverage. This implied that low or moderate survey coverage would be more suitable to obtain useful minimum counts of high density Peary caribou populations in Bathurst Island. The accuracy level of each survey design appeared to deteriorate under low density Peary caribou populations. This position seemed to run contrary with my expectation that intensive survey coverage would produce useful minimum count of low density Peary caribou in Bathurst Island. Despite the relatively good precision (CV of between 7 – 18%) and seemingly suitable detection probabilities for all the survey designs, there appeared to be significant difference between the estimated and simulated Peary caribou densities for intensive survey coverage in all density scenarios. This therefore showed that the accuracy levels of intensive survey coverage was relatively poor and spending huge cost on such an intensive survey appeared to be economically unjustifiable (Beasom et al. 1979). Past surveys seemed to reveal low abundance level of Peary caribou in Bathurst Island (Miller 1997a, Gunn and Dragon, 2002). It might be appropriate to field-test moderate or low survey coverage design which produced better accuracy levels and relatively good precision for Peary caribou survey in Bathurst Island.

5. Conclusion

The outcome of this modelling project showed that survey coverage in Peary caribou survey within the Bathurst Island Complex would have a significant impact on the accuracy and precision level of the estimates obtained. The detection probability of the survey coverage appeared to be suitable for Peary caribou survey in Bathurst Island as at least 50% of all simulated Peary caribou points were detected despite the imposition of the 500m strip width. The coefficient of variation for all the survey designs, which was a measure of the precision, was between 7-18%. This was accepted to be relatively low for all the survey coverage to be adjudged as suitable for Peary caribou survey. Contrary to my expectation, the percent difference between population estimates obtained from the distance estimation method and the simulated values for intensive survey coverage appeared to vary greatly. I observed 20% accuracy level for intensive survey coverage and at least 75% for both moderate and low survey coverage. This appeared to be imply relatively poor accuracy level for intensive survey design for the low density Peary caribou densities.

I would recommend that sample survey of the variables used in creating the Peary caribou habitat model be stratified along similar resource availability and use in order to fully establish their effects on Peary caribou resource selection function and to improve survey efficiency. Moderate or low survey coverage which produced better accuracy and precision could be field-tested to determine its practicability.

6. References

Babb, T. A., & Bliss, L. C. (1974). Susceptibility to environmental impact in the Queen Elizabeth Islands. *Arctic, 27*(3), 234-237.

Banfield, A. W. F. (1961). A revision of the Reindeer and caribou, genus *Rangifer. . Bulletin 177 National Museum of Canada, Biological Services* (66), 137.

Beasom, S. L. (1979). Precision in helicopter censusing of white-tailed deer. *Journal of Wildlife Management*. 43: 777 - 780

Bliss, L. C. (1975). Tundra grasslands, herblands and shrublands and the role of herbivores. *Geoscience and Man* (10), 51-79.

Bliss, L. C. (1977). *Truelove Lowland, Devon Island, Canada: a High Arctic ecosystem.* Edmonton: University of Alberta Press.

Buckland A. T., Burnham K. P., Laake L. J., Borchers, L. D & Thomas, L. (2001). *Introduction to distance sampling: estimating abundance of biological populations.* New York: Oxford University Press.

Canadian Council on Geomatics (1972) Canadian Digital Elevation and Land Cover Data. http://geobase.ca/geobase/en/data/index.html. Accessed 23 Feb. 2013.

Caughley, G. (1974) Bias in aerial survey. *Journal of Wildlife Management, 38*(4), 921-933.

Caughley, G. (1977). *Analysis of vertebrate populations*. London: John Wiley and Sons.

Caughley, G., & Goddard, J. (1972). Improving the estimates from inaccurate censuses. *Journal of Wildlife Management, 36*(1), 135-140.

Caughley, G., Sinclair, R., & Scott-Kemmis, D. (1976). Experiments in aerial survey. *Journal of Wildlife Management, 40*(2), 290-300.

Cochran, W. G. (1963). *Sampling techniques* (Second edition ed.). New York: John Wiley and Sons.

COSEWIC (2004). COSEWIC assessment and update status report on the Peary caribou *Rangifer tarandus pearyi* and the barren-ground caribou *Rangifer groenlandicus* (Dolphin and Union population) in Canada . Committee on the Status of Endangered Wildlife in Canada Ottawa, ON).

Cuyler, C., Rosing, J. D. C., Linnell, A., Loison, T., Ingerlsev, T., & Landa, A. (2002). Status of the Kangerlussuaq-Sisimiut caribou population (Rangifer tarandus groenlandicus) in 2000, West Greenland. (Vol. 42, pp. 52): Greenland Institute of Natural Resources. Technical Report.

Eberhardt L. (1978). Transect Methods for Population Studies. *The Journal of Wildlife Management*, *42*(1), 1-31.

Edlund, S. A., & Alt, B. T. (1989). Regional congruence of vegetation and summer climate patterns in the Queen Elizabeth Islands, Northwest Territories, Canada Arctic. *42*(1), 3-23.

Ferguson, M. A. D. (1991). Peary caribou and muskoxen on Bathurst Island, North West Territories, from 1961 – 1981. Northwest Territories Department of Renewable Resources File Report No. 88, Yellowknife, NWT.

Ferguson, M. A. D., & Messier, F. (2000). Mass emigration of arctic tundra caribou from a traditional winter range: Population dynamics and physical conditions. *Journal of Wildlife Management*, *64*(1), 168-178.

Gunn, A. and Dragon, J. (2002). Peary caribou and muskox abundance and distribution on the Western Queen Elizabeth Islands, Northwest Territories and Nunavut (June – July 1997). Northwest Territories Department of Resources, Wildlife and Economic Development File Report No. 130, Yellowknife, NT.

Gunn, A., Miller, F. L., & Thomas, D. C. (1981). The current status and future of Peary caribou (*Rangifer tarandus pearyi*) on the Arctic Islands of Canada. *Biological Conservation*(19), 283-296.

Hone, J. (2008). On bias, precision and accuracy in wildlife aerial surveys. Wildlife Research 35, 253–257.

Jenkins, D., Campbell, M., Hope, G., Goorts, J., & McLoughlin, P. (2011). Recent trends in abundance of Peary Caribou (*Rangifer terandus pearyi*) and Muskoxen (*Ovibos moschatus*) in the Canadian Arctic Archipelago, Nunavut (pp. 184). Pond Inlet, Nunavut: Department of Environment, Government of Nunavut.

Kremen, C., Merelender M. A. & Murphy D. (1994). Ecological monitoring: a vital need for integrated conservation and development programs in the tropics. *Conservation Biology, 8*, 388-397.

Laws, R. M., Parker, S. C., & B., Johnstone R. C. (1975). *Elephants and their habitats*. Oxford: Clarendon Press.

Maher, A.I., Treitz, M. P., Ferguson, M. A. D. (2012). Can Landsat data detect variations in snow cover within habitats of arctic ungulates? *Wildlife Biology*, 18: 75 - 87

Miller, F. L. (1997a). Peary caribou conservation studies. Bathurst Island Complex, Northwest Territories, April – August 1994 and June – July 1995. Canadian Wildlife Service, Prairie and Northern Region Technical Report Series No. 295, Edmonton, AB.

Miller, F. L., & Gunn, A. (1982). Nursing behaviour of Peary caribou, *Rangifer tarandus pearyi*. . *Canadian Field-Naturalist* (96), 200-202.

Miller, F. L., Russel, R. H., & Gunn, A. (1977a). Distribution, movements and numbers of Peary caribou and muskoxen on western Queen Elizabeth Islands, Northwest Territories, 1972-74. *Canadian Wildlife Service Report Series*(40), 55.

Natural Resources Canada (2013) Topographic data of Bathurst Island, Nunavut. http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/7cf8650f-0b69-46e7-81a7-ddc86977fd53.html. Accessed 23 Feb. 2013.

Nellemann. C. (1996). Terrain Selection by Reindeer in Late Winter in Central Norway. *ARCTIC*, *40*(4), 339-347.

Norton-Griffiths M. (Ed.). (1978). *Counting Animals.* (Second ed.). Nairobi: African Wildlife Leadership Foundation.

Nellemann, C., and Fry, G. (1995). Quantitative analysis of terrain ruggedness in reindeer winter grounds. Arctic 48:172–176.

Parker, G. R., Thomas, D. C., Broughton, E., & Gray, D. R. (1975). Crashes of muskox and Peary caribou populations in 1973-74 on the Parry Islands, Arctic Canada. *Canadian Wildlife Service Progress Notes*(56), 10.

Polunin, N. (1951). The real Arctic: suggestions for its delimitation, subdivision and characterisation. *Journal of Ecology*(39), 308-315.

Polunin, N. (1960). *Introduction to Plant Geography and Some Related Sciences*. New York: McGraw Hill.

Røed, K. H., & Whitten, K. R. (1986). Transferrin variation and evolution of Alaskan reindeer and caribou, *Rangifer tarandus* L. . *Rangifer Special Issue*(1), 245-251.

Tews, J., Ferguson, M. A. D., & Fahrig, L. (2007). Potential net effects of climate change on High Arctic Peary caribou: Lessons from a spatially explicit simulation model. *Ecological Modelling, 207*, 85-98.

Thomas, L., Stephen, Buckland T., Eric, Rexstad A., Jeff, Laake L., Samantha, Strindberg, Sharon, Hedley L., Kenneth, Burnham P. (2010). Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology, 47*, 5-14.

Walker, D. A., Raynolds, M. K., Daniels, J. A., Einarsson, E., Elvebakk, A., Gould, W. A., Yurtsev, B. A. (2005). The circumpolar Arctic vegetation map. *Journal of Vegetation Science*(16), 267-282.

Young, S. B. (1971). Vascular flora of St. Lawrence Island, with special reference to floristic zonation in the arctic regions. *Contributions from the Gray Herbarium of Havard University* (201), 11-115.

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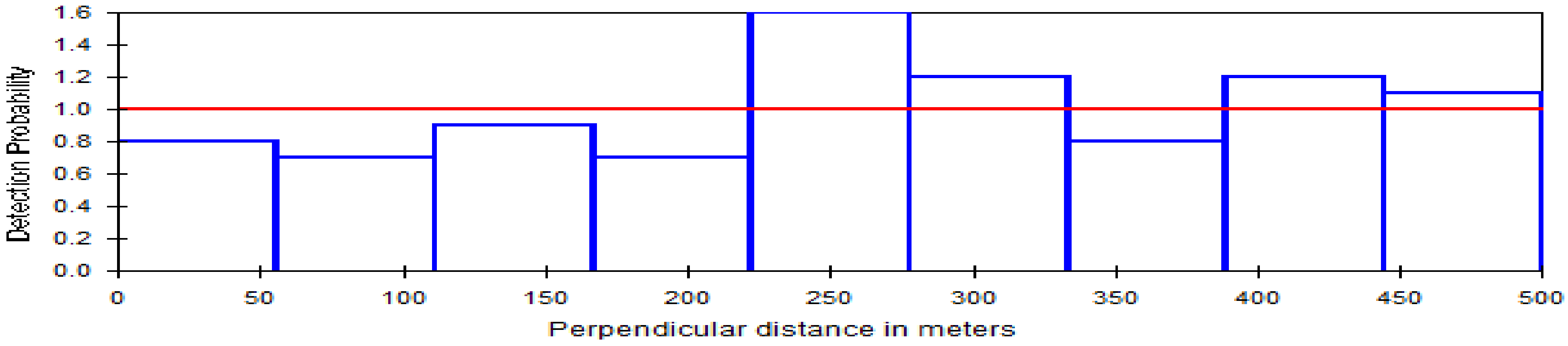
8. Appendix

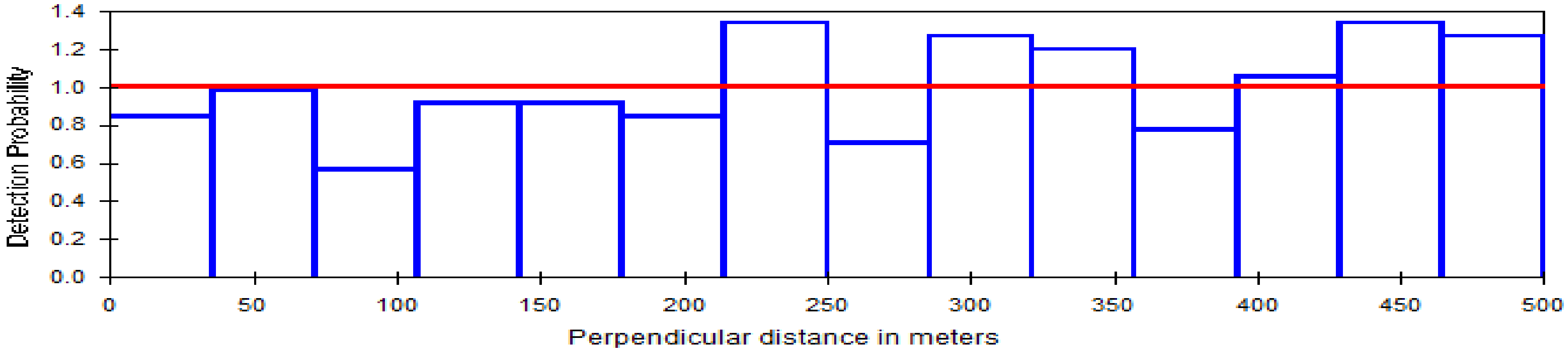
Detection Probability graphs and the summary of the candidate models for the simulated P. caribou population density and the survey designs

A(i) R1000T10 – 1000 Simulated Peary caribou points and 10km Transect spacing



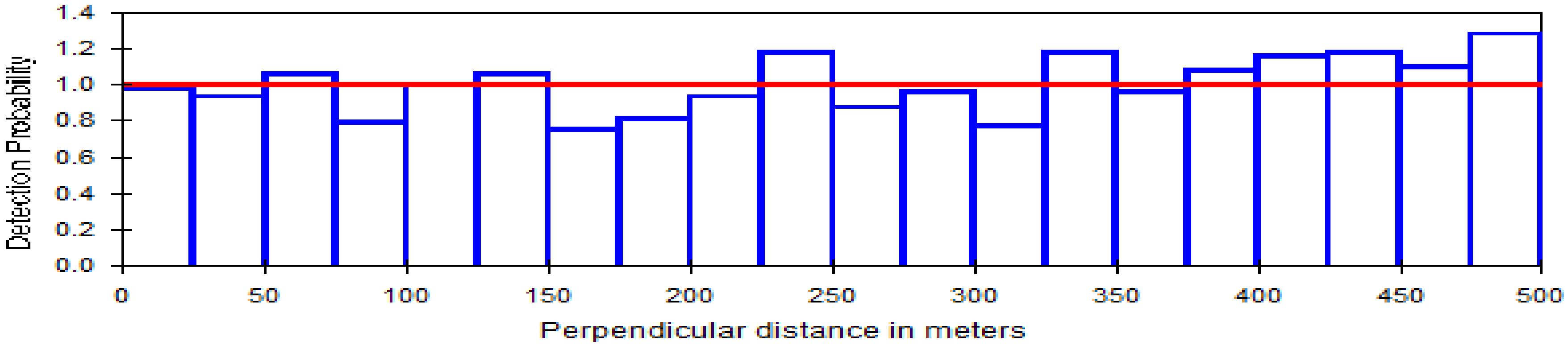
NameR1000T10	Par	Delta AIC	AIC	ESW (m)	Density(Caribou/km2)	D LCL	D UCL	D CV
Uniform Cosine	0	0.00	1118.63	500.00	0.043	0.035	0.035	0.105
Half-normal Simple Poly	1	2.00	1120.63	500.00	0.043	0.032	0.032	0.156

A(ii) R1000T5 – 1000 Simulated Peary caribou points and 5km Transect spacing



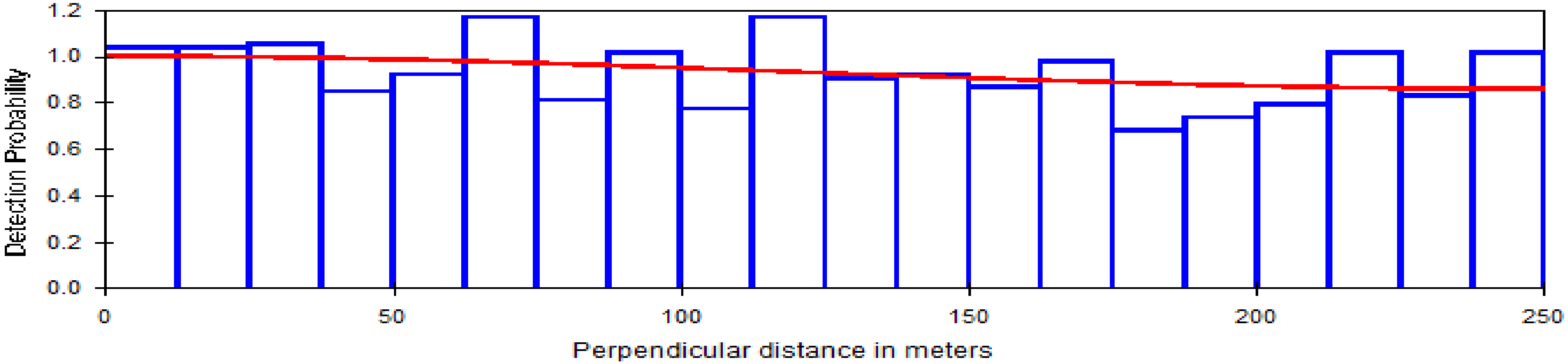
NameR1000T5	Par	Delta AIC	AIC	ESW (m)	Density(Caribou/km2)	D LCL	D UCL	D CV
Uniform Cosine	0	0.00	2473.41	500.00	0.048	0.041	0.056	0.077
Half-normal Simple Poly	1	2.00	2475.42	499.95	0.048	0.039	0.059	0.108
Half-normal Hermite Poly	1	2.00	2475.42	499.5	0.048	0.039	0.059	0.108

A(iii) R1000T1 – 1000 Simulated Peary caribou points and 1km Transect spacing



NameR1000T1	Par	Delta AIC	AIC	ESW (m)	Density(Caribou/km2)	D LCL	D UCL	D CV
Uniform Cosine	0	0.00	12242.78	500.00	0.049	0.046	0.052	0.031
Half-normal Hermite Poly	1	2.01	12244.79	499.95	0.049	0.044	0.053	0.046

A(iv) R1000T0.5 – 1000 Simulated Peary caribou points and 0.5km Transect spacing



NameR1000T0.5	Par	Delta AIC	AIC	ESW (m)	Density(Caribou/km2)	D LCL	D UCL	D CV
Uniform Cosine	1	0.00	10887.35	232.08	0.056	0.051	0.062	0.051
Uniform Hermite Poly	0	0.97	10888.32	250.00	0.052	0.049	0.055	0.029
Half-normal Hermite Poly	1	1.01	10888.36	237.96	0.055	0.050	0.060	0.045
Half-normal Cosine	1	1.01	10888.36	237.96	0.055	0.050	0.060	0.045