BC Boreal Caribou Implementation Plan

Aerial Moose Survey in North East BC 2013

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– Inventory Project
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Executive Summary

A survey was conducted January 14th to 27th, 2013 to estimate moose abundance within seven Caribou Core Areas (CCA) and one Resource Review Area (RRA) in northeastern British Columbia (BC). The abundance of moose within these areas will inform biologists responsible for measuring effectiveness of RRAs and CCAs as a component of the Boreal Caribou Implementation Plan (BCIP) for ongoing management of boreal caribou in BC.

Distance sampling was the technique used along a total of 3,931 kms of transect within a combined area of 14,516 km^2 for an average effort of 0.271 km/km^2. Moose density was generally low; a total 313 moose were observed (0.08/km of transect) for an overall density estimate of 0.095 moose/km^2 (95% CI 0.076 – 0.120, CV 11.7%). The estimate of moose population density varied across the areas surveyed, with the lowest estimated density in Etthithun (0.044 ± 0.025 moose/km) and the highest in Chinchaga (0.151 ± 0.037 moose/km^2). This density result translates to 1,379 moose with a 95% confidence range of 1,103-1,742 in the combined study areas (although removing, Prophet and Ettithun, increases the estimate to 1,466 moose). The variation indicated a larger sampling effort may be required in future surveys of this type. The moose population demographics overall yield 51 calves:100 cows (95% CI 41 – 60) and 60 bulls:100 cows (95% CI 43 – 76). Since this study did not overlap the previous Management Unit level surveys, we used the relative change in calf ratios to demonstrate that moose populations are likely increasing in the sampled areas.

The Distance sampling approach was easily implemented, but there are still methodological changes that could be made to improve estimates. Improvements should focus on adding measures of covariates associated with the sightability of moose observed in different classes of habitat. Future surveys could serve the Boreal Caribou Implementation Plan better if the extent of the sampling area included moose habitat peripheral to the RRA and CCAs. Still further improvement could be made if sampling was stratified by moose habitat quality as this may increase efficiency of the sampling, improve precision of the estimates, and enable classification of results in a manner that is more relevant to the management of caribou range.

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Introduction

Our objective was to estimate the abundance of moose (*Alces alces*) in and around Caribou Core Areas (CCAs) in northeastern British Columbia (BC). The survey provides a baseline of current inventory data on moose in these areas that can be used to track changes in moose populations and distribution. The abundance of moose within these areas will inform biologists responsible for measuring effectiveness of Resource Review Areas (RRAs) and CCAs as a component of the Boreal Caribou Implementation Plan (BCIP) for ongoing management of boreal caribou in BC. The survey was specifically designed to augment a previous survey conducted within CCAs in the Horn River Basin (Thiessen 2010) using Distance sampling (Buckland et al. 2001).

Moose is the largest member of the deer family and as such plays a large role for people in wildlife viewing and as a food source. Indeed it is the primary wild-food species for people in northeastern BC. The annual harvest of moose represents a significant component of hunting and hunting, even as a recreational pursuit, is an important source of revenue provincially (Rowe 2008) and so, the linkage to CCAs notwithstanding, moose represent an important resource on its own. In order to manage this important resource in a responsible manner, biologists need to monitor changes in moose populations (abundance and population structure) so informed decisions about management actions can be made to maintain moose and their habitat in a condition that is consistent with management goals.

In this study, seven of the eight areas of interest are specifically designated as CCAs for boreal caribou (*Rangifer tarandus caribou*) (Heard and Vagt 1998). The CCA designation resulted in part from a joint study between BC Environment and Slocan/Canadian Forest Products Ltd. in which fine-scale vegetation information was compared to caribou habitat use observed from caribou movement data collected in that study as well as others (Culling et al 2006; BCTAC 2004, Thiessen 2009, Rowe 2007). Core areas are considered to have high current suitability based on general habitat requirements and on the documented occurrence of caribou within them, and were a first approximation of critical habitat for boreal caribou (BCTAC 2004). The CCA designation that has been placed on high-valued habitat provides the provincial government with opportunities for establishing management actions specifically focused to enhance environmental conditions for these caribou which were listed by the federal government as threatened – “a wildlife species that is likely to become an endangered species if nothing is done to reverse the factors leading to its extirpation or extinction” (SARA 2012). The management actions therefore, are part of a strategy that has been developed for managing boreal caribou and that strategy is the basis for the BCIP (Pasztor and Westereng 2011). As part of this plan, a Research and Effectiveness Monitoring Board (REMB) has been established to conduct research and inventory projects, such as this aerial inventory of moose.

The abundance of moose and other prey species within or adjacent to caribou range in some other parts of Canada has apparently been increasing in recent years as a result of habitat alteration (Wittmer et al. 2007, Serroya et al. 2011, Latham et al. 2011). Moose are the primary prey species for wolves, so their increase in an area may result in increased predation on secondary prey species such as boreal caribou. Anthropogenic alteration of caribou range may increase the abundance of early seral habitats thereby enhancing habitat suitability for moose and other non-caribou ungulates. While this may be positive for people, there is a negative for caribou. A consequence of an increase in primary prey for predators, is an increase in the number and distribution of those predators (Messier 1995), and along with that, an associated increase in coincidental predation-related caribou mortality (Rettie and Messier 1998, Chowns and Gates 2004, Wittmer et al. 2005, GA 2010). The negative effect on caribou as a secondary prey species is assumed to be exacerbated because the density-dependent relationship with predators typical for primary prey, is lacking for caribou as a secondary prey (Wittmer et al. 2005, GA 2010). A further exacerbating influence, especially in much of northeastern BC, is a presumed functional response by predators based on easier and quicker searches for prey facilitated by a relatively high spatial density of linear features (James and Stuart-Smith 200, McKenzie et al. 2012). Sorenson et al. (2008) and Environment Canada (2008) both demonstrated an overall cumulative effect on population growth rates of boreal caribou based on the calculated amount of disturbance where populations were generally in decline if the total area of the buffered disturbance footprint surpassed 35% of the caribou range.

As a result of the negative aspects of increased predation on caribou by increased moose populations and distribution (all apparently brought on by disturbance to habitat), the management goals for moose and caribou in northeastern BC have become a complex problem. The BC government has established RRAs to monitor and manage the ecological situation (Pasztor and Westereng 2011). There is also an extensive coverage of Ungulate Winter Ranges throughout boreal caribou core areas that are used to help conserve range values for caribou (Culling and Cichowski 2010). Estimating moose abundance in and around caribou range was one of the recommended performance measures for evaluating the effectiveness of the RRAs for boreal caribou (Cichowski et al. 2012). The results of this moose inventory will provide the REMB a key set of data to support management decisions in and around the CCAs and RRAs.

Study Areas

The eight study areas (Chinchaga, Etthithun, Clarke, Prophet, Etsho, East Kotcho, North Kotcho and Milligan) are situated in northeastern BC southeast of the Horn River Basin (HRB) and roughly corresponded to boreal caribou core areas (Culling et al. 2006) and one RRA (Chinchaga) (Figure 1A). The Etsho, East Kotcho, and North Kotcho areas were grouped resulting in six units for the purposes of this survey. These areas contain a wide variety of habitat types and levels of anthropogenic disturbance that greatly affect moose density and distribution. The incidence of core caribou habitat tended to select for some moderate to low capability levels for moose habitat (Figure 1B).

The Chinchaga RRA is a newly established (June 2010) management tool for Boreal caribou. No new oil and gas, mineral, placer or coals tenures are allowed in RRAs for a minimum of 5 years. Effectiveness of RRAs will be assessed in 2015. The role of RRAs is to provide conditions that are more favourable for caribou persistence than conditions that exist outside RRAs. The Chinchaga RRA totals 13,898 km^2. The remaining survey units are comprised of the CCAs including the Etthithun (822 Km^2), Milligan (4,929 Km^2), Clarke (1,381 Km^2), Prophet (915 Km^2), Etsho (62 km^2), Kotcho North (748 km^2) and Kotcho East (318 Km^2).

The Chinchaga, Etthithun, and Milligan study areas overlap the Clear Hills ecosection, which is described as a smooth rolling upland gradually rising in elevation towards the north and east into Alberta. This ecosection receives moist summers and cold dry winters and consists of underlain flat

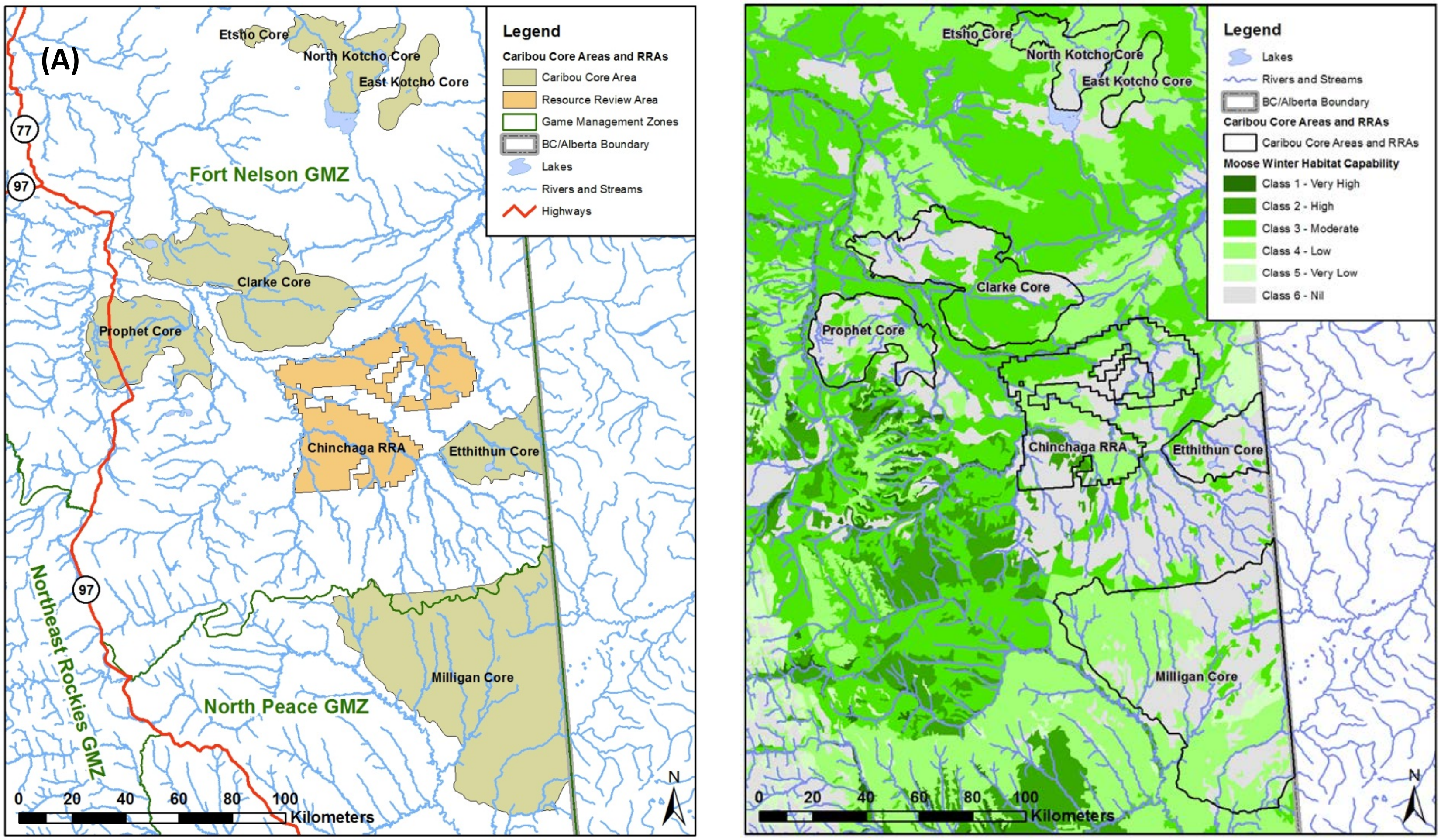

Figure 1. Caribou core areas and Resource Review Areas (RRAs) in relation to wildlife management units (A) and moose habitat capability (B) in northeastern British Columbia. Moose Winter Habitat Capability Mapping adapted from MoE shapefile – BEI moose Andersoni (data source: BC Min. of Forests, Lands, and Natural Resource Operations, Prince George, BC).

lying sedimentary sandstone that has been buried by the Continental Glaciers. The upland forests are a mix of black and white Spruce with lodgepole pine on drier, well-drained sites. Fire impacted areas result in regeneration of trembling aspen and willow patches (Demarchi 2011). The Prophet and Clarke study areas overlap the Fort Nelson Lowland ecosection and the Etsho/Kotcho study areas fall into the Etsho Plateau ecosection (Demarchi 2011). The Fort Nelson Lowland ecosection is a broad lowland area with some gently rolling portions. The lowland area is estimated at ~610 m in elevation along sandstone scarps. Drainage in this ecosection is not well developed and is drained to the north by the Fort Nelson River and to the east by the Hay River. This area can experience long periods of intense cold temperatures in the winter with short days. Black and white spruce is the main forest type in this ecosection, but there are many wetlands and muskeg that are surrounded by black spruce and tamarack. White spruce is generally situated on the alluvial soils along the rivers and drier sites (Demarchi 2011). The Etsho Plateau ecosection is rolling uplands of gentle eastward dipping sandstone that rises steeply. Elevation varies from 750 m to 950 m. The summer has localized showers, high humidity and cumulus clouds due to surface heating of water bodies. This area withstands extreme cold Arctic air in the winter, often accompanied with clear skies (Demarchi 2011).

All of the sampling areas are within the BWBS Biogeoclimatic zone (Meidinger and Pojar 1991). The general climate for the study area is characterized as having frequent outbreaks of arctic air masses, with long very cold winters and short growing seasons. The mean annual temperature for long-term climatic stations within the zone is -2.9 to 2°C. Annual precipitation averages between 330 and 570 mm with 35-55% of this occurring as snow fall (Meidinger and Pojar 1991).

Within the Peace Region, moose are managed at the wildlife management unit (MU) scale. The survey units that make up the study area overlap MUs 7-55, 7-56, 7-47, 7-48, 7-49 and 7-46. Rowe (2008) further lumps these areas into Game Management Zones (GMZ), of which our study area overlaps the Fort Nelson GMZ (G and H) and North Peace GMZ (C). It was not feasible to overlap each of these MU's or GMZ's entirely and still survey the core caribou areas.

Many of the relevant MUs have historically had low recorded densities of moose (Rowe 2008). The recorded density for moose in GMZ subzone G (Etsho, North Kotcho, East Kotcho, Clarke study areas) was 0.087 moose/ km^2 with ratios of 76.3 bulls/100 cows and 23.7 calves/100 cows (Rowe 2008, Backmeyer 2004). The Thiessen (2010) inventory also overlaps this area and recorded an overall density of 0.116 moose/km^2, with the closest area in MU 7-56 to our study area being 0.124 moose/km^2. There was no density estimate for MU 7-48 (Prophet), but the recorded density for MU 7-47 (Chinchaga and Ettithun) was the lowest in the Peace Region at 0.044 moose/km^2 +/- 24.6% and recorded calf ratios of 9.4 calves/100 cows +/- 75.1% and bull ratios of 63.5 bulls/100 cows +/- 44.7% (Rowe 2005, Rowe 2008). The recorded density for MU 7-46 (Milligan study area) ranges from 0.0875 moose/km^2 +/- 23.32% with a ratio of 38.4 bulls/100 cows +/- 38.1% and 47.98 calves/100 cows +/- 20% for 7-46 combined with 7-33 (Rowe 2005) to a density for just 7-46 of 0.05 moose/km^2 +/- 28.39% with a ratio of 53.7 bulls/100 cows +/- 38.19% (Rowe 2008).

The study area overlaps the Chinchaga, Prophet and a portion of the Snake-Sahtaneh boreal caribou herd ranges. Of the estimated 21,800 Woodland Caribou in BC, boreal caribou are approximately 1,300 in number (Culling and Cichowski 2010). Culling *et al*. (2004) identified a total of 13 Core Habitats within 4 Boreal Caribou Ranges and an additional 2 Core Habitats (Prophet and Parker) without any broader range. The most reliable enumeration of boreal caribou was made in 2000-2010; bolded numbers in Table 1 are for the study areas used in this report.

Table 1 - Current population estimate, trend, risk status and density of Boreal Caribou populations in British Columbia[1]. Populations estimated to be declining are given in ***bold (****adapted from Culling and Cichowski 2010)****.***

Herd (#)[1]	**Population Estimate[2]**	**Recent Trend[3]**	**Population Risk Status**	**Range Area** (km²)
BC Chinchaga (# 1)[4]	**250[6]**	**Decline**	**Vulnerable**	**13,979**
BC Maxhamish (# 10)	300	Unknown	Vulnerable	7,095
BC Calendar (# 11)	290	Unknown	Vulnerable	4,962
BC Snake Sahtaneh (# 12)	**360**	**Decline**	**Vulnerable**	**11,980**
BC Parker Core (# 13)	25[5]	Unknown	Vulnerable	224
BC Prophet Core (# 14)	**54**	**Unknown**	**Vulnerable**	**915**
Total	1,290-1,340			39,155

[1] Herd numbers from Environment Canada (2008)
[2] From Ministry of Environment unpublished data (2008) unless otherwise stated
[3] Recent trend defined as trend over last 7 years (1 generation length). Trend based on >20% change
[4] Environment Canada classifies AB and B.C. Chinchaga caribou as a single population; pop. estimate and range area refer to BC portion of population only (estimate based on Ministry of Environment 2008)
[5] From Thiessen (2009)
[6] Culling et al 2004 places this range at 433 to533 animals

Table 2 is used to characterize the amount of anthropogenic disturbance that has occurred within each of the study areas as calculated by Thiessen (2009)[1]. The Snake-Sahtaneh herd range area of 11,980 km² had a disturbance footprint of 10,043 km² or 83.8% impacted (Table 2). The Chinchaga herd range area of 13,979 km² had a disturbance footprint of 12,012 km² or 78.8% impacted and the large Milligan Core Habitat area was over 92.5% impacted. These relatively high levels of anthropogenic disturbance may have already resulted in widespread improvements to moose habitat because of the early seral setting established through disturbance. Also, we presume that habitat value for caribou has been altered detrimentally due to the removal of older seral states which promote lichen growth and better caribou habitat.

Table 2 –Area (km²) of boreal caribou cores and anthropogenic disturbance within them, and the percent area impacted by disturbance (adapted from Thiessen (2009)). Core areas are sorted from low to high percent impact. Bold numbers indicate ranges above the 61% threshold.

Core	**Core area**	**Disturbance area**	**% Impacted**
Etsho	62	38	**61.9**
North Kotcho	748	554	**74.0**
Etthithun	822	620	**75.4**
Prophet	915	716	**78.2**
East Kotcho	318	272	**85.4**
Milligan	4929	4560	**92.5**
Clarke	1381	1292	**93.5**
West Kotcho	362	342	**94.4**

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[1] Note that these disturbance calculations, although similar in nature to those made by Sorenson et al. (2008) and Environment Canada (2008) were based on different input data which undoubtedly compromises the direct comparison to the published threshold disturbance levels. Nevertheless, the magnitude of disturbance levels in most areas is likely still indicative of levels that exceed the published thresholds.

Methods

Distance sampling

Historically, and still in most places in BC today, the usual method for estimating moose population density is by stratified random block (SRB) surveys (Gasaway et al. 1986). In a couple of previous occasions that we are aware of (Peters et al. 2010 , Thiessen 2010), distance sampling (Buckland et al. 2001) has been assessed in an attempt to reduce the cost of such surveys. Distance sampling was specified for this survey to facilitate comparisons to previous moose surveys (Thiessen 2010) and since a relatively large portion of this region in NE BC was to be sampled, it was considered that the survey would be more efficient using the Distance technique. Distance sampling requires observations to be taken along pre-determined transects with the primary assumption that all sample objects (i.e., moose) occurring on the transect line are observed perfectly (i.e., 100%). There is a decreasing probability of detecting moose with increasing distance from the line and the distance data that are recorded (Figure 2) allow a detection probability to be calculated. It is from that detection probability (P_a) that a population density estimate (D) can be derived (Buckland et al. 2001) where a is the area surveyed calculated as $a = 2wL$, L is the total transect length, and w is the perpendicular distance from the transect at which moose are observed. The expected number of moose in a E(n), is equal to the expected number of animals in the survey area, D x a, multiplied by the probability of detection so that D = E(n) / a x P_a (Buckland et al. 2001). The numerator is modified to n x E(s) if observations are recorded as clusters of moose where n becomes the number of observations and E(s) is the expected cluster size. The denominator can also be modified with constants to account for specific survey designs (e.g., observations from only one side of the transect) or covariates (e.g., habitat strata).

Survey unit selection and transect establishment

Survey units were considered to be all CCAs and RRAs that were not previously sampled by Thiessen (2010) and boundaries of those areas (Figure 1) were identified using data downloaded from the BC Land and Resource Data Warehouse[2].

Transect lines were spaced every 3 or 6 kilometers and oriented east/west following Universal Transverse Mercator (UTM) zone 10 parameters for all survey areas except Prophet where transects were north/south and Etthithun where transects were diagonal northeast/southwest. The desire to orient transects in one of the cardinal directions was for ease of navigating along the lines in the field, returning to the line after retrieving coordinates of an observed animal, and for ease of post-survey data calculations (e.g., perpendicular distance of observed moose from the transect). Orientation was altered in the Prophet and Etthithun survey units in order to maximize individual transect lengths.

The 3-km transects were used to boost sample effort if the sampling crew considered it necessary to achieve the desired coefficient of variation (CV) for the estimate of moose density. The sample crew was not able to calculate a cumulative CV while the sampling was being conducted and so used a “rule of thumb” to facilitate the decision to increase sample effort. This rule entailed randomly adding 3 km spacing lines where the study area boundaries resulted in short transects and/or where low count numbers were encountered along consecutive transects. In practice this resulted in smaller study areas tending to have transects at 3 km spacing, while the larger areas only had an occasional random line inserted.

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[2] See http://archive.ilmb.gov.bc.ca/lrdw/ (accessed February 18, 2013).

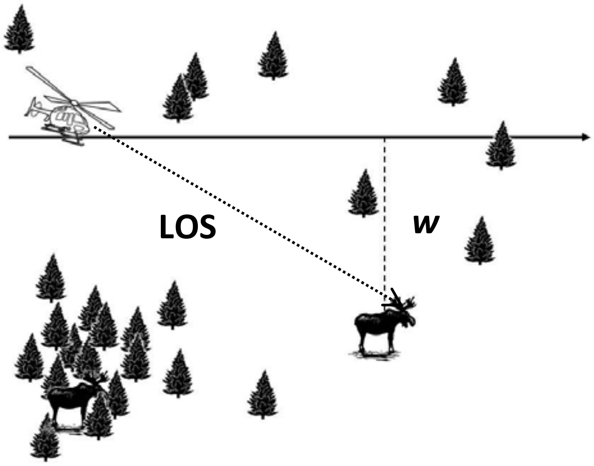

Figure 2. A schematic of the methods used in Distance sampling (adapted from Thiessen 2010) representing the perpendicular distance (w) between the transect line (solid) and the observed moose when it was first seen along the line-of-sight (LOS) from a helicopter.

Sampling

A laptop running OziExplorer (version 3.95.5p) tethered to a Garmin 62Sc handheld GPS receiver (+/- 3 to 5 m accuracy expected) was used to navigate along the transect lines. When moose were spotted their locations were obtained by flying off the transect to mark the UTM coordinate of the moose (or incidental species) from the helicopter. When more than one moose was observed in a group the UTM location was taken at the midpoint among the moose in the group. Moose > 100 meters apart were considered to be separate groups and each given their own UTM coordinate. Transects were flown at 75 – 120 km/h depending upon the density of the vegetation and at 100 meters above ground. Height above ground was modulated based on visual reference to the ground and by monitoring the difference between altitude and topographic contours from the GPS map.

Moose were classified by age and gender according to RISC Level II or III standards (Resource Inventory Committee 2002), dependent upon the presence or absence of antlers. When antlers were not present, gender was determined using the presence of the white vulval hair patch for females and the absence of the vulval hair patch and/or presence of antler scars for males. When antlers were present males were classified based on their antler architecture. Incidental observations of other wildlife species were recorded. Boreal caribou were classified as male (absence of black vulva), female (presence of black vulva), and calf. Wolves were recorded by colour. Grouse sightings and tracks were also recorded. Bovids were not classified, but recorded.

Collection of ancillary information

During the survey, temperatures and snow depths were recorded daily. Temperature was recorded from the on-board external thermometer in the helicopter prior to take off and snow depths were updated periodically at animal observations based upon the depth observed on the animal and estimated into a snow depth. Other information such as visibility, speed and wind direction were collected for each transect at the beginning of the line. Visibility categories were at the discretion of the navigator and broken down into five classes as described in Table 3. Due to the frequency of very poor and very good observations being low, these categories were merged with the adjacent category in analysis resulting in 3 visibility classes used as covariates.

In addition to the animal sightings data, a second habitat form was completed that was used to record slope, aspect, elevation, BEC zone, two primary habitat types, percent cover, canopy closure (low, medium, high), and snow cover (Table 4).

The sample data forms for collecting information are provided in Appendix 1.

Table 3 – Visibility Class ratings and explanation of criteria for surveyor ranking.

Visibility Class	**Criteria**
Very Poor	Overcast, snowing, dark and grey light conditions, observations restricted to ~100 m from the helicopter
Poor	Overcast, no snow to light snow, light grey light conditions, observations restricted to ~150-200 m from the helicopter. Also, bright sunny conditions with sun low in the sky and extensive shadows.
Moderate	Cloudy, light grey light conditions, observations restricted to ~300-500 m from the helicopter. Also, sunny conditions with shadows.
Good	Light cloud to bright sun with few shadows, observations not restricted laterally.
Very Good	Light cloud, good light conditions with no shadows, no visibility restrictions.

Table 4 – Physical measurement categories gathered at each animal observation

Slope Code			**Canopy Closure**	
1	**0%**	*Flat*	***L***	**Low (0-33%)**
2	**5-20%**	*Minimal Slope*	***M***	**Medium (34-66%)**
3	**20-50%**	*Moderate Slope*	***H***	**High (67-100%)**
4	**>50%**	*Steep*	Any vegetation that blocks the view of the moose; based on % of ground not being visible in a 10 m diameter around the moose initially sighted in a group.	
Snow Cover				
1	**poor (bare ground showing)**			
2	**good (some low veg showing)**			
3	**excellent (complete snowcover)**			

WA	*Water*	**SB**	*Spruce Eng./Subalp Fir/Scrub Birch*	**TA**	*Talus Slope*
WE	*Wetland/Bog*	**PS**	*Lodgepole Pine/Spruce Mixed*	**SU**	*Subalpine*
ME	*Meadow*	**CD**	*Confererous/Deciduous Mixed*	**BU**	*Burn*
RI	*Riparian*	**CS**	*Cottonwood/Spruce*	**CU**	*Cut Block*
WS	*Willow/Shrub*	**BS**	*Black Spruce*	**UV**	*Unvegetated*
DE	*Deciduous*	**AR**	*Alpine Ridge*	**RD**	*Road*
LP	*Lodgepole*	**AV**	*Avalanche Track*	**OG**	*Oil&Gas Site*

Analysis

Population Density

Estimates of moose densities were calculated using the program Distance 6.0 Release 2 (Thomas et al. 2009). We first undertook a number of exploratory analyses of the distributions of key variables and potential covariates, in order to determine the appropriate Distance modeling assumptions to apply. Of primary importance for estimating densities based on distance sampling are the assumptions that: (1) all animals located on or near the line are detected with certainty; (2) animals are detected prior to any responsive movement; and (3) measurements are made without errors (Buckland et al. 2007). For all areas pooled, and for each survey area separately, we plotted distributions of distances measured from transects to observations of moose (single or cluster). We also plotted distributions of observed cluster sizes (i.e. groups of moose), canopy closure, and visibility classification. We used the results of these plots to help make model-fitting assumptions and to help identify and interpret potential biases and limitations of the data.

In order to meet the assumptions of Distance 6.0, we 'left-truncated' (i.e. removed observations <

a specified distance) data from those survey areas where the frequencies of distances close to the transect were less frequent than distances farther away (i.e. see results below for Etsho/Kotcho and Prophet). For ambiguous cases (i.e., Clarke) we fit separate models with and without left truncation and used Akaike's Information Criterion (AIC, Burnham and Anderson 1998) to indicate the best fitting model. We assessed the following factors for possible explanation of the need to implement left-truncation using a Chi-square test: observer bias (starboard, port), cluster size (1, >1), and movement behavior (bedded, standing/moving). We did not apply a size-bias regression to the estimate of the detection function unless the regression was significant at $\alpha = 0.15$.

Observations > 1 km from transects were also truncated in our analyses (i.e. the largest 2% of the distances). Truncation of 5%-10% of the largest distance observations ('right-truncation') is recommended to improve the fit of the detection function (Buckland et al. 2001); but we needed to trade-off this recommendation with the desire to retain observations because overall sample sizes were quite small at the individual survey unit level (range of area-specific sample sizes: n = 7 to 47).

Preliminary model fits to the pooled data set indicated that detection probability functions were best fit (using AIC criteria) to the selected data using a half-normal key model with a cosine expansion. Fits made with either the hazard-rate key function, or other series expansions (e.g., simple and hermite polynomials; see Buckland et al. 2001 for descriptions), fit the pooled data set less well. We applied the half-normal key with cosine expansion model form for the detection functions for all survey areas to maintain a common model assumptions set. Estimates of variance were made using the empirical variance estimation approach (Buckland et al. 2001) for all model fits. Bootstrapping the estimate was used with the following exceptions: (1) when fitting cluster size as a covariate and (2) if model convergence errors or other warnings occurred.

We fit four detection models for both the pooled data and for each survey unit: (1) a model with no covariates; (2) a model using cluster (group) size as a covariate, testing whether larger groups are easier to observe; (3) a model using canopy closure as a categorical covariate testing whether observations are affected by the relative density of tree crowns; and (4) a model using visibility categories (Table 3) as a covariate, testing the effect of the index of visibility on the probability of observing moose (see Appendix 3: Figure 19 for exploratory plots of these covariates for all survey areas pooled). We entered covariates individually in our model formulations and did not examine multi-covariate models. All covariates were entered as factors to the models.

We evaluated candidate models with AIC (Burnham and Anderson 2002) and retained models with ΔAIC ≤2.0 (Burnham and Anderson 2001). Models that ran with convergence warnings or with highly correlated parameters leading to unreliable estimates of AIC and density were excluded. This model evaluation and selection procedure was necessary because we did not know the ecological and sampling factors that might have influenced the data. Estimates of density and extrapolated population estimates were made on the basis of the minimum AIC for a given unit. Pooled density estimates, as well as separate estimates for each individual survey area (Chinchaga, Clarke, Etthithun, Etsho/Kotcho, Milligan, and Prophet) were calculated. All estimates were calculated with two-sided 95% confidence intervals. The numbers of moose in each survey unit were simple extrapolations of the density estimates based on the area (ha) of each survey unit.

Population Structure and Demographics

Standard metrics that characterize moose population structure (i.e., calf:100 cows, calves as percent of the population, and bulls:100 cows) were calculated using Proc Survey, a statistical procedure available from SAS (An and Watts 2013). We used estimates of anthropogenic disturbance levels within each study area (as calculated by Thiessen 2009; the Chinchaga RRA was not included) and linear regression analyses to test for potential effects on observed moose populations (i.e., population density and calf:100 cows).

The finite rate of change (λ) for the moose populations assessed in this study could not be calculated on the basis of comparisons to historic population estimates because of the relatively restricted area that we surveyed. Rather, we used the estimated calf:100 cows ratio, an assumed equal sex ratio at birth, and an assumed adult cow total annual mortality rate of 12% (Bergerud and Elliott 1998) to estimate λ for the cow portion of the population. This approach could have included bulls but the initiating conditions for bulls:100 cows tends to vary more than the other parameters (i.e., bull mortality changes with licensed hunting regulations). As an example of the approach, with 40 calves:100 cows, 20 females are recruited per year and 12 adult cows die, leaving the $\lambda_{Cow} = (100+(20-12))/100 = 1.08$. $\lambda > 1$ indicates an increasing population, a $\lambda = 1$ represents a stable population, and $\lambda < 1$ indicates a decreasing population.

Results

Survey Characteristics

The survey was conducted between January 14 - 27, 2013 with 64.1 hours of helicopter services, 39 hours of which were direct effort (Etsho/Kotcho 7.3 hours, Clarke 7.7 hours, Prophet 4.3 hours, Milligan 8.75 hours, Chinchaga 7.65 hours, Ettithun 3.3 hours). Visibility ratings were mostly moderate, with 2 hours of very good visibility and 2.8 hours of very poor visibility. Temperatures during the survey were slightly warmer and snow depths slightly deeper than normal (normal daily minimum temperature= -22°C), and snow depth=62.1 cm) by Environment Canada (Figure 3). During the entire survey, 3,795.64 km's of transect were flown (Appendix 2) with a range of 197.6 km (Ettithun unit) to 1,061.11 km (Milligan unit) in each individual unit (Table 5). The relative sampling effort for each survey unit was about 0.27km of transect per km^2 (Table 5) and an overall total of 313 moose were observed (Table 6).

Table 5. Area of each survey unit, sampling effort in each unit (km's of transect flown), km's of transect flown per km^2 of survey area, and the number of moose groups sighted per km of transect flown for the January 2013 moose survey.

Survey area	Survey unit area (km^2)	Sampling effort (km)	Number of moose groups	Km of transect/km^2	# of moose groups / km
Chinchaga	2,403.23	677.18	47	0.281779	0.069
Clarke	2,224.04	669.38	46	0.300975	0.069
Etsho/Kotcho	2,718.84	936.20	31	0.344338	0.033
Etthithun	780.31	197.61	7	0.253246	0.035
Milligan	5,196.18	1,068.4	47	0.205613	0.044
Prophet	1,193.03	382.45	25	0.320567	0.065
All combined	14,515.63	3,931.22	203	0.270827	0.052

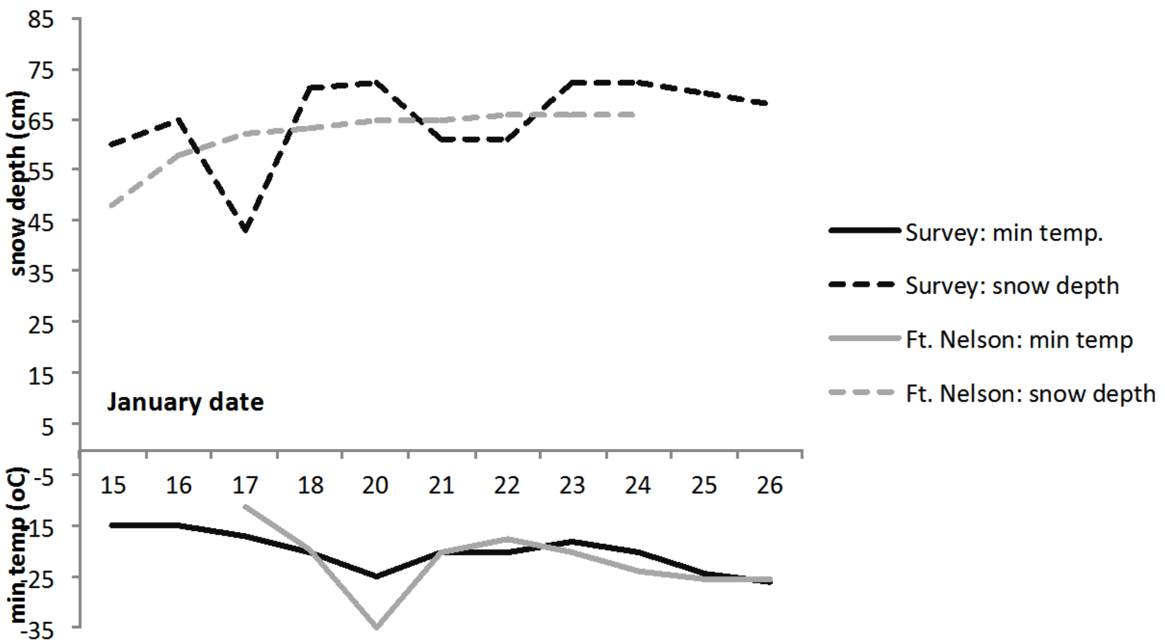

Figure 3. Daily minimum temperatures (°C) and snow on ground (cm) from data taken by the survey (black lines), and at Environment Canada's Fort Nelson weather station over the survey period in January 2013.

Table 6 – A summary of moose (Alces alces) observations made during a Distance sampling survey conducted in north-eastern British Columbia, January 2013.

Survey area	Total Moose	# Cows	# Calves	# Bulls	# unclassified
Chinchaga	81	29	17	34	1
Clarke	74	35	22	16	1
Etsho/Kotcho	40	19	6	14	1
Etthithun	7	6	0	1	0
Milligan	70	37	18	15	0
Prophet	41	20	11	7	3
All combined	**313**	**146**	**74**	**87**	**6**

Exploratory Analyses

Exploratory analyses (Appendix 3) indicated that for the pooled dataset, the distribution of detection distances followed a monotonically decreasing distribution (Appendix 3: Figure 15), satisfying a key distributional assumption of the Distance analysis (Buckland et al 2001, 2007). However, detections in a few of the survey areas showed less frequent detections of moose at shorter distances (e.g., < 100-200 m) from the transect than were detections > 200 m (Appendix 3: Figure 16). There was little evidence to suggest potential reasons why detections at the transect were presumably less than perfect (Table 7): port versus starboard observer bias ($X^2_{(2,195)} = 1.76$, P = 0.62) or bedded versus standing/movement bias ($X^2_{(3,199)} = 6.61$, P = 0.36). Also, we found little supporting evidence that large cluster sizes increased detection at greater distances (i.e. a size-bias effect on detectability) either for all surveys pooled (Appendix 3: Figure 17) or for individual survey areas (Appendix 3: Figure 18), although it is possible such a relationship could be masked either by interactions with other covariates or most likely by small sample sizes per survey area.

Table 7 Number of moose observations made by distance class from the transect and behavior of moose (top) and side of helicopter (i.e., observer).

	Distance Class (m)				
	0-199	200-399	400-599	>599	Total
Behavior					
Bedded	19	12	3	4	38
Standing	52	41	17	16	126
Moving	12	17	5	1	35
Total	83	70	25	21	199
Side of Helicopter					
Port	51	37	13	12	113
Starboard	30	32	12	8	82
Total	81	69	25	20	195

Models of Detection Probability and Moose Density Estimates

The candidate models (each survey area and areas pooled) are shown in Table 8. Estimated probabilities of detection ranged from 0.16-0.43 with an overall estimate of detection probability = 0.44 for all areas pooled. Visibility and cluster size emerged as candidate covariates for several areas, although models fit with these covariates were not superior to models fit without covariates (Table 8). For the entire survey area, we estimated a density of 0.095 moose/km^2 (0.076-0.120 at 95% confidence interval (CI)) which produced a population estimate of 1,379 moose (1,060-1,742 at 95% CI) (Table 9). The coefficient of variation for the density estimate was 11.7% indicating the observed data over the areas pooled was well represented by the modeled detection probability (Figure 4). Survey area -specific detection functions are presented in Figure 5. The maximum distance moose groups were spotted (after truncation) was 964 meters.

Table 8. Candidate detection models fit to the selected distance data for each survey area and for all areas pooled.

Survey Area	Covariate	*K*	AIC	ΔAIC	P_d^2	GOF[3]
Chinchaga	--	1	609.77	--	0.39	*p* = 0.66
	cluster size	2	610.74	0.97	0.39	*p* = 0.66
Clarke	--	1	580.08	--	0.38	*p* = 0.69
	visibility	3	580.24	0.16	0.35	*p* = 0.92
	cluster size	2	582.07	1.99	0.38	*p* = 0.70
Etsho/Kotcho	visibility	5	299.11	--	0.16	*p* = 0.81
Etthithun	--	1	93.73	--	0.43	*p* = 0.83
Milligan	visibility	3	579.18	--	0.28	*p* = 0.90
	--	1	580.18	1.10	0.28	*p* = 0.84
Prophet	cluster size	2	250.96	--	0.37	*p* = 0.74
	--	2	251.11	0.16	0.17	*p* = 0.94
Overall (areas pooled)	--	2	2618.23	--	0.43	*p* = 0.67
	visibility	5	2618.49	0.26	0.44	*p* = 0.63
Overall (no Etthithun)	--	5	2526.44	--	0.43	*p* = 0.59
	visibility	3	2526.97	0.53	0.45	*p* = 0.63
Overall (no Etthithun or Prophet)	--	4	2284.76	--	0.39	*p* = 0.66
	visibility	1	2284.80	0.03	0.40	*p* = 0.70

[1] *Number of parameters*

[2] *Probability of detection*

[3] *Goodness of fit test results using Kolmogorov-Smirnov tests of the fit of the fitted detection function to empirical data.*

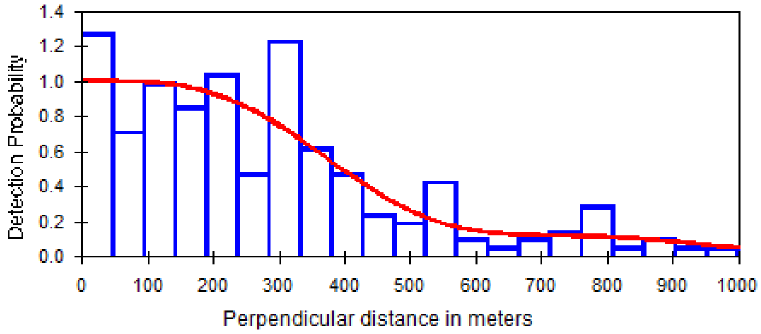

Figure 4. Detection probability plot for moose observations from all survey units pooled from the 2013 NEBC moose survey (N = 202 moose observations).

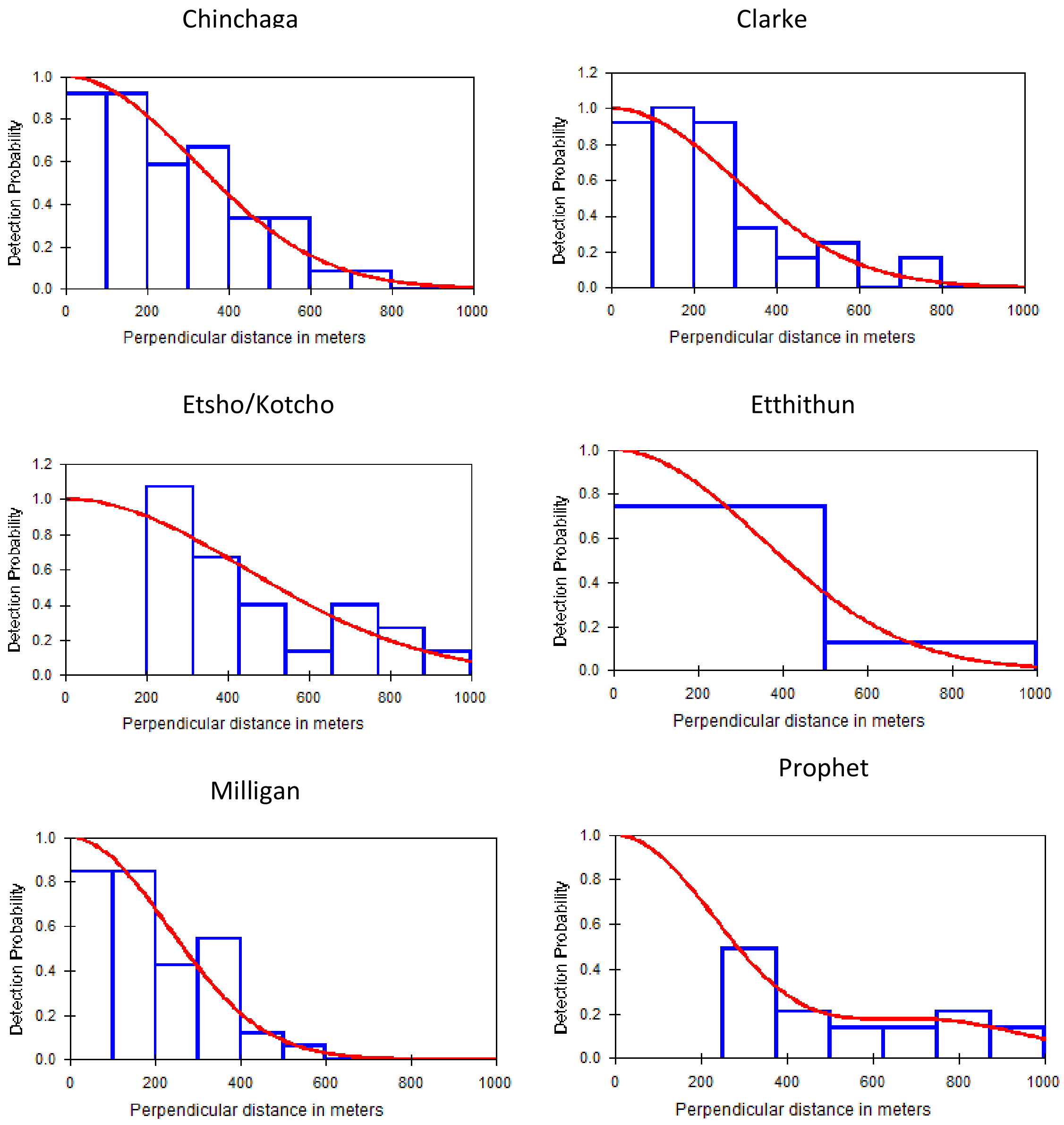

Figure 5. Detection probability plots for moose observations for each of the 6 areas surveyed during the 2013 NEBC moose survey.

Densities ranged from a low of 0.044 moose/km^2 in the Etthithun unit (Table 9 and Appendix 2: Figure 13) to 0.151 moose/km^2 in the Chinchaga unit (Table 9 and Figure 12). Extrapolating from these estimated densities on the basis of each unit's area lead to estimates of the number of moose in each survey unit ranging from a high of 587 moose (348 - 987 at 95% CI) in the Milligan unit to a low of 34 moose (10 – 209 at 95% CI) in the Etthithun unit (Table 9).

Table 9. Estimated density and population size estimates of moose from the six survey units and total study area of the January 2013 moose survey.

Survey area	Number observed	Population		Density (#/km^2)		% Coefficient of Variation
		Estimate	95% CI	Estimate	95% CI	
Chinchaga	81	363	216 - 591	0.151	0.09 - 0.246	**24.2**
Clarke	74	322	209 - 500	0.145	0.094 - 0.225	**21.6**
Etsho/Kotcho	40	345	128 - 932	0.127	0.047 - 0.343	**51.3**
Etthithun	7	34	10 - 209	0.044	0.013 - 0.147	**57.2**
Milligan	70	587	348 - 987	0.113	0.067 - 0.190	**25.6**
Prophet	41	144	31 - 657	0.121	0.026 - 0.551	**84.0**
Overall (areas pooled)	313	1,379	1,103 – 1,742	0.095	0.076 - 0.120	**11.7**
Overall (no Etthithun)	306	1,423	1,253 – 1,592	0.098	0.088 - 114	**11.9**
Overall (no Etthithun/Prophet)	265	1,466	1,281 – 1,651	0.101	0.088 - 114	**12.6**

The percent CV for all areas pooled was 11.7%. Estimated CVs at the level of the individual survey unit ranged widely from a maximum of 84.0% in the Prophet survey area to a minimum of 21.6% in the Clarke survey area. The area-weighted average CV among the individual units was 38.4%.

Moose Population Structure and Demographics

The number of calves:100 cows ranged from 32 in the Etsho/Kotcho unit to as many as 62 calves:100 cows in the Clarke unit. The sample size in the Etthithun unit was too small to achieve an accurate population structure (Table 10). For all the units combined there were 51 calves:100 cows. The number of bulls:100 cows ranged from 35 in the Prophet unit to 117 in the Chinchaga unit and was 60 across the entire study area (Table 10).

There was a direct positive relationship evident between calves:100 cows and moose density and between bulls:100 cows and moose density (Figure 6). The number of calves:100 cows was only weakly related (R^2 = 0.1297) to the % area impacted by anthropogenic disturbance and there was essentially no relationship (R^2 = 0.0295) between moose density and disturbance level. When data were pooled with those of Thiessen (2010), we observed the same result (Figure 7). The calculation of population status represented by relative growth rate (λ_{Cow}) indicated that all but the Etthithun area had positive growth (Table 11).

Table 10. Calves:100 cow moose, percent calves in population, and bulls:100 cow moose from the 2013 NEBC moose survey (95% confidence interval in parentheses).

Survey area	Calves:100 cows	% calves	Bulls:100 cows	Number of cows
Chinchaga	59 (39-78)	21 (14-28)	117 (57-177)	29
Clarke	63 (42-84)	30 (22-37)	46 (18-73)	35
Etsho/Kotcho	32 (27-60)	15 (3-27	74 (19-128)	19
Etthithun	0	0	17 (0-64)	6
Milligan	49 (29-68)	26 (17-34)	41 (13-68)	37
Prophet	55 (33-77)	27 (17-37)	35 (5-65)	20
All combined	51 (41-60)	24 (20-27)	60 (43-76)	146

Table 11 – Summary of the calculation of λ across the survey units

Survey area	**Density**	**Calves:100 cows**	**% calves**	**Number of Cows**	**Cow λ**
Chinchaga	0.151	59	21	29	1.175
Clarke	0.145	62	30	35	1.19
Etsho/Kotcho	0.127	32	15	19	1.04
Etthithun	0.044	0	0	6	0.88
Milligan	0.113	49	26	37	1.125
Prophet	0.121	55	27	20	1.155
All combined	**0.095**	51	23	146	1.135

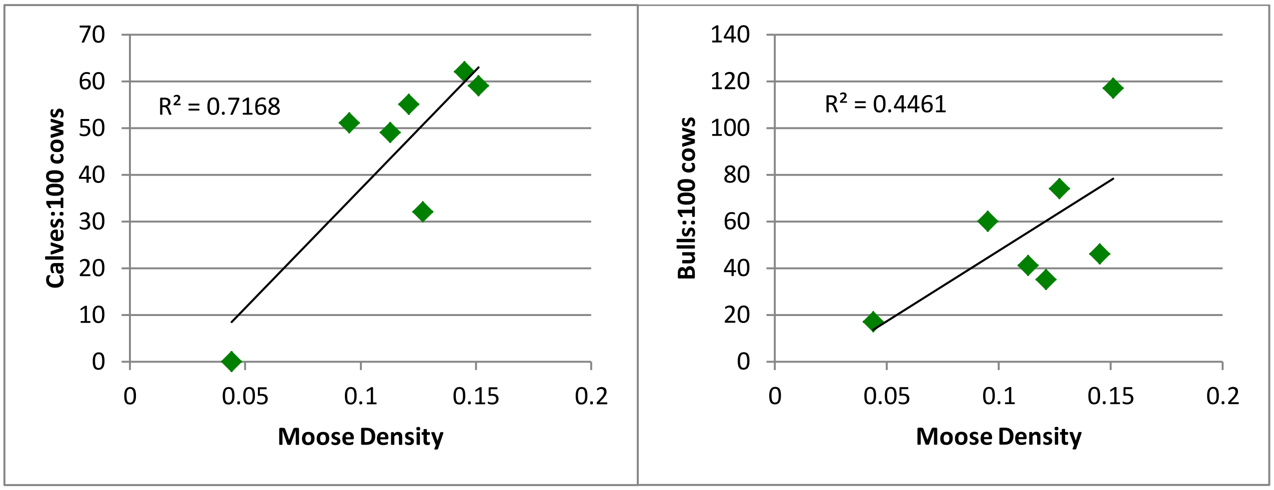

Figure 6 - Relationship between moose density and calf:cow ratios and bull:cow ratios in six units surveyed during the 2013 aerial moose inventory of NE BC.

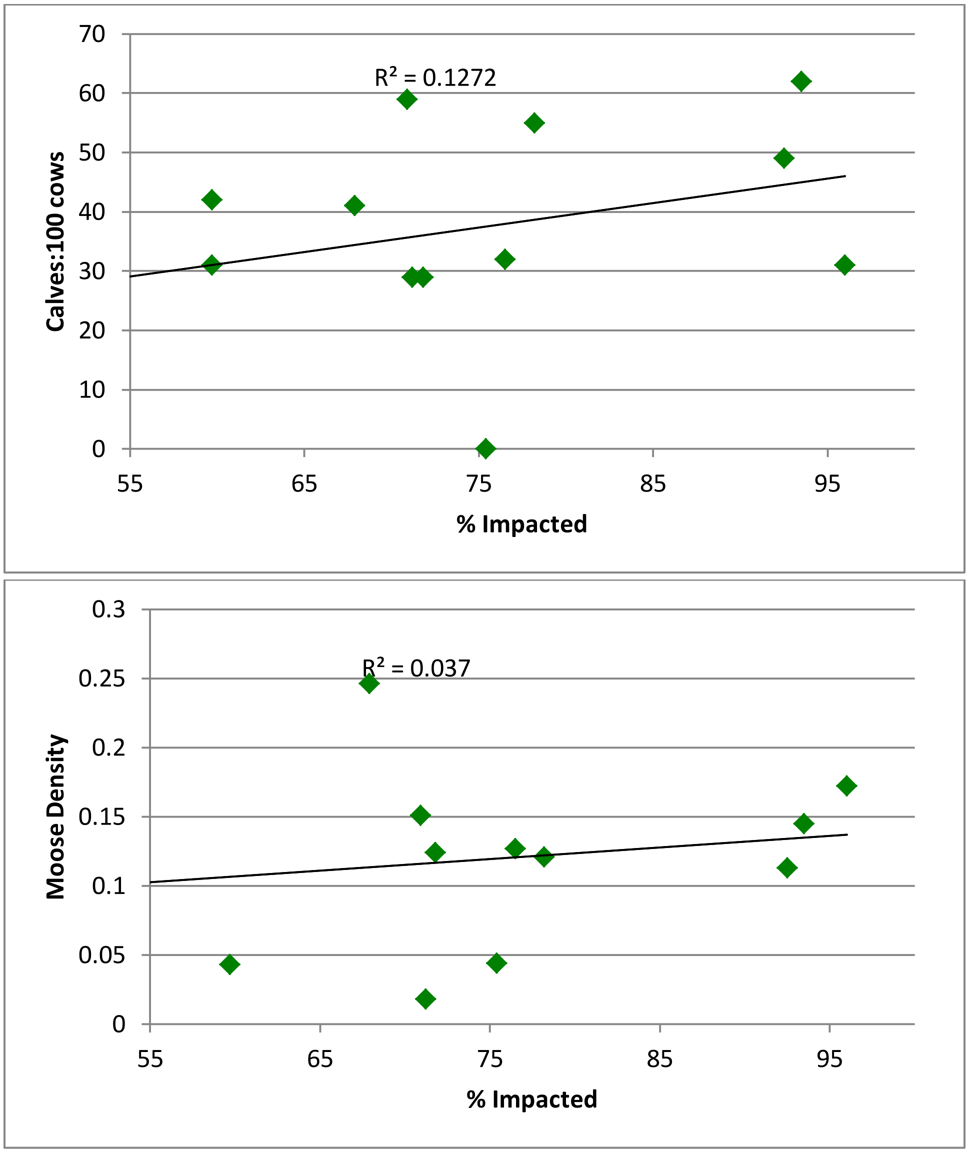

Figure 7 – Calves:100 cows and Moose density shown to hold no significant relationship across all the CCA's as % area impacted by anthropogenic disturbance.

Incidental Observations

During the survey, a variety of species other than moose were sighted and recorded. Of primary interest were boreal caribou and large predators. Boreal caribou occurred at densities too low to analyze using Distance sampling, however we were able to calculate some demographic parameters from the observations. When all caribou sightings were pooled they totaled 220 individuals, of which 65 were not identified to sex. Of the 155 that had been identified for sex, there was a ratio of 47.7 calves:100 cows and 28.4 bulls:100 cows. While this bull ratio is similar to that observed by Thiessen (2010) of 31 bulls:100cows, the calf ratio is triple that observed in the previous study of 17 calves:100 cows. We can see in Table 12 that this was a consistently higher calf ratio across all study areas. Two separate wolf packs were observed one contained 3 wolves and the other 4 wolves. One lone wolf was also observed. One dead moose was observed during the survey, due to the carcass being fully intact and lack of blood in the area wolves were not suspected. No elk or white-tailed deer were observed but several groups of wood bison were observed for a total count of 49. Sharp-tailed grouse were evident in the majority of the survey units. A single porcupine was also noted in the Etsho/Kotcho survey unit.

Table 12. Incidental species sighted during the NEBC moose population survey.

Survey Area	Boreal caribou			Bison	Wolf	Coyote	Sharp-tailed Grouse
	Total	Calves:100 cows	Bulls:100 cows				
Chinchaga	28	42.8	9.5	0	3	0	0
Clarke	46	21.9	21.9	0	0	0	26
Etsho/Kotcho	60	55.5	11.1	0	0	0	6
Etthithun	4	N/A	N/A	8	0	0	0
Milligan	70	40.6	34.4	41	1	3	12
Prophet	12	50	50	0	4	0	16
Total	**220**	**47.7**	**28.4**	**49**	**8**	**3**	**60**

Discussion

Detection Model

We found that it was difficult to distinguish between candidate detection models fit with no covariates, or with visibility and cluster size as covariates, although the overall best fitting model for the pooled data appeared to be with no covariates. Canopy closure did not produce a satisfactory candidate model for any of the areas. This apparent lack of influential covariates is somewhat surprising since we know from other studies that detection of moose is highly correlated with habitat structure (Quayle et al. 2001). The study areas had large areas of relatively low habitat structure which could have led in part to this lack of effect. However, there were still islands of conifers capable of concealing moose. In this regard, we consider that Distance sampling and perhaps even other survey techniques, still have room for methodological improvements. If, for example, habitat along a hypothetical sampling transect was homogenous (lines A or B, Figure

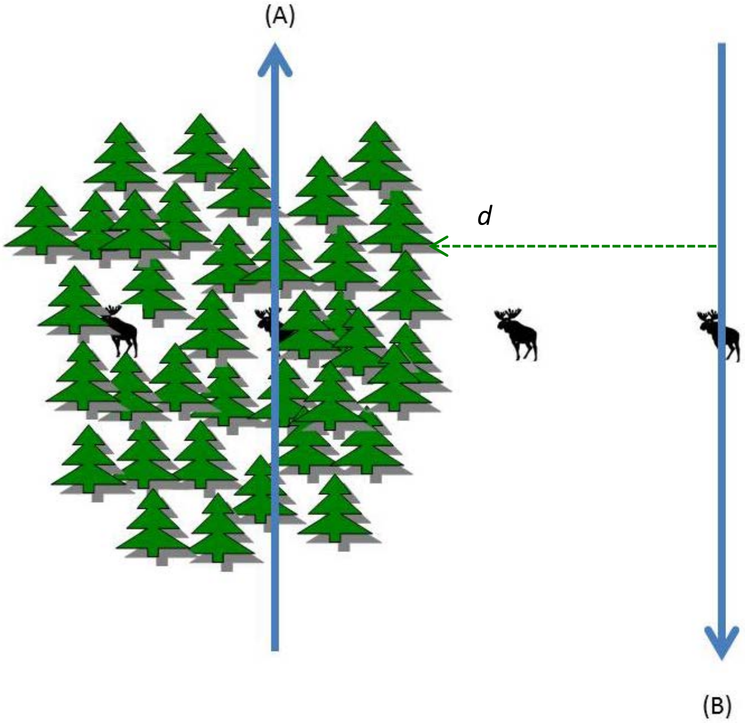

Figure 8. An illustration of the potential for distance detection functions to be compounded depending on distance to habitat edges (d) when transects are flown in heterogeneous habitats.

8), then the detection function is expected to have a normal decline with distance from the line, although the individual functions would vary considerably for different habitat types (i.e., function α and function β). Furthermore, in heterogeneous habitat, the shape of the detection function is affected not only by the types of habitat encountered but also the spatial arrangement of edges and distance from the line to those edges (*d* in Figure 8) and in practice, the resulting detection function would be some combination of the two types, α and β. We consider there is still opportunity to explore this notion of compound detections by creating post-survey covariates for each observation that characterize the distance to, and type of, habitat edge. In addition, we could have used a covariate, sightability correction factor (SCF) more similar to that used in Stratified Random Block surveys (Quayle et al. 2001) rather than the simple classified % cover that we did test. Either approach (i.e., compound detection functions or SCF) may have resulted in a more robust estimate of density and lower CVs. The Probability of Detection did not vary much over the areas and while we tested hypotheses for why this occurred (i.e., observer bias, animal behavior) the data did not support either hypothesis and therefore no adjustments could be made.

Even though a small portion of the study (i.e., 2.8hrs) was conducted during relatively poorer visibility than most of the survey, the influence on the detection function was not sufficient to support selection of visibility as a covariate. We take this result to mean that the visibility conditions we encountered provided a small influence on the data but would need to be more extreme to be considered a factor in the definition of the detectability function.

Estimate of Moose Population Density

Our overall estimate of moose abundance for the 14,516 km^2 area surveyed was 1,379 moose with a 95% confidence range of 1,103-1,742. The overall pooled point density estimate (0.095 ± .011 $moose/km^2$) was quite variable across the 6 areas surveyed, with the lowest estimated density in Etthithun (0.044 ± 0.025 moose/km) and the highest in Chinchaga (0.151 ± 0.037 $moose/km^2$.

Moose habitat capability mapping showed the majority of the study area to be of quite low habitat value for moose (Figure 1B). According to these map predictions, the Clarke Core and the northern portion of the Chinchaga RRE have some moderate capability, which did translate into more moose sightings (Table 9). Overall there are large tracts of low capability moose habitat associated with the core caribou ranges. This low capability for moose might be anticipated since caribou are thought to space themselves in the environment away from other ungulates and their predators (Bergerud and Elliot 1998, Latham et al. 2011). We expect that, as habitat is altered into a more suitable condition for moose, it is likely that the distinctness of any spatial separation between moose and caribou will become blurred through lagging responsiveness both behaviorally (Schaefer and Mahoney 2007) and perhaps demographically. Two notions may have led to lack of a strong relationship between moose population density and anthropogenic disturbance levels. First, the underlying capability for moose is generally low so potential improvements to habitat for moose, if realized, will only be relatively small. Second, the observed disturbance levels were mostly at the high end of the range and it may take a broader range of observations to understand the true nature of the relationship.

While the overall estimate with a relatively small CV should serve well as a baseline, the individual estimates for each CCA are too poor to be relied upon. A post-survey modification to help address the relatively high CVs observed would be to stratify the study areas into relatively higher or lower expected moose density (perhaps based on the capability mapping or upon a more current suitability mapping). The relatively high variance for individual areas notwithstanding, the overall estimate of moose density was quite low which is consistent with the fact that the survey was conducted primarily within areas of high value for caribou and low value for moose. The Etthithun and Prophet areas had very low moose groups and so high CV's, so influence the data accordingly. When the low density estimated in Etthithun area was excluded, the recalculated average density of moose in this survey would increase to 0.098 moose/km^2, and if both Etthithun and Prophet are excluded, the average density would be 0.101 moose/km^2 which is higher than the 0.087 moose/km^2 which Rowe (2008) reported for the GMZs (i.e., CCAs plus outer lying moose habitat) and therefore may indicate that an increase in moose within CCAs has occurred. In the future we recommend that the survey be conducted on a slightly broader extent so that the peripheral areas adjacent to the CCAs are assessed as well. These areas may be of better quality for moose and the effect of moose outside the core area is relevant to the predator-prey dynamics in the core areas. In future studies there would be an advantage to ensuring that the survey areas are large enough to get better CV's, rather than restrict the count to the CCA boundaries, as this tends to pre-stratify to mostly low value moose habitat. If a stratified design is developed as recommended above, the estimated density of moose on the periphery of caribou range would be a valuable piece of information for wildlife managers, as these moose would affect predator numbers within the CCA.

Moose Population Demographics

While our population estimates had higher CV's than would be desired, we can make some comparisons to recent surveys that were conducted in and adjacent to these areas. Thiessen (2010) estimated moose densities in the northern CCA's of 0.116 moose/km^2, which was not significantly different from our calculated densities for the southern CCA's of 0.095 moose/km^2. The population demographics did vary with the northern CCA's having 32 calves:100 cows and 72 bulls:100 cows, while the southern CCA's had 51 calves:100 cows and 60 bulls:100 cows. However, the comparison to results from the Horn River study area (Thiessen 2010) is qualified by the previous study being MU based while this study was biased to caribou CCAs (i.e., relatively lower capability for moose).

There was minor overlap between the two surveys in the Paradise CCA of 0.124 moose/km^2 and the combined Etsho/Kotcho CCA's of 0.127 moose/km^2. The calves:100 cows were also similar at 29 and 32 respectively, while likewise the bulls were at 83 and 74 respectively. Both of these areas had similar habitat, so this result is expected based on the 2010 inventory. The Clarke study area to the south of Paradise was 0.145 moose/km^2 and had a much higher calves:100 cows ratio of 62, but was also noted to comprise slightly better habitat quality (Figure 1B). We also note that the smaller Etsho/Kotcho study area resulted in a much higher CV (51.3%) than the Paradise (20.2%) and Clarke (21.6%) study areas, emphasizing the importance of keeping the study areas larger to reduce the CV.

Previous densities for GMZ subzone G (overlapping the Etsho/Kotcho and Clarke Study areas) was 0.087 moose/km^2 (Backmeyer 2004), so our more current estimates do indicate an increase in moose density compared to the previous survey results, caveated by the large CV and the very different land areas of the three estimates. The population demographics from the previous larger land area study showed ratios of 23.7 calves:100 cows and 76.3 bulls:100 cows, so this study shows many more calves at this time in these two portions of the GMZ than those earlier reported for the entire GMZ. This may indicate an improving status for moose or that moose in less dense areas have a higher recruitment (that is predators focusing on more dense moose areas).We calculated a λ of 1.04 for Etsho/Kotcho and 1.19 for Clarke indicating a predicted increase in moose density should occur over time.

The recorded density for MU 7-47 (Chinchaga and Etthithun) was the lowest in the Peace Region at 0.044 moose/km^2 +/- 24.6% and recorded calf ratios of 9.4 calves/100 cows +/- 75.1% and bull ratios of 63.5 bulls:100 cows +/- 44.7% (Rowe 2005, Rowe 2008). No estimate was available for MU 7-48 (Prophet). This moose inventory has estimated the Chinchaga study (MU 7-47 and 7-56) area to have a density of 0.151 moose/km^2 with a ratio of 59 calves:100 cows and a ratio of bulls of 11 bulls:100 cows at a CV of 24.2%. The Etthithun CCA (MU 7-47) had a density of 0.044 moose/km^2 with no cow/calf ratio calculated, which is in line with the 7-47 density estimate, although a CV of 57.2% was encountered. This survey estimated a density in the Prophet CCA of 0.121 moose/km^2 and calf ratios of 55 calves:100 cows and bull ratios of 35 bulls:100 cows, however having a CV of 84%. The range for the Prophet CCA is 0.026 – 0.551 moose/km^2, so again with the small study area and large CV, this result can only be applied with caveats to management in this area. The cow λ for Chinchaga was 1.175 and in Prophet 1.155, so predicts an increasing population, while in Etthithun the cow λ was 0.88 based upon the null calf observations and may indicate a declining population. Overall this would indicate that moose would be increasing in this area based upon the calf recruitment. This survey has not covered the entire MU that the previous estimates were from but rather has been artificially biased to the Core Caribou Area, which tends to be lower quality habitat for moose (Figure 1B). If we are then seeing an increase in density and calf ratios in the lower quality habitat, this may indicate an overall increase in the MU.

The recorded density for MU 7-46 (Milligan study areas) ranges from 0.0875 moose/km^2 +/- 23.32% with a ratio of 47.98 calves:100 cows and a ratio of 38.4 bulls:100 cows +/- 38.1% for 7-46 combined with 7-33 (Rowe 2005) to a density of just 0.05 moose/km^2 +/- 28.39% with a ratio of 53.7 bulls:100 cows +/- 38.19% (Rowe 2008). The Milligan CCA came in at a density of 0.113 moose/km^2 and a ratio of 49 calves:100 cows and a ratio of 41 bulls:100 cows at a CV of 25.6%. Objectively the southern portion of the Milligan CCA had much higher moose densities which may have resulted in the higher density. The λ for calf:100 cow ratios in Milligan was 1.125, so indicates an increasing population.

In general, our estimates of moose population densities were higher, calf ratios higher to similar, and bull ratios varied. Although none of those contrasts are statistically significant, we note consistent trends for all indicators that point to an apparently healthier moose population than previously observed. This is especially of interest because the apparent increase in density was found within specific locations (i.e., CCAs) where we would have expected lower population density relative to the broader region. Previous inventories were conducted with a broader and more regional extent where there apparently are relatively better conditions for moose than within individual CCAs (Figure 1). This speculation notwithstanding, our results still demonstrate that within CCAs moose population density tends to be improving.

Other Learnings

Thiessen (2010) indicated that the length of transects necessary for achieving a minimum sample size at a given level of precision for moose distance sampling can be estimated where the density of moose can be estimated from past surveys from:

$L = n/(0.3299*d_e + 0.0154)$

L = transect length
n = number of moose groups to achieve a desired level of precision
d_e = estimated density of moose in the area.

Thiessen (2010) recommended that in subsequent moose inventories that the above calculation be used to plan the survey to achieve more precise estimates. In the design, we were confined to the boundaries of the CCA's and spacing of 3 to 6 kms which did not allow this recommendation to be followed and it is suggested it be redressed in future surveys. From our data we see lower CV's at moose groups of 75 per survey unit (as an average of the study areas that had CV's between 20-25%), which would translate into average transect length per survey area of from 1150 (based upon the high end density of 0.151 moose/km^2) to 1423 kms (based upon the lower end density of 0.113 moose/km^2). This would require from 100 to 1200 kms more transects per study area. Additionally in the Chinchaga, Clarke and Milligan survey units where the moose groups were high enough to give lower CV's, only 600 – 1000 kms were flown. Table 13 provides the calculated and recommended (based upon these results) lengths of line recommended to be flown per study area.

Table 13 – Calculated and recommended transect lengths to fly per study area to improve precision of future estimates.

Survey area	**Survey unit area (km^2)**	**2013 Sampling effort (km)**	**2013 Moose Density**	**Calculated Length (L) (km)**	**Moose Groups**	**CV %**	**Recommended Length (km)**
Chinchaga	2403.23	677.18	0.151	1150	81	24.2	800
Clarke	2224.04	669.38	0.145	1186	74	21.6	800
Etsho/Kotcho	2718.84	936.20	0.127	1309	40	51.3	1300
Etthithun	780.31	197.61	0.044	2507	7	57.2	1400
Milligan	5196.18	1,068.40	0.113	1424	70	25.6	1100
Prophet	1193.03	382.45	0.121	1356	41	84	1350
All combined	**14515.63**	**3,931.22**	**0.095**	**8932**	313	**11.7**	**6750**

Some of the specific learnings that we identified in the project design are as follows:

- Given the accuracy of the survey estimates for the units, assuming similar accuracy in the next count, and the λ estimated from this survey, a recount would need to wait a minimum of 3 years (to test the accuracy of these results) to 5 years (as recommended in Thiessen 2010). A survey in three years based upon the combined λ of 1.135 (Table 10) and the calculated combined estimate of 0.095 moose/km^2 (95% CI 0.076 - 0.120) would give a potential future density in three years higher than the confidence limits and potentially almost double at five years. It should be noted that these values are extremely predictive based upon the low densities and subject to many factors of variability (ie. differences in bull survival). Further modeling is recommended to test this strategy.
- Make survey areas large enough to include moose which would affect predator – wolf numbers in the CCA. The study area should include all rankings of moose habitat types, low, medium and high.
- Square off your study areas such that the minimum line length flown is 40 kms, to ensure a good potential of encountering moose groups if they are in the area.
- Keep all lines either north-south or east-west for ease of calculating distance from UTM lines.

- Ensure fuel is evenly available across the study areas to minimize transit time and maximize time flying transects. Place your flight bases at remote camps near the fuel caches and inventory areas.
- Budget for developing a sightability index/ better estimate of the effect of covariates based upon habitat/canopy cover, ie. would require flight time to fly over objects of known location under varying cover/weather conditions to determine a proper correction that could then be applied to the data.
- Design a study specifically to address the nature of the relationship between anthropogenic disturbance levels, moose density, and subsequent levels of predation on caribou.
- This type of survey does not lead to an estimate of wolf numbers. Surveys can be designed/run to achieve that objective.

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Appendix 1: Sample Data Sheet

Animal Observation Form - Ungulate (Aerial) Transect - Distance Sampling

Page ___/___

Project **Survey** **Study Area**

Transects on this form: ____________________ **Trans Comment** ____________________

Obs Date _____/_____/_______

Obs Day	Time	CC	Wind	Temp	Precip	Snow Depth	Snow Cover
Start							
End						5 cm Snow ____	

Pilot: ____________

Front Left: ____________

Rear Left: ____________

Rear Right: ____________

Other: ____________

Transect Name	Length	Start UTM	End UTM	6 km or 3km

Spp __________

Transect	WPT	Observer (FR,FL, RR, RL)	Species	Group Total	Ungulate Classification									Activity (B=bedded, S=Standing, M=Moving)	Comments
					unclass-ified	Cow	Calf	Yearling Male	MM drop	Bulls I	Bulls II	Bulls III	Bulls IV		
														B S M	
														B S M	
														B S M	
														B S M	
														B S M	
														B S M	
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														B S M	

Habitat Observation Form - Ungulate (Aerial) Transect - Distance Sampling

Page ___/___

Project **Survey** **Study Area**

Transects on this form: ______________________________ **Trans Comment** ______________________________

Obs Date ______/______/________ **Habitat Observer** ______________________________

* **Habitat Code**

WA *Water*
WE *Wetland/Bog*
ME *Meadow*
RI *Riparian*
WS *Willow/Shrub*
DE *Deciduous*
LP *Lodgepole*
SB *Spruce Eng./Subalp Fir/Scrub Birch*
PS *Lodgepole Pine/Spruce Mixed*
TA *Talus Slope*
SU *Subalpine*
CD *Confirerous/Deciduous Mixed*
CS *Cottonwood/Spruce*
BS *Black Spruce*
AR *Alpine Ridge*
AV *Avalanche Track*
BU *Burn*
CU *Cut Block*
UV *Unvegetated*
RD *Road*
OG *Oil&Gas Site*

** **Slope Code**

1	**0%**	*Flat*
2	**5-20%**	*Minimal Slope*
3	**20-50%**	*Moderate Slope*
4	**>50%**	*Steep*

**** **Snow Cover**

1	**poor (bare ground showing)**
2	**good (some low veg showing)**
3	**excellent (complete snowcover)**

*** **Canopy Closure**

L	**Low (0-33%)**
M	**Medium (34-66%)**
H	**High (67-100%)**

Any vegetation that blocks the view of the moose; based on % of ground not being visible in a 10 m diameter around the moose initially sighted in a group.

Transect Name	Length	Start UTM	End UTM

Transect	WPT	Slope	Aspect	Elevation	BEC Zone	Habitat Type I	Habitat Type II	Percent Cover(=100%)					Canopy Closure	Snow Cover	Comments
		*code***		*meters*		*code**	*code**	Pine *%*	Spruce *%*	Decid *%*	Mixed *%*	Open *%*	***	****	
													L M H	1 2 3	
													L M H	1 2 3	
													L M H	1 2 3	
													L M H	1 2 3	
													L M H	1 2 3	
													L M H	1 2 3	
													L M H	1 2 3	
													L M H	1 2 3	
													L M H	1 2 3	
													L M H	1 2 3	
													L M H	1 2 3	
													L M H	1 2 3	
													L M H	1 2 3	
													L M H	1 2 3	
													L M H	1 2 3	
													L M H	1 2 3	

Moose Classification Levels

Class	Criteria	Code	Level 1	Level 2	Level 3	Level 4
Adult	· ≥ 1 year of age	a	X			
Calf	· < 1 year of age · small body size without antlers	j	X	X	X	X
Adult Bull	· antlers or antler scars · absence of white vulval patch	m		X		
Adult Cow	· no antlers and short bell, medium size · distinguished by white vulval patch · usually has light brown face colour · sometimes accompanied by calf	f		X	X	X
Mature Bull	· bull with palmated antlers	mm			X	
Yearling Bull	antler, if palmated, does not extend beyond eartip · antler pole-type usually a spike or fork	ym			X	X
Class I Bull	· antlers palmated, extends beyond tip of ear; · brow tine a spike or fork	I				X
Class II Bull	· antler palmated, extends beyond tip of ears · brow tine palmated with usually more than 2 points · inner most points of brow palm close over face	II				X
Class III Bull	· antlers palmated, but smaller than Class II · brown tine usually a spike or fork, like Class I	III				X

Rocky Mountain Elk Classification Levels.

Class	Criteria	Code	Level 1	Level 2	Level 3	Level 4
Adult	· ≥ 1 year of age	a	X			
Calf	· <1 year of age · small body size without antlers	j	X	X	X	X
Adult Bull	· antlers or antler pedicels	m		X		
Adult Cow	· medium size, without antlers	f		X	X	X
Mature Bull	· branch-antlered bull	mm			X	
Yearling Bull	· spike antlers or with light 1 to 2 point antlers	ym			X	X
Class I Bull	· small antlers with 3 or 4 points (raghorn)	I				X
Class II Bull	· large 4 point antler, small 5 point antler, spindly (raghorn)	II				X
Class III Bull	· large 5 point antler, small 6 point antler, heavy antlers	III				X
Class IV Bull	· large antlers with 6 or 7 points/antler, massive	IV				X

Deer Classification Levels.

Class	Criteria	Code	Level 1	Level 2	Level 3	Level 4
Adult	· ≥ 1 year of age	a	X			
Fawn	· < 1 year of age · spotted pelage in summer · smaller body size and shorter nose in winter	j	X	X	X	X
Adult Buck	· antlers or antler pedicels	m		X		
Adult Doe	· medium size and no antlers · adults may be accompanied by fawns	f		X	X	X
Yearling Buck	· spike or 2-points on one or both antlers	ym			X	X
Mature Buck	· branch-antlered buck	mm			X	
Class I Buck	· large 2 point or small 3 point antlers	I				X
Class II Buck	· medium size antlers with 3 points/antler	II				X
Class III Buck	· medium size with 3 or 4 points/antler · moderate to large bodied	III				X
Class IV Buck	· large antlers with 4 or 5 points/antler	IV				X

Appendix 2: Survey Area Maps and transects

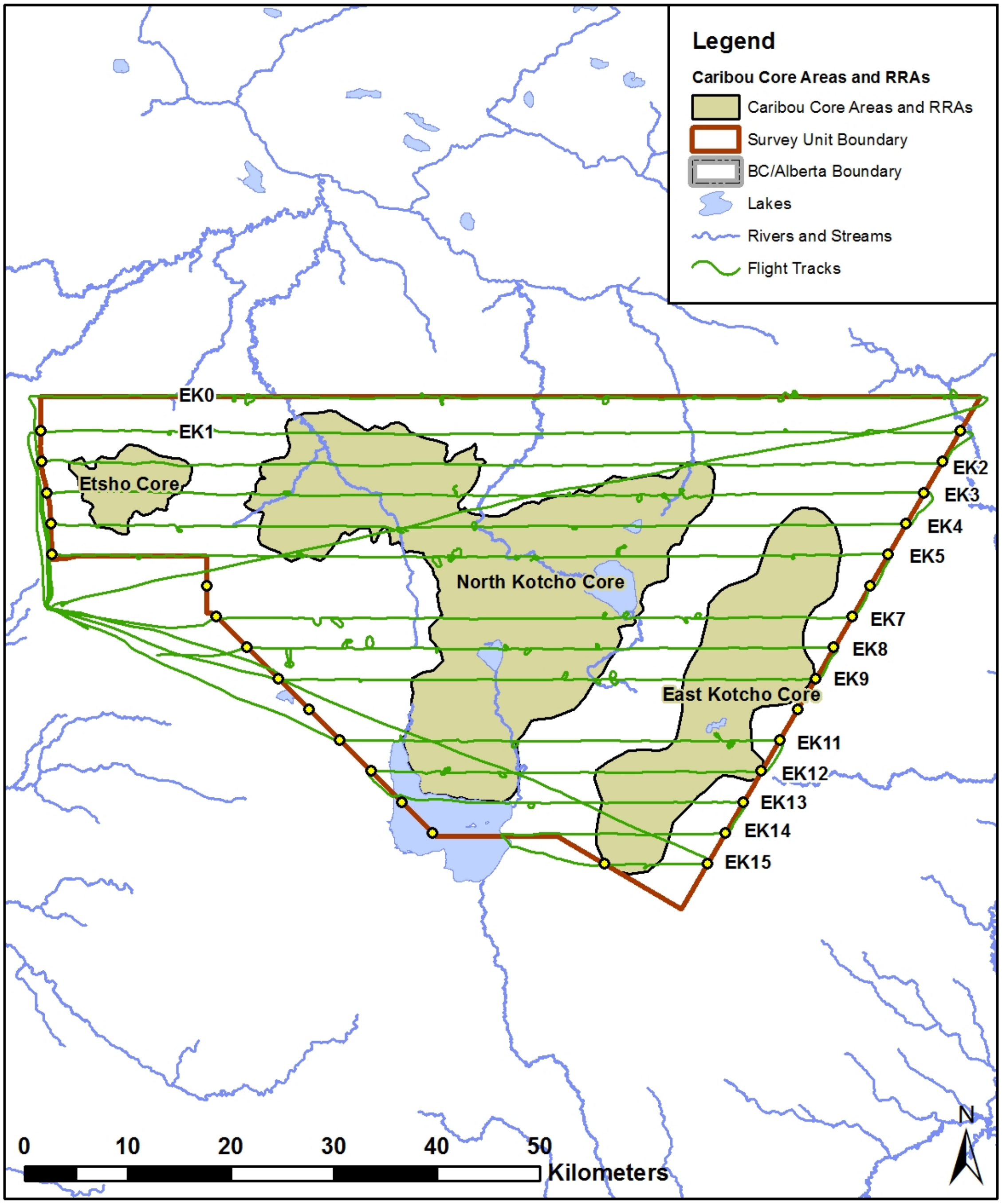

Figure 9. Actual transect courses flown for a Distance-based survey of moose abundance within and adjacent to the Etsho and Kotcho caribou core areas in northeastern British Columbia.

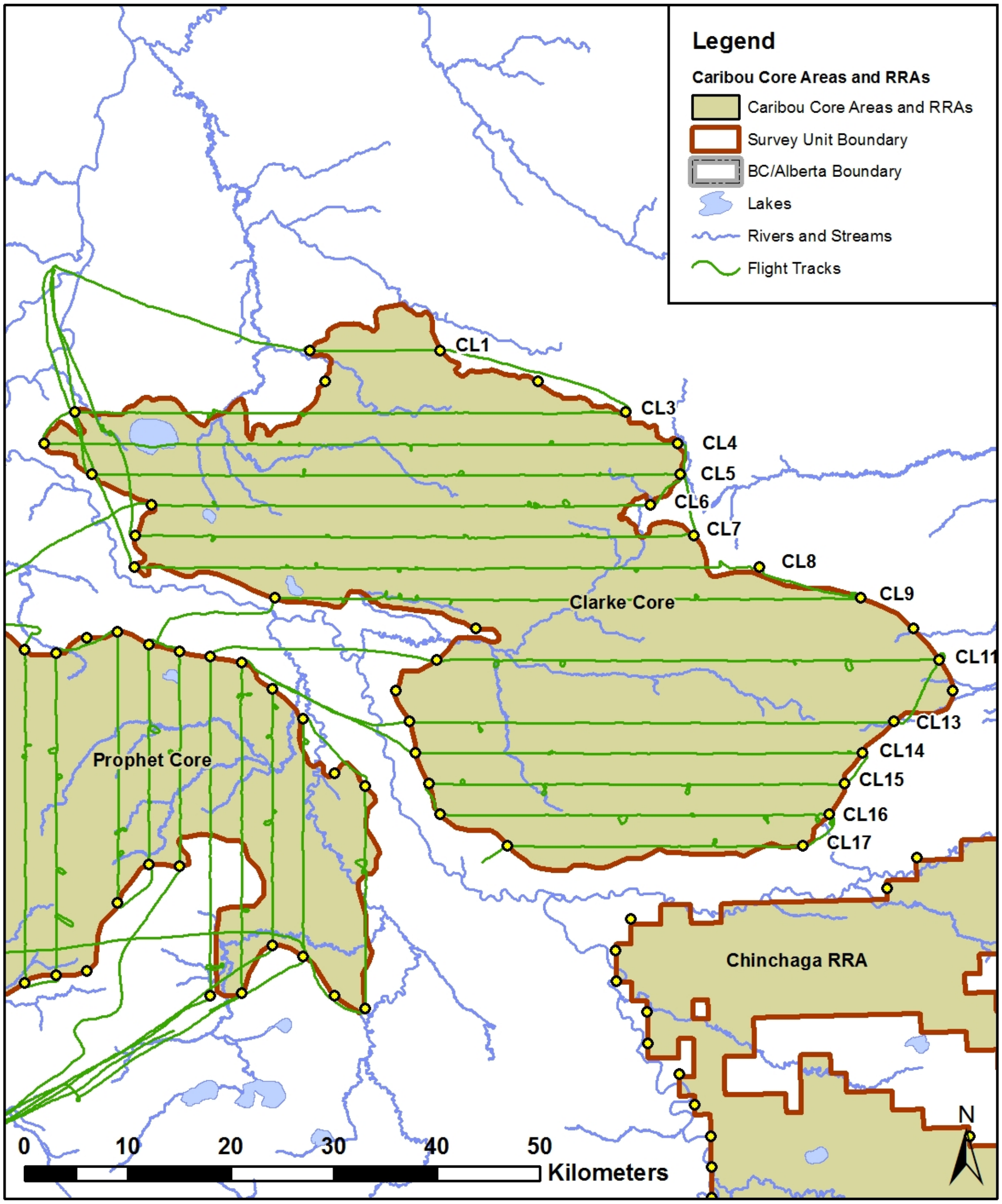

Figure 10. Actual transect courses flown for a Distance-based survey of moose abundance within the Clarke caribou core area in northeastern British Columbia.

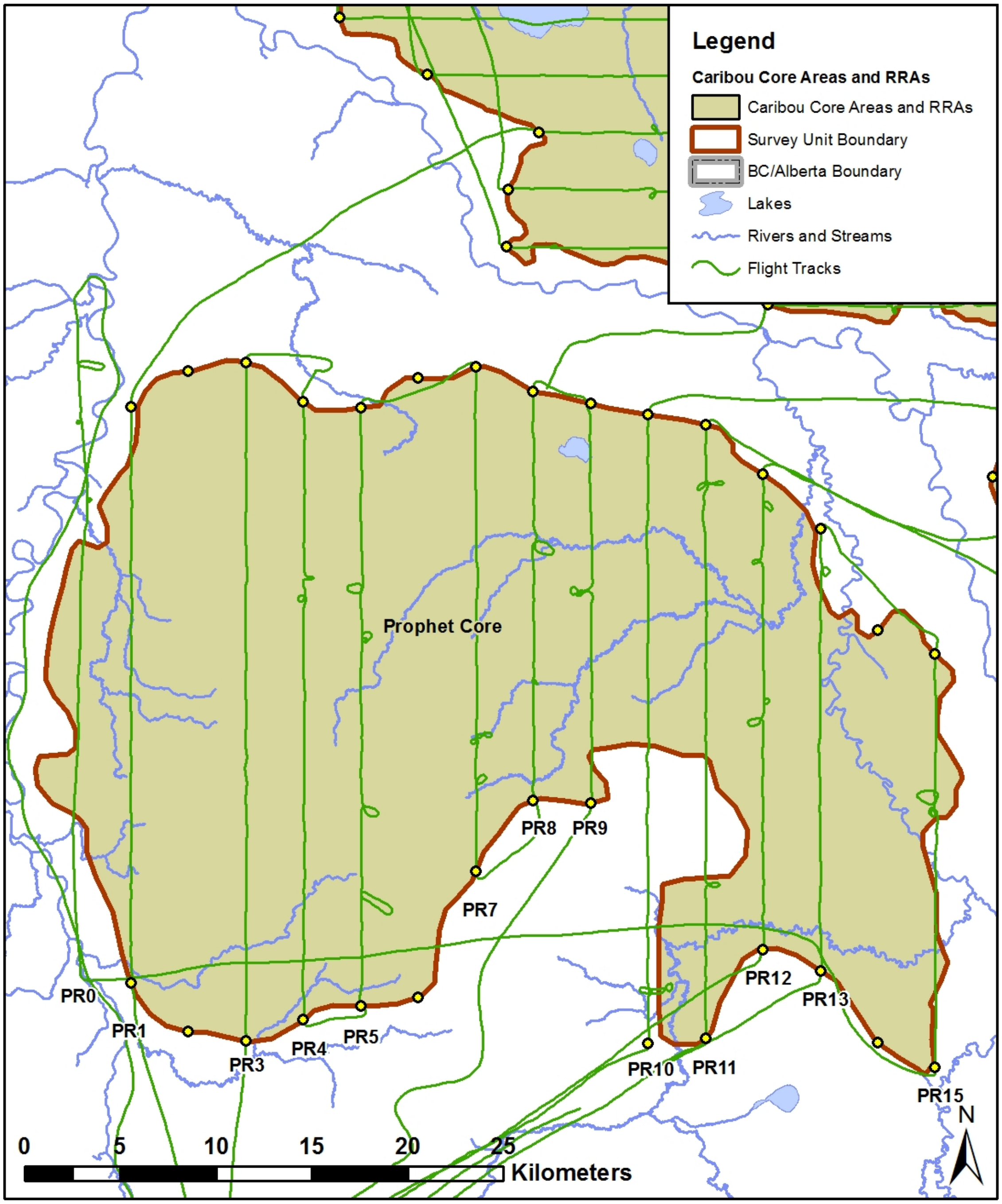

Figure 11. Actual transect courses flown for a Distance-based survey of moose abundance within the Prophet caribou core area in northeastern British Columbia.

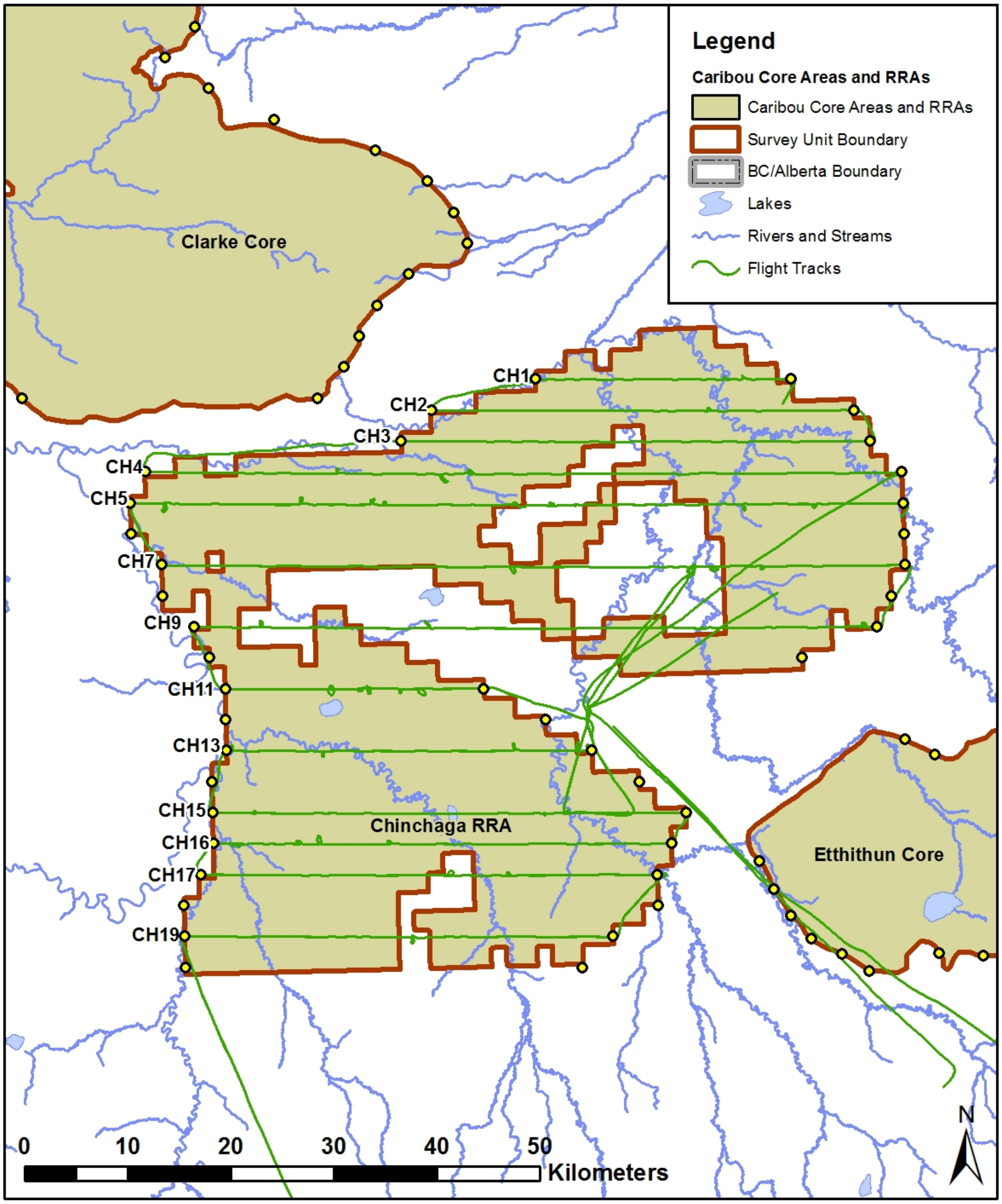

Figure 12. Actual transect courses flown for a Distance-based survey of moose abundance within the Chinchaga caribou core area in northeastern British Columbia.

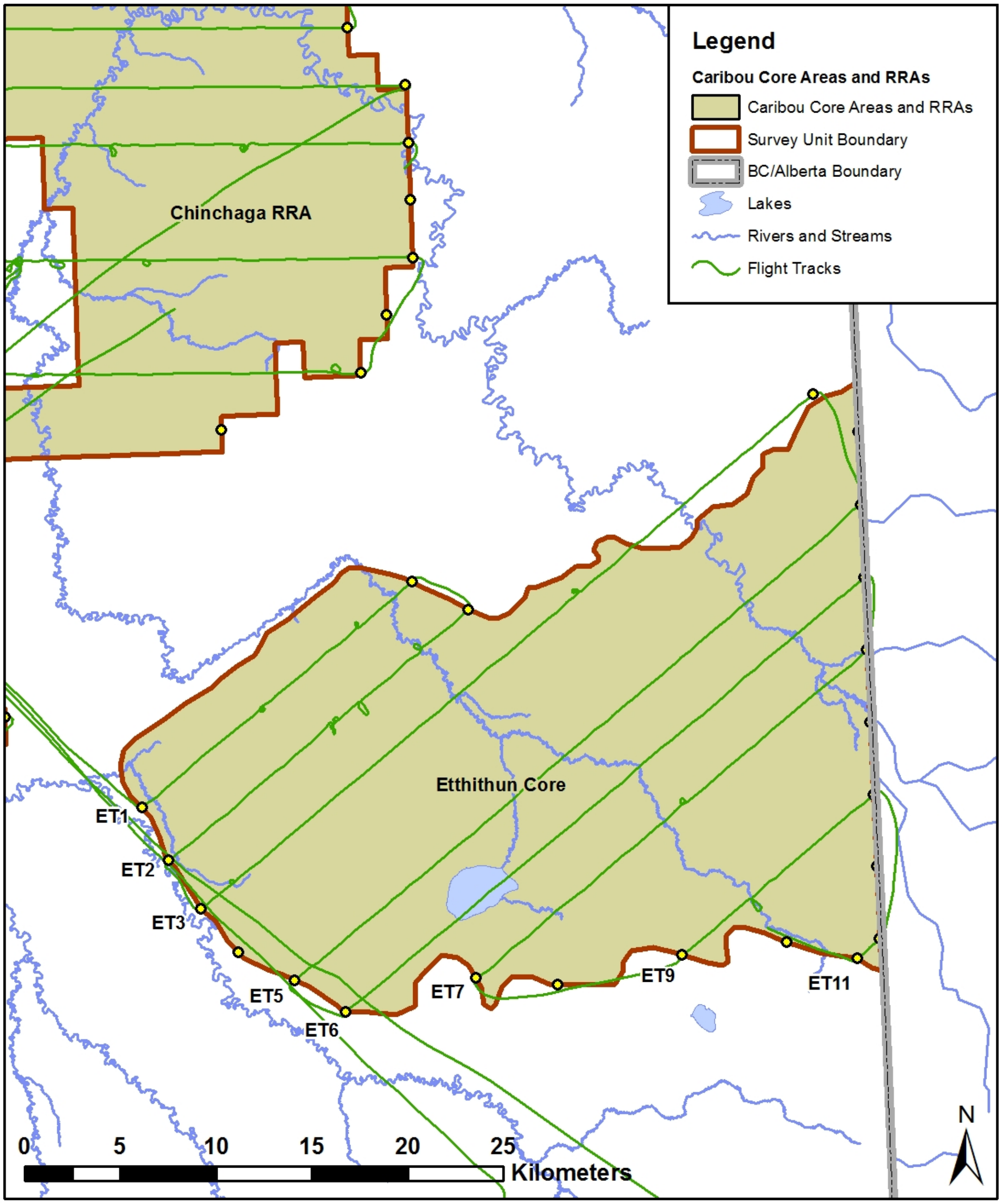

Figure 13. Actual transect courses flown for a Distance-based survey of moose abundance within the Etthithun caribou core area in northeastern British Columbia.

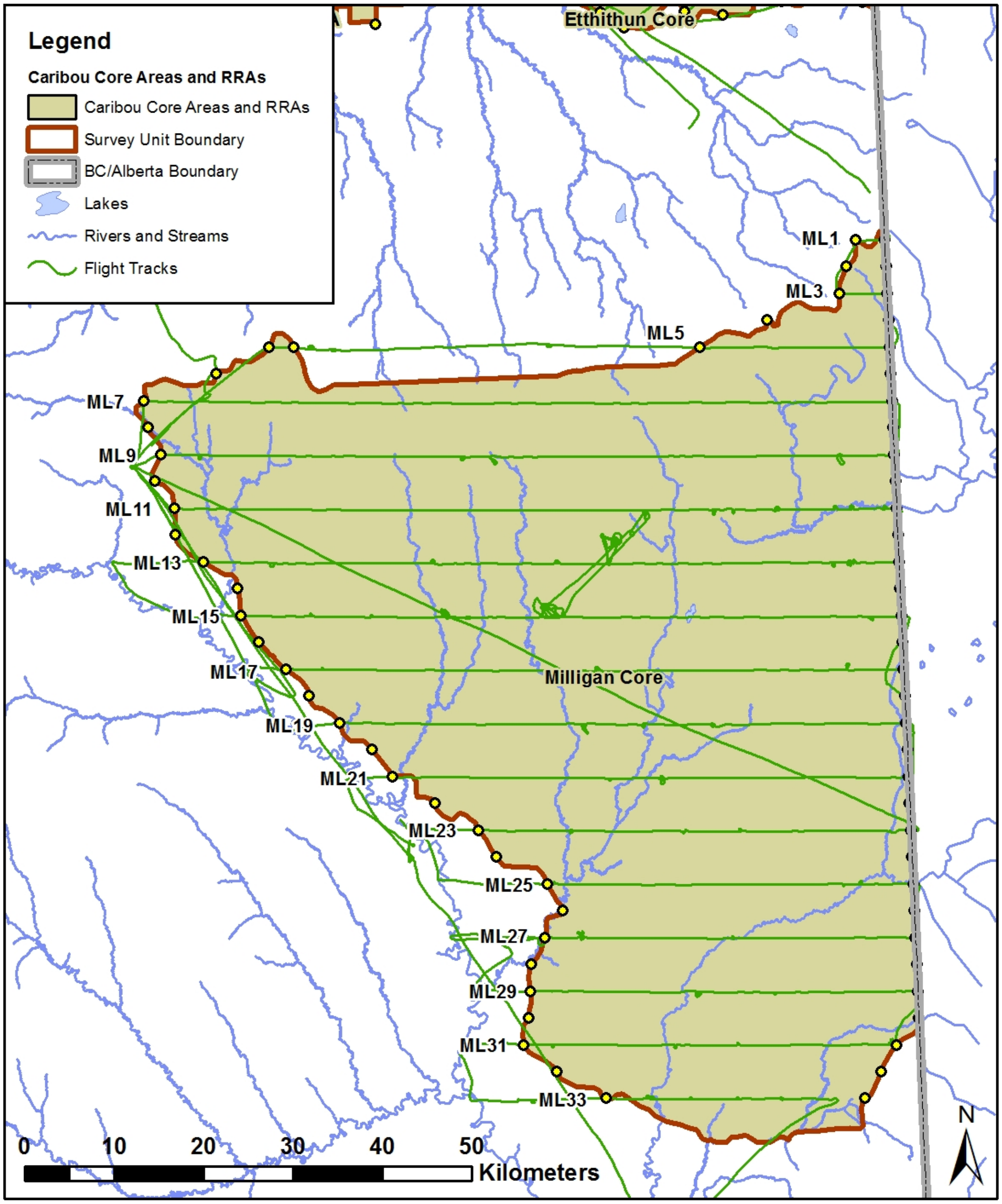

Figure 14. Actual transect courses flown for a Distance-based survey of moose abundance within the Milligan caribou core area in northeastern British Columbia.

Appendix 3: Exploratory data analysis results for the key observed variables.

Below are shown the exploratory graphical plots used to define the models constructed for density estimation in Distance 6.0 for each survey area, and for the pooled data. We examined the frequency distributions of observed distances (pooled: Figure 15, individual survey areas: Figure 16), the relationships between observed cluster (group) size and distance (pooled: Figure 17; individual survey areas: Figure 18), and the distribution of each covariate that was considered in the models (pooled only: Figure 19).

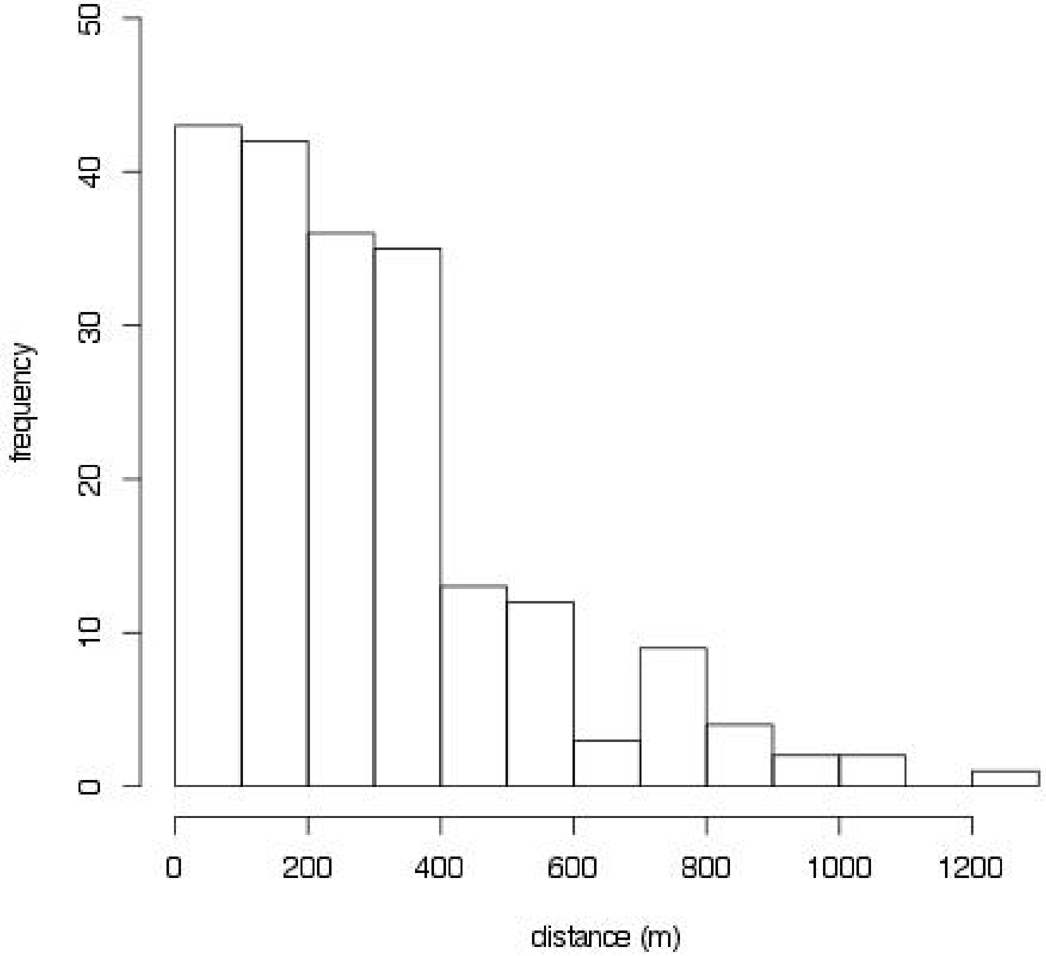

Figure 15. Frequency distribution of measured perpendicular distances from transects to observed moose (individuals or clusters of individuals) for all 6 survey areas pooled. Total sample size (N) = 202 observations.

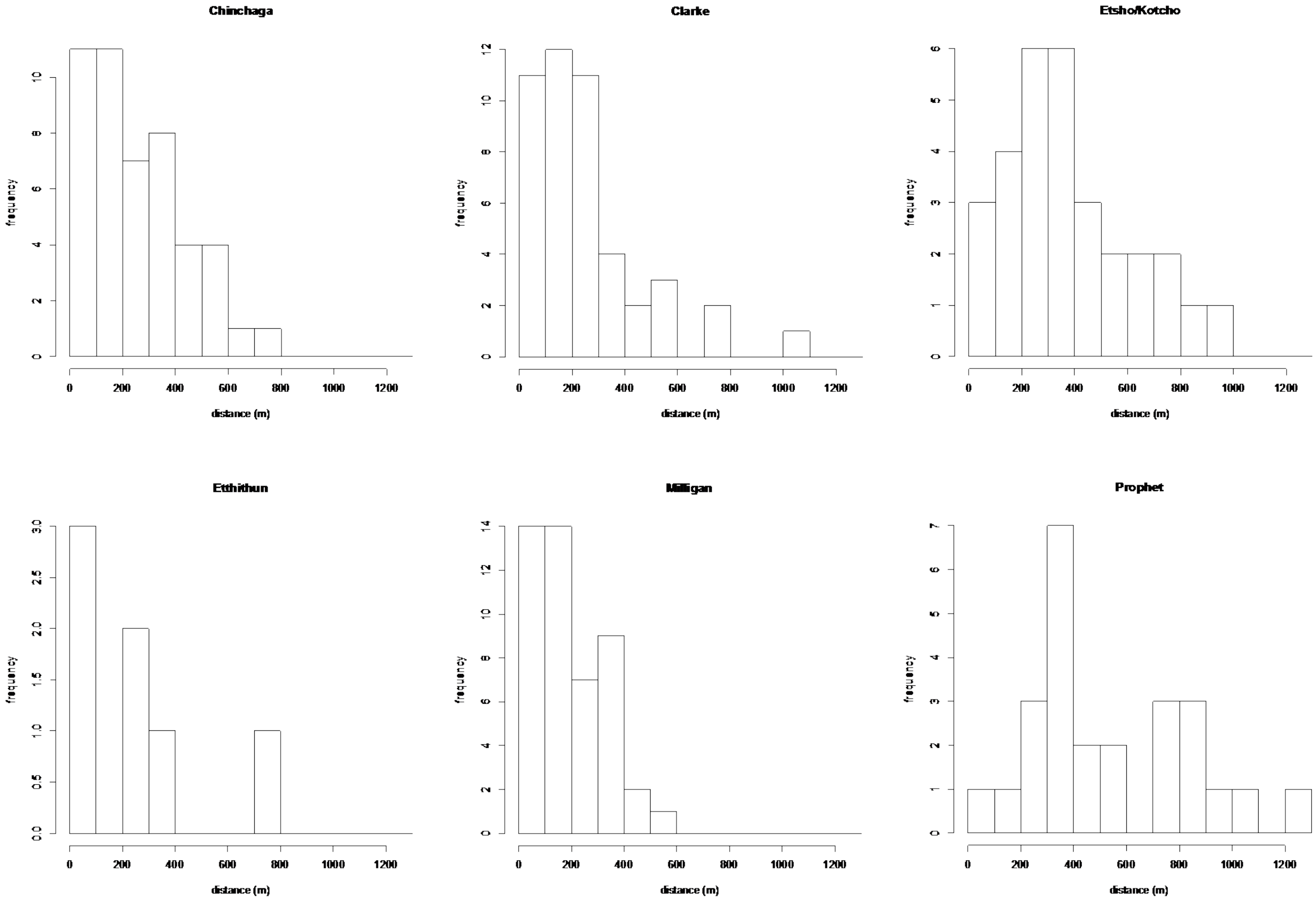

*Figure 16. Distribution of perpendicular distances (m) from transects to observations of moose (individuals or clusters of individuals) for each individual survey area. Sample sizes (*N *observations) are as follows: Chinchaga* N=47*; Clarke* N=46*; Etsho/Kotcho* N=30*; Etthithun* N=7*; Milligan* N=47*; Prophet* N=25*.*

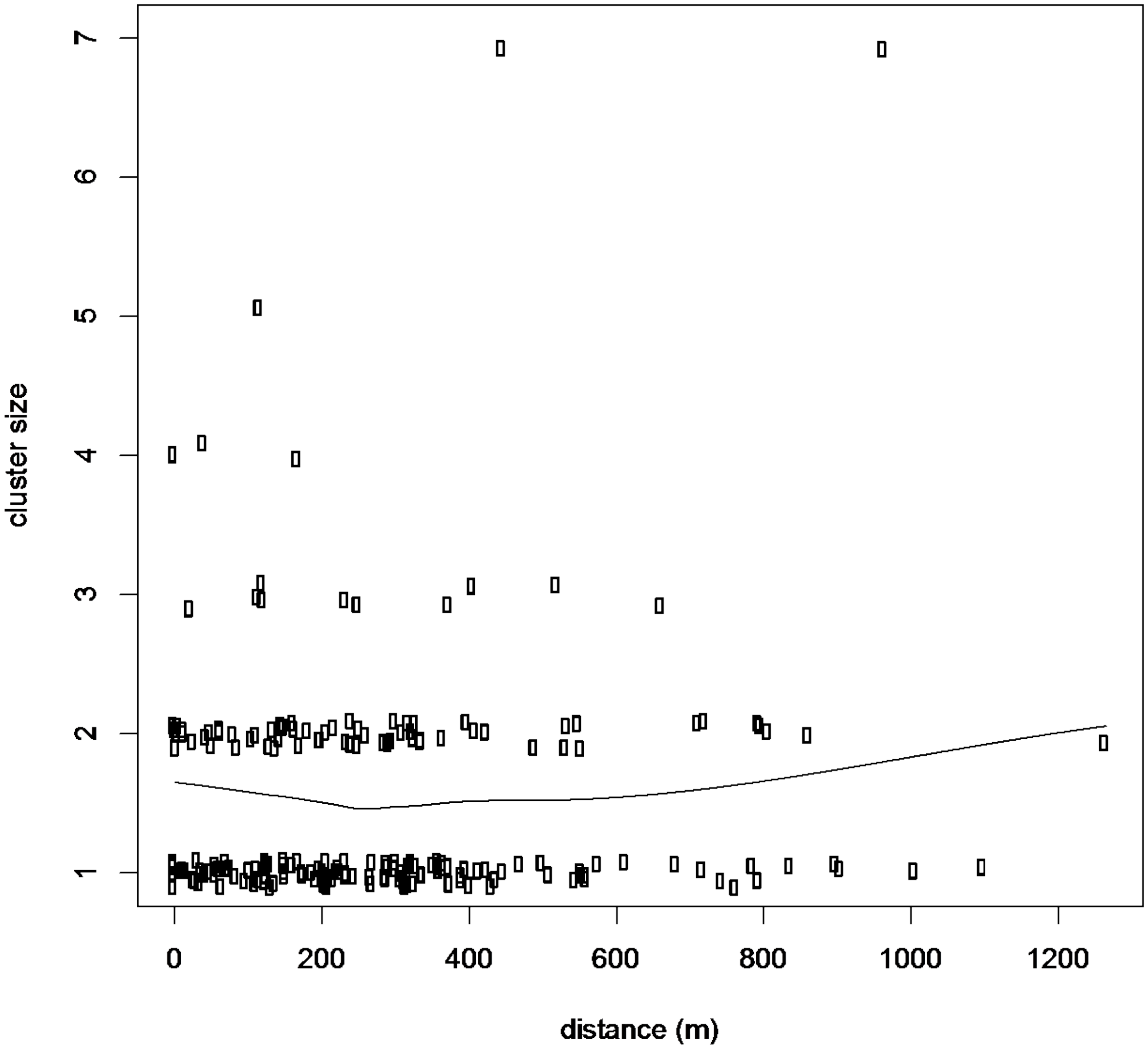

*Figure 17. Observed relationship between observed group sizes (i.e. cluster sizes) and their measured distances (m) from transects with all observations in the 6 survey areas pooled. The smoothed line represents a LOESS (locally weighted polynomial regression) line fitted to these points, where 67% of the points influence the smooth at each value. Total sample size (*N*) = 202 observations.*

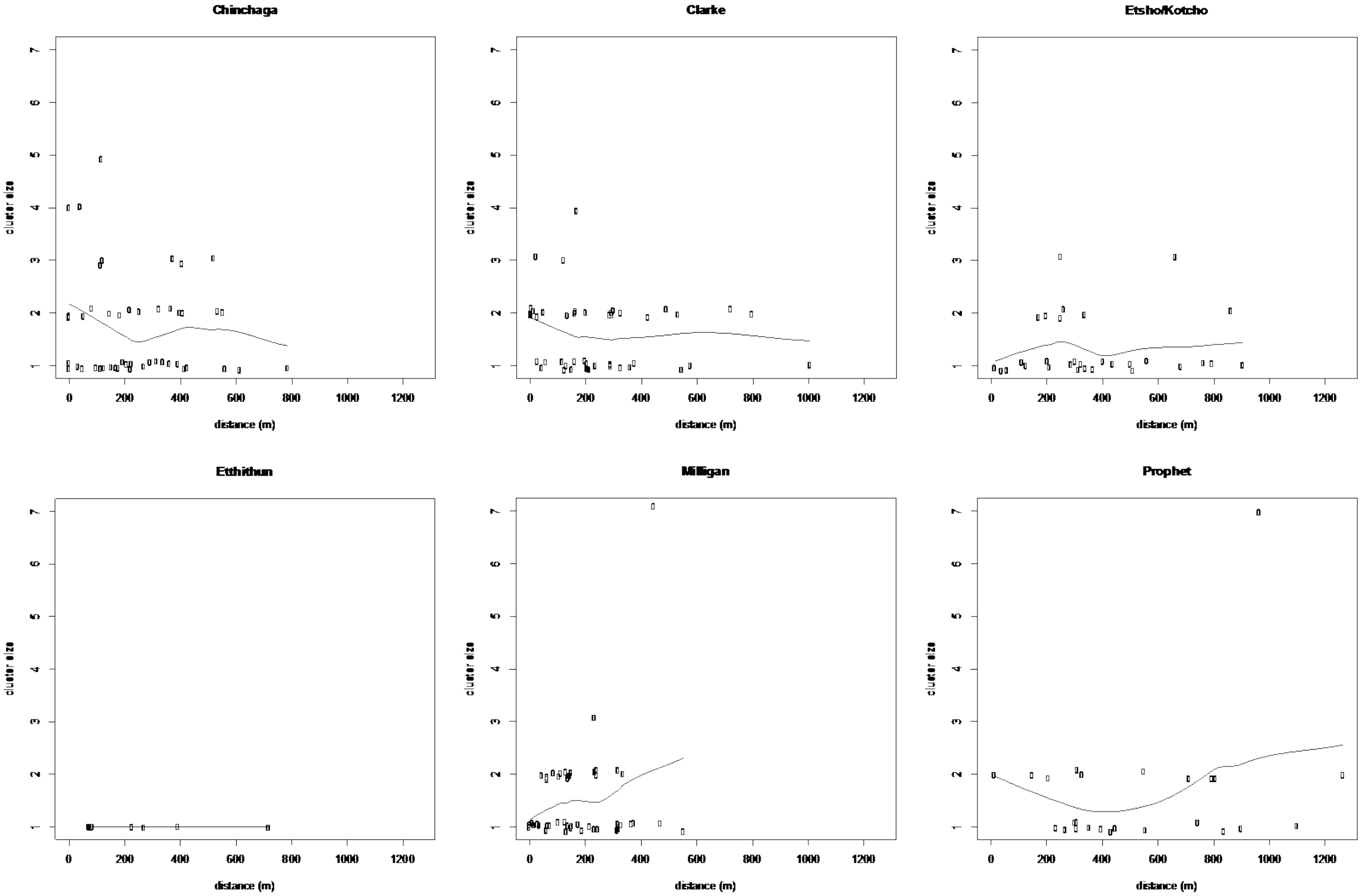

*Figure 18. Observed relationships between observed group sizes (i.e. cluster sizes) and their respective measured distances (m) from transects in each of the 6 survey areas. Smoothed lines represent LOESS (locally weighted polynomial regression) lines fitted to the points in each survey area, where 67% of the points influence the smooth at each value. Sample sizes (*N *observations) are as follows: Chinchaga* N*=47; Clarke* N*=46; Etsho/Kotcho* N*=30; Etthithun* N*=7; Milligan* N*=47; Prophet* N*=25.*

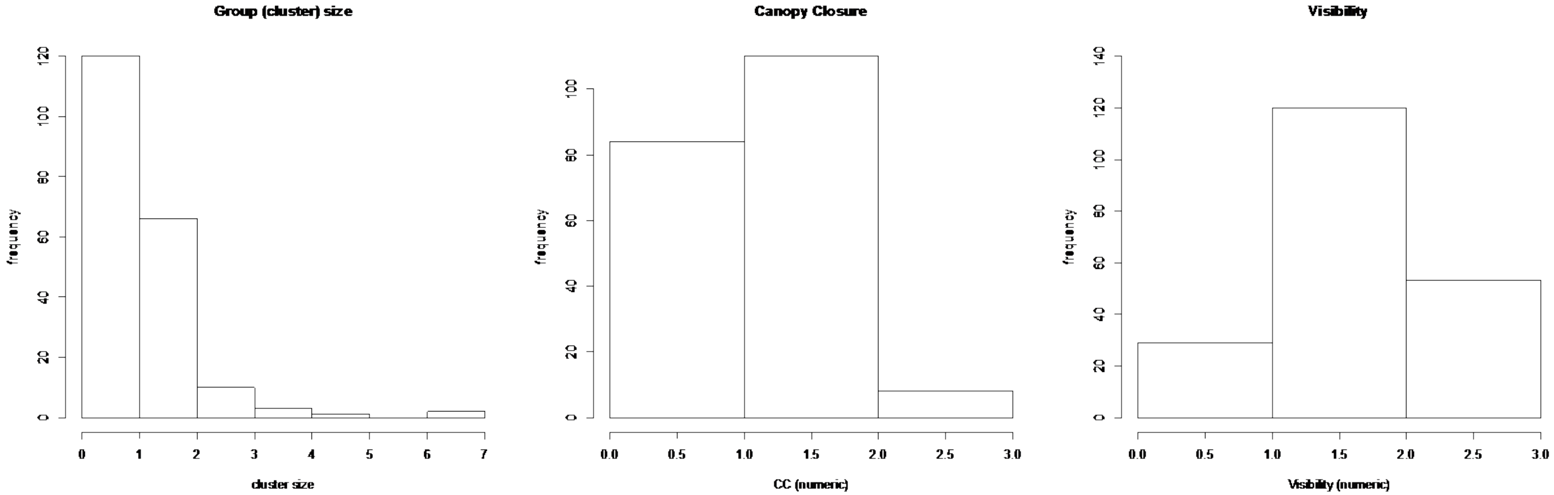

Figure 19. Frequency distributions of the three variables used as covariates of the detection distance functions used in fitting models for determining density for all survey areas pooled. Codes for canopy closure values (x-axis centre graph) are 0-1: Low; 1-2: Medium; 2-3: High (see text for details). Codes for visibility values (x-axis of right-most graph) are 0-1: very poor and poor combined; 1-2: moderate; 2-3: good and very good combined