FOREST RESOURCE IMPROVEMENT ASSOCIATION OF ALBERTA

FRIP OF-13-006

Interim Progress Report September 2015

Prepared by

Laura Finnegan, Doug MacNearney, and Karine Pigeon

foothills
RESEARCH INSTITUTE
Research Growing Into Practice

1. Project Overview and Status

1.1. Introduction and objectives

Boreal and mountain caribou are protected under SARA with a target under the federal boreal recovery strategy to achieve a minimum of 65% undisturbed habitat within the range of each local population. The forestry sector is under pressure to implement habitat restoration of disturbed areas to achieve this 65% target. It is imperative to determine whether the extent of natural regeneration in previously disturbed areas influences caribou response to these features; when can this disturbed habitat be considered functional caribou habitat? Answering this question is fundamental to accurately define the extent of disturbed habitat within the range of each local population, and can be applied by land managers to prioritize areas for restoration that will be the most beneficial for caribou. In addition, monitoring of reproductive rates and population size in relation to restoration practices is essential to assess the efficacy of actions and continually inform management practices to improve caribou habitat and attain self-sustaining populations of caribou.

In keeping with these restoration goals, this two year FRIAA and industry funded project is using existing telemetry data and LiDAR based terrain metrics to address the following research objectives:

1. Determine whether caribou and predator response to roads and pipeline right of ways (RoWs) is influenced by the extent of re-vegetation and human use of these features.
2. Evaluate whether currently accepted 500m buffers on roads and pipeline RoWs apply when line characteristics incorporate information on regeneration.
3. Assess how human activity of linear features is affected by topography, geographic barriers, and re-vegetation height.
4. Determine whether activity at worksites (active industrial activity) affects the movements of caribou.
5. Use non-invasive fecal DNA collections for caribou during the winter to determine the relationship between re-vegetation and current restoration activities on the distribution, and the size and health of caribou populations.
6. Assess whether the response of boreal caribou in the Chinchaga range (mixedwood upland and peatland habitat) to re-vegetation stage of disturbed habitat differs from that of boreal and mountain caribou in conifer dominated landscapes.

7. Produce a list of landscape variables (e.g. re-vegetation height and human use thresholds) that can be used to quantify the extent of caribou functional habitat in our study area and elsewhere.
8. Create of a map evaluating priority areas for restoration that are the most beneficial for caribou, and the most cost effective for the forestry sector and other industrial landscape users.

1.2. Project activities and current status

Year 1 (2014-2015):

1. Determine whether caribou and predator response to roads and pipeline RoWs is influenced by the extent of re-vegetation and human use of these features. **Completed see Table detailing the number of pipelines and seismic lines monitoring below:**

Herd	Seismic line	Pipeline
LSM/ALP	**N/A**	**35**
RPC/NAR	**N/A**	**77**
Chinchaga	**121**	**55**

2. Assess how human activity of linear features is affected by topography, geographic barriers, and re-vegetation height. **Data collection completed – analysis underway**

3. Determine whether activity at worksites (active industrial activity) affects the movements of caribou. **Completed March 2015.**

Year 1 and 2 (2014-2016):

4. Evaluate whether currently accepted 500m buffers on roads and pipeline RoWs apply when line characteristics incorporate information on regeneration. **Field data completed. The final data analysis will take place in Year 2 (2015-2016).**

5. Use non-invasive fecal DNA collections for caribou during the winter to determine the relationship between re-vegetation and current restoration activities on the distribution, size, and health of caribou populations. **Fecal samples are currently being genetically typed for year one, results expected November 2015; planning for the second winter of data collection is underway.**

6. Assess whether the response of boreal caribou in the Chinchaga range (mixedwood upland and peatland habitat) to re-vegetation stage of disturbed habitat differs from that of boreal and mountain caribou in conifer dominated landscapes. **Underway; detailed data analysis will be completed by March 2016, <u>preliminary data analysis included in this report</u>.**

Year 2 (2015-2016):

7. Produce a list of landscape variables (e.g. re-vegetation height and human use thresholds) that can be used to quantify the extent of caribou functional habitat in our study area and elsewhere. **Underway; final list will be compiled in March 2016.**

2. Does response of boreal caribou to re-vegetation stage vary across different sub-regions?

Laura Finnegan fRI Caribou Program, Karine Pigeon fRI Caribou Program, Jerome Cranston Arctos Ecological Consultancy, & Doug MacNearney fRI Caribou Program

2.1. Introduction

Functional caribou habitat is associated with a high probability of caribou occurrence and high levels of population level fecundity (high calf recruitment and low predation risk). Fragmentation of habitat within caribou ranges reduces the extent of functional habitat available to caribou, increases niche overlap with alternate prey driving a numerical response in wolf populations, and ultimately decreases caribou survival due to apparent competition (James *et al.* 2004; DeCesare *et al.* 2010). The effect of habitat disturbance extends beyond the physical footprint of the disturbance itself (Dyer *et al.* 2001; Polfus *et al.* 2011; Boulanger *et al.* 2012), and research has shown that caribou actively avoid areas within 500m of disturbed areas (Dyer *et al.* 2001). For caribou predators, the opposite is true and they frequently select for anthropogenic disturbance, in particular linear access corridors that may facilitate movement (Whittington *et al.* 2005; Stewart *et al.* 2013; Tigner *et al.* 2014). To reflect this loss of functional habitat, all "disturbed habitat" within caribou ranges includes the disturbance feature itself and a 500m buffer (Environment Canada 2012). It is unknown whether this buffer reflects how caribou and their predators respond to linear features at all stages of re-vegetation. Understanding of how re-vegetation stage affects use of disturbed areas by caribou and their predators will help prioritize areas for restoration within caribou ranges.

Remote sensing is increasingly used to inform landscape planning for species at risk (Weclaw and Hudson 2004; Nielson *et al.* 2010). High resolution light detection and ranging (LiDAR) data increases the accuracy of remote sensing-based habitat assessments as these data provide information in three dimensional space (e.g. canopy cover and canopy height; Lefsky *et al.* 2002), and have been used to remotely map habitats for wildlife at a fine scale (Vierling et al. 2008; Martinuzzi et al. 2009; McKay et al. 2014a), and to predict vegetation regrowth patterns within caribou ranges (van Rensen *et al.* 2015). LiDAR surfaces have sufficiently high resolution (1m horizontal resolution) to accurately measure vegetation height within linear access corridors; with vertical and horizontal accuracies of about 40cm.

Recent research in West-central Alberta has assessed how caribou, wolves, and grizzly bears respond to vegetation height of linear features (Finnegan *et al.* 2014). Although analyses from Phase One of this project revealed no effect of vegetation stage on selection of areas near seismic lines by caribou or their predators, assessments of movement rates of grizzly bears and wolves found that both species moved faster near seismic lines that had low vegetation height (<1.4m). This research was focused within the lower and upper foothills and subalpine ecoregions. It remains unknown whether this pattern applies in other natural subregions, including the mixedwood and boreal highlands subregions in North-west Alberta. Following this, the goals of this activity are to use LiDAR-based measurements of vegetation height to determine how caribou respond to seismic lines at different stages of re-vegetation within a mixedwood subregion. Our objectives were 1) to create a Geographic Information System (GIS) layer of LiDAR-attributed seismic lines for the Chinchaga caribou range in North-west Alberta, and 2) to determine caribou response to these seismic lines at different stages of re-vegetation using resource selection functions (RSF).

2.2. Methods

2.2.1. Study area

The study area encompasses the range of the Chinchaga caribou herd in North-west Alberta (Figure 1). The Chinchaga caribou herd belongs to the boreal ecotype and occurs in the boreal forest year round (Bergerud 1992; Briand *et al.* 2009). Boreal caribou are listed as threatened under Alberta's *Wildlife Act*, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), and the *Species at Risk Act* (SARA). A federal recovery strategy for this ecotype was released in 2012 (Environment Canada 2012).

Elevation within the study area ranges from 600m to 800m above sea level and topography is relatively flat. Forests consist of black spruce (*Picea mariana*), larch (*Larix laricina*), muskeg, and fen in lowland areas, and white spruce (*Picea glauca*), aspen (*Populus tremuloides*), and poplar (*Populus balsamifera*) in upland areas (Natural Subregions Committee 2006; Tigner *et al.* 2014). Moose (*Alces* alces) are the most abundant ungulate although whitetail and mule deer (*Odocoileus virginianus* and *O. hemionus*), elk (*Cervus canadensis*), and wood bison (*Bison bison athabascae*) are also present (Rowe 2007). The predator guild for this region includes wolves (*Canis lupus*), black bears (*Ursus americanus*), grizzly bears (*Ursus arctos*), coyotes (*Canis latrans*), wolverine (*Gulo gulo*), and lynx (*Lynx canadensis*).

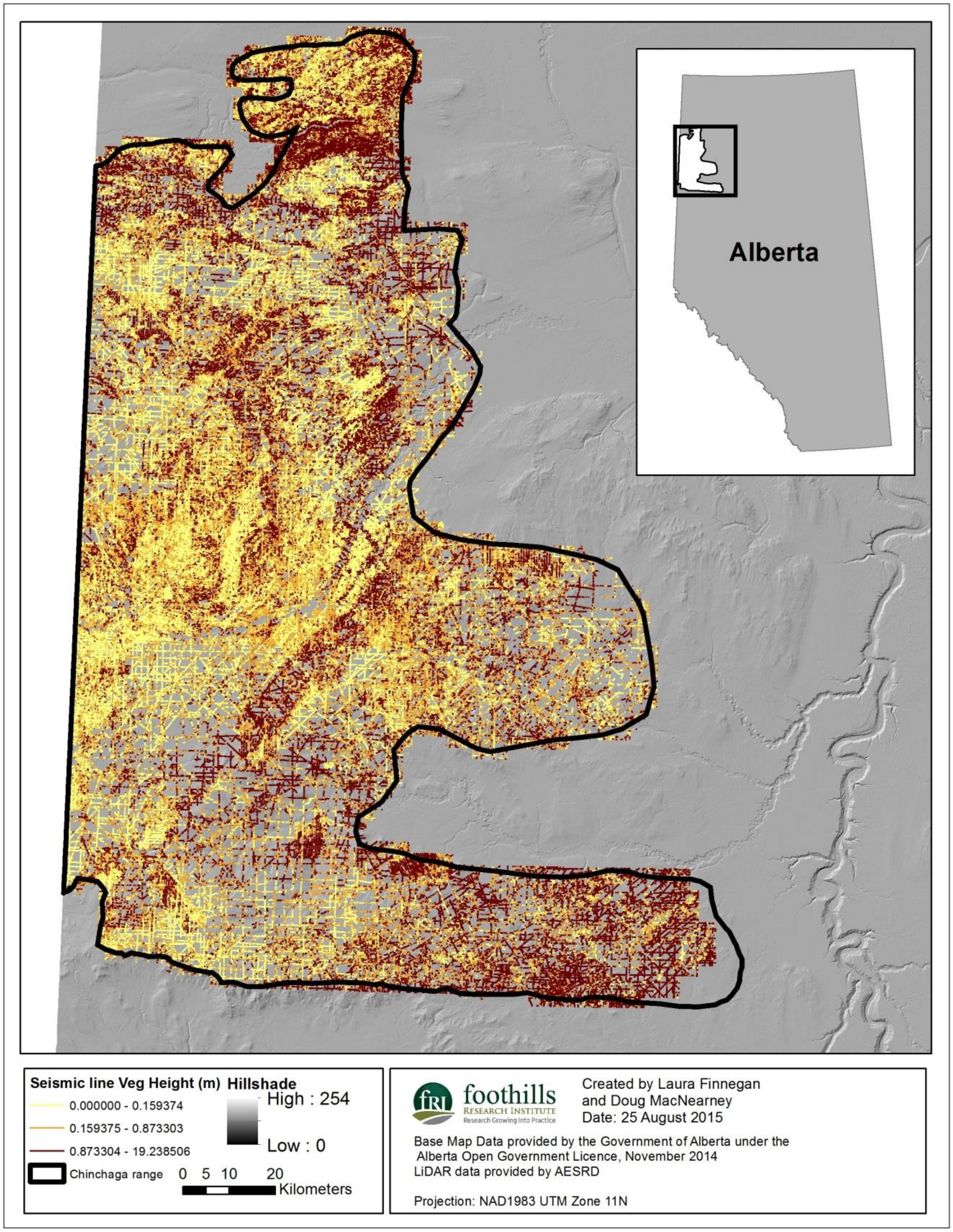

Figure 1. Seismic lines detected by LiDAR between 2003 and 2008 and displayed by vegetation height quantiles in the Chinchaga caribou range.

2.2.2. *LiDAR vegetation height along seismic lines*

We used LiDAR data collected between 2003 and 2008 provided to fRI by the Government of Alberta to attribute vegetation height to 60,648km of seismic lines across our study area (Figure 1). Prior to extracting vegetation height, we subset the Chinchaga caribou range (17,517km^2) seismic layers into 29 individual 28km x 28km tiles (780km^2, corresponding to 1:50,000 NTS mapsheets) for data processing. The raw LiDAR signal returns (the Point Cloud) were resolved into two sets of points: Bare Earth, representing ground signals, and Full Feature, representing returns from the forest canopy. These point datasets were then converted to ASCII text files of x, y, and z coordinates, and were subsequently converted to Bare Earth (Digital Elevation model, or DEM) and Full Feature (Digital Surface Model, or DSM) ESRI grid surfaces at 1m horizontal resolution. A Canopy Height surface was derived by subtracting the DEM from the DSM.

Seismic line features (polyline) were obtained from Government of Alberta base features. We developed an automated GIS process to derive topographic and vegetation metrics for seismic lines from our LiDAR-based surfaces. Because the process is automated, it is far less expensive than Softcopy interpretation, thereby freeing up more resources to be directed to actual on-the-ground reclamation treatments.

Although GIS tools can extract underlying raster attributes from digitized lines (e.g. mean, minimum, and maximum values for slope and elevation), seismic line features digitized by photo-interpreters usually are not accurate enough to yield reliable information on vegetation along the entirety of the line. In addition, seismic cutline right-of-ways are typically so narrow (3 to 6m) that small errors in digitizing or geo-referencing will cause the digitized line to lie outside the corridor and fall within adjacent forest stands. To obtain accurate canopy height values for vegetation on the seismic line, the line must precisely follow the actual seismic corridor. To obtain accurate vegetation height data, our GIS process clips the canopy height surface to within 20m of the original seismic line feature. A least-cost path raster was generated between the start point (source) and endpoint (destination) of the line feature and this path was then converted to a line features. The resulting line features were divided into segments of approximately 100m and we derived mean vegetation height along the least-cost path by overlaying the adjusted line feature with the canopy height surface.

2.2.3. Animal GPS data

Our caribou telemetry data consisted of 6 hour GPS location data (Lotek 2200/3300, Lotek Engineering Systems, Newmarket, Ontario, Canada) collected by Alberta Environment and Parks between 2007 and 2009 from 18 adult female caribou (Figure 2). Details of animal capture are outlined in Slater (2013).

To account for seasonal differences in caribou movement, we partitioned our data into seven seasons that combined previously described caribou seasons in the same area (Nagy 2011; DeMars & Boutin 2013): Calving – 15 April to 15 July; Early summer – 16 July to 12 August; Late summer – 13 August to 12 September; Fall – 13 September to 30 November; Early winter – 1 December to 25 January; Mid winter – 26 January to 15 March, and Late winter – 16 March to 14 April.

As we were interested in animal response to vegetation height of seismic lines, we used ArcGIS 10.2.2. (ESRI) to buffer the seismic line footprint within the study area by 500m (the buffer width applied under the Federal Recovery Strategy (Environment Canada 2012), and then clipped caribou locations to this buffered area. Only caribou with > 100 locations/season within this 500m buffered area were included in the analysis.

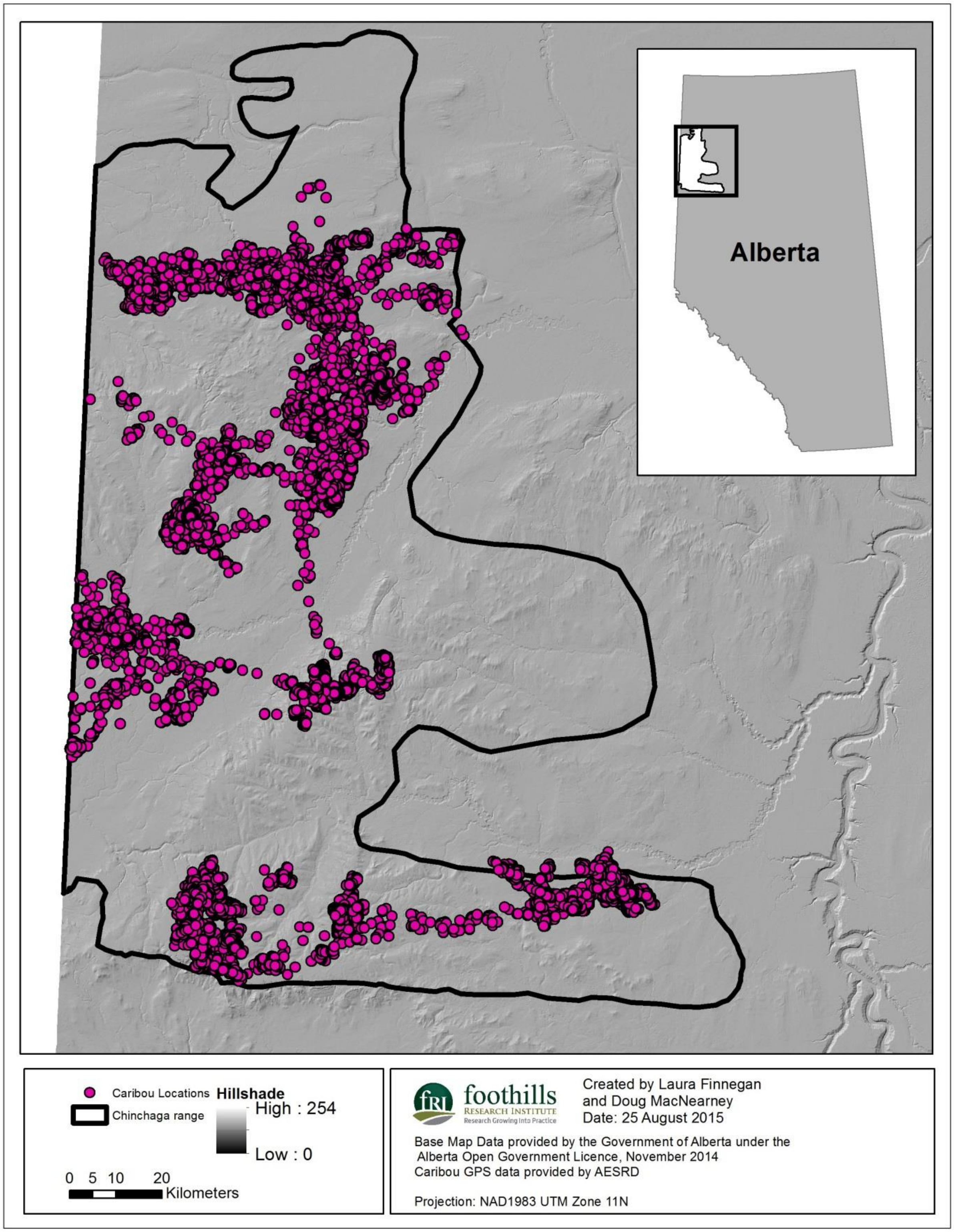

Figure 2. Distribution of caribou telemetry locations for the Chinchaga caribou range (2007-2009).

2.2.4. Data analysis

As previous analysis has found that linear features affect animal at the individual scale (Neufeld 2006; DeCesare *et al.* 2012), we carried out our resource selection function (RSF) at the individual or 3rd order scale. We followed a 'design III' approach (Manly *et al.* 2002), retaining the individual animal as our sampling unit, and drawing random available locations at a 1:1 ratio to used locations from areas within 500m of seismic lines that fell within a minimum convex polygon (MCP) created for each animal/season using Geospatial Modelling Environment (www.spatialecology.com/gme) and ArcGIS 10.2.2 (ESRI 2015). We then calculated the distance to the nearest seismic line segment for each of the used and available locations, and extracted the mean vegetation height attributes of this seismic line segment using ArcGIS 10.2.2 (ESRI 2015).

We used generalized linear mixed models to determine relative caribou habitat use in relation to vegetation height and distance to seismic lines (Bolker *et al.* 2009). We used the 'lme4' package (Bates *et al.* 2014) in R (R Core Team 2013) and RStudio (RStudio Team 2015) to construct models for each season and included the individual animal as a random effect. As we were interested in how the proximity to seismic lines at different stages of re-vegetation affected habitat use, we fit all models with an interaction between distance to seismic lines and vegetation height. We report our results as odds ratios; the exponent of the averaged beta (β) coefficients and confidence intervals estimated from the logistic regression, and as the relative probability (p) of selection ($p = \exp(\beta)/(1+\exp(\beta))$).

We assessed the predictive capability of our models using the area under a Receiver Operating Curve (ROC, Cumming 2000) calculated in the package 'ROCR' (Sing *et al.* 2005) in R 3.0.1 (R Core Team 2013) and RStudio (RStudio Team 2015). ROC values of 0.5 indicate a model with no predictive power and values of 1 are models with perfect predictive power. We visualized our results using the 'ggplot2' package (Wickham 2009) in R 3.0.1 (R Core Team 2013) and RStudio (RStudio Team 2015).

2.3. Results

2.3.1. LiDAR vegetation height along seismic lines

The average vegetation height along seismic lines was 0.97 m (range: 0 - 19.23m, standard deviation: 1.42m). Of 60,648km of seismic lines identified in the study area, 69.55% had vegetation height of less than 1m. Quantile intervals (33%, 66%, 100%) for vegetation height on seismic lines were 0 - 0.15m; 0.16 - 0.87m; and 0.84 - 19.23m.

2.3.2. Caribou habitat selection in relation to seismic line re-vegetation

Our final dataset consisted of 159,745 GPS locations across seven seasons with a mean of 1650 locations per animal per season (range: 132 – 5584 locations).

We found that the caribou response to re-vegetation height of seismic lines varied with respect to season and distance to seismic lines (Table 2; Figure 3). Overall, the probability of caribou selecting areas near seismic lines decreased with increasing vegetation height, (Table 2; Figure 3). In general however, the probability of selection was greater for areas further from seismic lines, and the slope of the relationship between the relative probability of selection and the vegetation height on seismic lines decreased with increasing distances from seismic lines (Figure 3). During calving, fall, and early winter, the relative probability of selection consistently decreased with increasing vegetation heights, regardless of distances to seismic lines but the slope of the relationship between the relative probability of selection and the height of vegetation on seismic lines was less pronounced when caribou were located 500m from seismic lines (Figure 3A, 3D, and 3E). During early and late summer, we also observed a reduction in the relative probability of selection with increasing vegetation height of seismic lines across all distances, but the probability of selection for areas at 500m from seismic lines was much greater than the relative probability of selection for areas < 500m (Figure 3B and 3C). Finally, in mid and late winter, the slope of the relative probability of selection in response to the vegetation height on seismic lines was similar to the other seasons at distances of 50m and 100m but this relationship changed at distances of 250m and 500m (Figure 3F and 3G). In mid and late winter, the relative probability of selection for areas at 250m from seismic lines still decreased with increasing vegetation heights, but the slope was less pronounced. At distances of 500m, the relationship between the relative probability of selection and vegetation height changed, with caribou selecting areas at 500m from seismic lines more with increasing vegetation heights on seismic lines (Figure 3F and 3G).

Table 1: Odds ratios (± 95% confidence intervals) of the selection for areas within 500m of seismic lines in relation to distance to seismic lines (Seis_dist) and vegetation height of seismic lines (Veght) by caribou in the Chinchaga caribou herd, Alberta, between 2007 and 2009. Odds ratios significantly different from 1 are in bold.

	Calving	**Early summer**	**Late summer**	**Fall**
Seis_dist	**1.001 (± 0.0002)**	**1.002 (± 0.0004)**	**1.003 (± 0.0004)**	**1.001 (± 0.0002)**
Veght	**0.451 (± 0.025)**	**0.606 (± 0.082)**	**0.665 (± 0.0722)**	**0.683 (± 0.023)**
Seis_dist * Veght	1.000 (± 0.0003)	**1.001 (± 0.0007)**	1.000 (± 0.0006)	**1.0005 (± 0.0002)**
	Early winter	**Mid winter**	**Late winter**	
Seis_dist	**0.9987 (± 0.0003)**	**0.9981 (± 0.0003)**	**1.001 (± 0.0004)**	
Veght	**0.580 (± 0.028)**	**0.622 (± 0.035)**	**0.721 (± 0.048)**	
Seis_dist * Veght	**1.0013 (± 0.0002)**	**1.0016 (± 0.0002)**	**1.001 (± 0.0003)**	

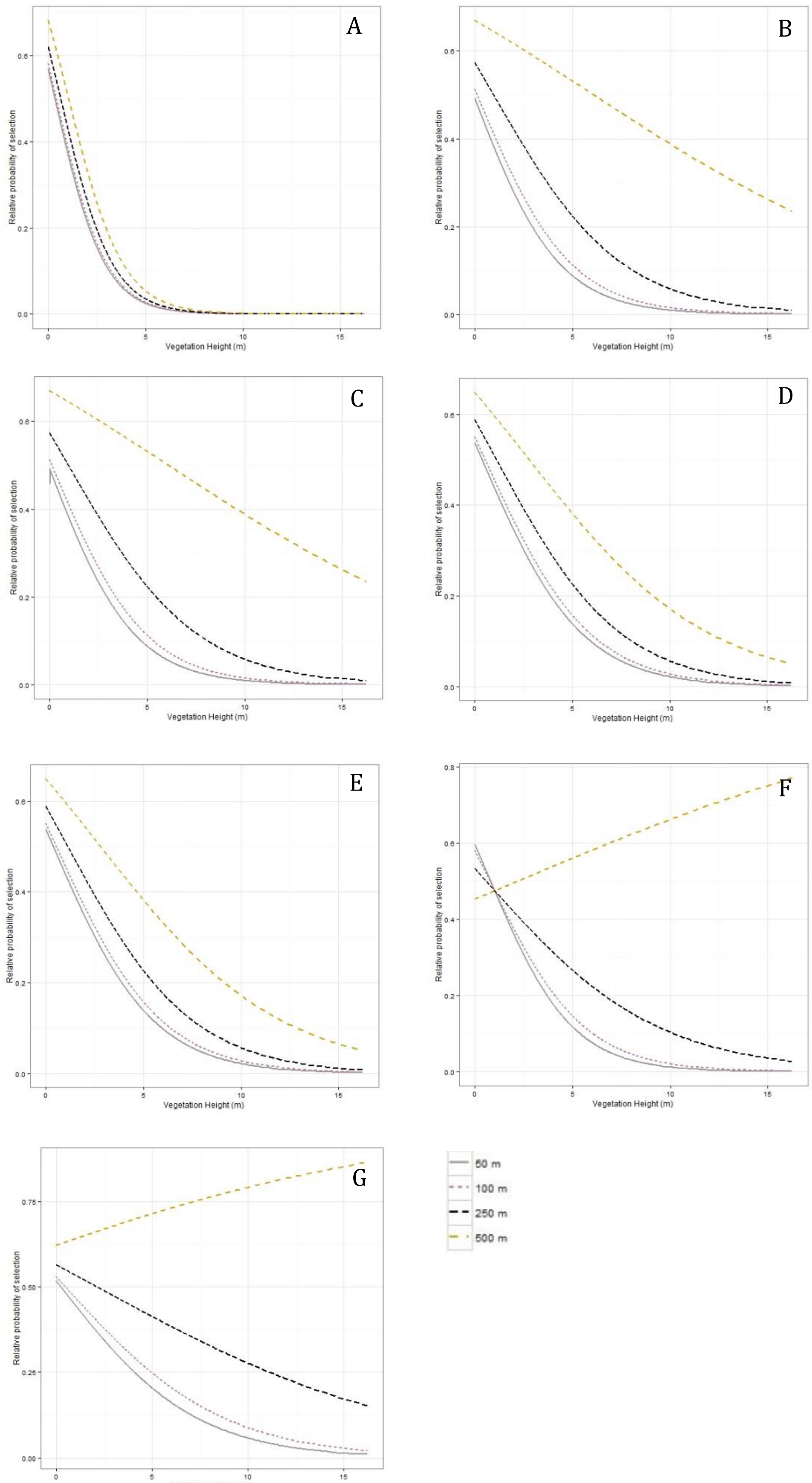

Figure 3: Relative probability of selection by adult female Chinchaga caribou of the areas near seismic lines as a function of vegetation height of seismic lines and distance to seismic lines (plotted using 4 intervals – 50m, 100m, 250m and 500m) for A) Calving, B) Early summer, C) Late summer, D) Fall, E) Early winter, F) Mid winter and G) Late winter seasons.

2.4. Discussion

Using LiDAR-based measurements of re-vegetation height on seismic lines collected within the Chinchaga caribou range between 2003 and 2008, and using caribou GPS data collected within 500m of seismic lines between 2007 and 2009, we determined whether different stages of re-vegetation of seismic lines affected the relative probability of selection of caribou near seismic lines. We found that circa 2007, the re-vegetation status of seismic lines in the Chinchaga caribou range was quite low. The majority (69.55%) of seismic lines had regenerated to less than 1m in height, and only 21.69% had regenerated to heights above 1.5m. Using logistic regression, we found that vegetation height and distance to seismic lines affected the relative probability of selection of areas close to seismic lines by caribou. Although the relationship between the relative probability of selection of areas near seismic lines and the height of vegetation on seismic lines was seasonally dependent, caribou generally selected for low vegetation seismic lines when located within 250m of seismic lines. These results suggest that low vegetation seismic lines that have been shown to facilitate predator movement (Whittington *et al.* 2005; Stewart *et al.* 2013; Tigner *et al.* 2014), and that were pervasive throughout the Chinchaga range when LiDAR flights occurred, could be acting as ecological traps for caribou, therefore further exacerbating population declines.

Except during the calving season, caribou selected areas further from seismic lines more than areas closer to seismic lines, regardless of season and vegetation height. This result is consistent with the idea that caribou avoid seismic lines at a zone of influence near 500m (Dyer *et al.* 2001) and confirms that overall, caribou select areas away from seismic lines itself (Dyer *et al.* 2001; Polfus *et al.* 2011; Boulanger *et al.* 2012). These findings are also in accordance with observed seasonal variations from a previous study conducted in North-east Alberta where caribou avoided areas within 100m of seismic lines during calving, summer, fall, and early winter, and within 250m during late winter (Dyer *et al.* 2001). When considering the vegetation height of seismic lines at 500m distances, low vegetation seismic lines could still be acting as ecological traps during all seasons, except for mid and late winter when caribou increasingly selected areas at distances 500m from seismic lines that had higher vegetation heights.

If low vegetation height sesimic lines contain important food resources for caribou, the selection of these low vegetation height seismic lines, especially during the calving season, may be explained by females spending time in proximity to food resources when energy needs for lactation are highest (Parker *et al.* 2009). Our findings suggest that caribou may be selecting for low vegetation seismic lines to access food, as suggested by (James & Stuart-Smith 2000), and a previous analysis in West-central

Alberta revealed similar results (Finnegan et al. 2014). We observed different patterns of selection for low vegetation seismic lines across seasons, and this observation is in accordance with the idea that the availability of food on low vegetation seismic lines may be driving selection of these seismic lines during calving, summer, fall, and early winter since food would be accessible on seismic lines during snow-free periods. If food availability is driving selection of low vegetation seismic lines, it is likely that caribou would increasingly select areas further from seismic lines with increases in vegetation height, just as we observed, and especially during winter when food should be less accessible on low vegetation seismic lines because of snow cover. Futher investigation of the potential influence of food availability on low vegetation seismic lines for caribou behaviour may shed light onto the importance of seismic lines as potential ecological traps. We hope to answer this question in the future by using our ongoing field measurements of caribou foods on seismic lines.

Overall, our results have shown that when located near seismic lines, caribou selected low vegetation seismic lines and that low vegetation seismic lines are potentially acting as ecological traps. Caribou predators select these linear features as travel corridors because they facilitate movement, and to prey on ungulates (Latham, Latham & Boyce 2011; Whittington *et al.* 2011; Stewart *et al.* 2013). As caribou potentially make movement decisions based more on food resources than predator avoidance (Avgar *et al.* 2015), encounters with predators are likely while caribou are near seismic lines (Whittington *et al.* 2011), and may be further increase on or near linear features with low vegetation.

2.5. Ongoing work

Our findings do not refute the currently accepted 500m buffer applied to seismic lines across caribou ranges. The inclusion of vegetation height into assessments of habitat selection did not reveal the predicted patterns of selection for caribou. Because we found that when caribou are near seismic lines, caribou select seismic lines with low vegetation height, the restoration of these low vegetation height seismic lines should be a priority. To further shed light onto the potential reasons for selection for low vegetation seismic lines by caribou, data collection of caribou foods on seismic lines is ongoing. Also, ongoing data analysis that includes additional topographic (e.g. slope and digital elevation model (DEM)) and habitat (e.g. land cover) variables and RSFs created at distances >500m should help to determine the putative thresholds of vegetation regrowth on seismic lines when caribou avoidance is no longer detected. Our next step will be to investigate the probability of selection of areas within categories of specific distances from seismic lines (i.e. 0m – 100m vs. 100m – 200m vs. 200m – 300m etc.) in respect to vegetation heights on seismic lines rather than investigating selection using distance as a binned continuous variable. We hope that this new approach, along with food data collected on seismic lines, will shed light onto the selection patterns of caribou near seismic lines, help us understand the potential of low vegetation seismic lines as ecological traps for caribou, and further contribute to the identification of seismic lines that should be prioritized for restoration.

2.6. Literature Cited

Avgar, T., Baker, J. a, Brown, G.S., Hagens, J.S., Kittle, A.M., Mallon, E.E., McGreer, M.T., Mosser, A., Newmaster, S.G., Patterson, B.R., Reid, D.E.B., Rodgers, A.R., Shuter, J., Street, G.M., Thompson, I., Turetsky, M.J., Wiebe, P. a & Fryxell, J.M. (2015) Space-use behaviour of woodland caribou based on a cognitive movement model. *The Journal of Animal Ecology*.

Bates, D., Maechler, M., Bolker, B. & Walker, S. (2014) lme4: Linear mixed-effects models using S4 classes.

Bergerud, A. (1992) Rareness as an antipredator strategy to reduce predation risk for moose and caribou. *Wildlife 2001: populations* (eds D. McCullough & R. Barrett), pp. 1008–1021. Elsevier Applied Science, New York.

Bolker, B.M., Brooks, M.E., Clark, C.J., Geange, S.W., Poulsen, J.R., Stevens, M.H.H. & White, J.-S.S. (2009) Generalized linear mixed models: a practical guide for ecology and evolution. *Trends in ecology & evolution*, **24**, 127–35.

Boulanger, J., Poole, K.G., Gunn, A. & Wierzchowski, J. (2012) Estimating the zone of influence of industrial developments on wildlife : a migratory caribou Rangifer tarandus groenlandicus and diamond mine case study. *Wildlife Biology*, **179**, 164–179.

Briand, Y., Ouellet, J.-P.P., Dussault, C. & St-Laurent, M.-H.H. (2009) Fine-scale habitat selection by female forest-dwelling caribou in managed boreal forest: Empirical evidence of a seasonal shift between foraging opportunities and antipredator strategies. *Ecoscience*, **16**, 330–340.

Canada, E. (2012) *Recovery Strategy for the Woodland Caribou (Rangifer Tarandus Caribou), Boreal Population, in Canada. Species at Risk Act Recovery Strategy Series*. Ottawa.

Cumming, G. (2000) Using between-model comparisons to fine-tune linear models of species ranges. *Journal of Biogeography*, **27**, 441–455.

DeCesare, N.J., Hebblewhite, M., Robinson, H.S. & Musiani, M. (2010) Endangered, apparently: the role of apparent competition in endangered species conservation. *Animal Conservation*, **13**, 353–362.

DeCesare, N.J., Hebblewhite, M., Schmiegelow, F., Hervieux, D., McDermid, G.J., Neufeld, L., Bradley, M., Whittington, J., Smith, K.G., Morgantini, L.E., Wheatley, M. & Musiani, M. (2012) Transcending scale dependence in identifying habitat with resource selection functions. *Ecological applications*, **22**, 1068–83.

DeMars, C.A. & Boutin, S. (2013) *Assessing Spatial Patterns of Predation Risk to Boreal Caribou Calves: Implications for Management*.

Dyer, S., O'Neill, J., Wasel, S. & Boutin, S. (2001) Avoidance of industrial development by woodland caribou. *The Journal of Wildlife Management*, **65**, 531–542.

Finnegan, L., Pigeon, K., Cranston, J., & Stenhouse, G. (2014). Analysis and restoration of seismic cutlines in Southern Mountain and Boreal Caribou Range in West-Central Alberta. HSP 6617. Report prepared for Environment Canada. pp83

James, A.R.C., Boutin, S., Hebert, D.M. & Rippin, B. (2004) Spatial separation of caribou from moose and its relation to predation by wolves. *Journal of Wildlife Management*, **68**, 799–809.

James, A.R.C. & Stuart-smith, A.K. (2000) Distribution of Caribou and Wolves in Relation to Linear Corridors. *Journal of Wildlife Management*, **64**, 154–159.

Latham, A.D.M., Latham, M.C. & Boyce, M.S. (2011) Habitat selection and spatial relationships of black bears (Ursus americanus) with woodland caribou (Rangifer tarandus caribou) in northeastern Alberta. *Canadian Journal of Zoology*, **89**, 267–277.

Lefsky, M.A., Cohen, W.B., Parker, G.G. & Harding, D.J. (2002) Lidar Remote Sensing for Ecosystem Studies. *Bioscience*, **52**, 19–30.

Manly, B.F.J., McDonald, L.L., Thomas, D.L., McDonald, T.L. & Erickson, W.P.. (2002) *Resource Selection by Animals: Statistical Design and Analysis for Field Studies*, 2nd ed. Chapman and Hall, Boston, Massachusetts, USA.

Martinuzzi, S., Vierling, L.A., Gould, W.A., Falkowski, M.J., Evans, J.S., Hudak, A.T. & Vierling, K.T. (2009) Mapping snags and understory shrubs for a LiDAR-based assessment of wildlife habitat suitability. *Remote Sensing of Environment*, **113**, 2533–2546.

McKay, T., Graham, K. & Stenhouse, G. (2014) *Grizzly Bears and Pipelines: Response to Unique Linear Features. Year 2 (2013) Final Report*. Report prepared for PTAC.

Michele, L. & Neufeld, L. (2006) *Spatial Dynamics of Wolves and Woodland Caribou in an Industrial Forest Landscape in West-Central Alberta*. University of Alberta.

Nagy, J. (2011) *Use of Space by Caribou in Northern Canada*. University of Alberta.

Nielsen, S., McDermid, G., Stenhouse, G. & Boyce, M. (2010) Dynamic wildlife habitat models: Seasonal foods and mortality risk predict occupancy-abundance and habitat selection in grizzly bears. *Biological Conservation*, **143**, 1623–1634.

Parker, K.L., Barboza, P.S. & Gillingham, M.P. (2009) Nutrition integrates environmental responses of ungulates. *Functional Ecology,* **23**, 57–69.

Polfus, J.L., Hebblewhite, M. & Heinemeyer, K. (2011) Identifying indirect habitat loss and avoidance of human infrastructure by northern mountain woodland caribou. *Biological Conservation*, **144**, 2637–2646.

Van Rensen, C.K., Nielsen, S.E., White, B., Vinge, T. & Lieffers, V.J. (2015) Natural regeneration of forest vegetation on legacy seismic lines in boreal habitats in Alberta's oil sands region. *Biological Conservation*, **184**, 127–135.

Rowe, M. (2007) *Boreal Caribou and Wolf Movement and Habitat Selection Within the Chinchaga Range*. Peace Region Technical Report.

Sing, T., Sander, O., Beerenwinkel, N. & Lengauer, T. (2005) ROCR: visualizing classifier performance in R. *Bioinformatics*, **21**, 7881.

Slater, S.C. (2013) *Woodland Caribou Conservation in Alberta: Range Delineation and Resource Selection*. M.Sc. Thesis, University of Alberta.

Stewart, B., Nelson, T., Laberee, K., Nielson, S., Wulder, M. & Stenhouse, G. (2013) Quantifying grizzly bear selection of natural and anthropogenic edges. *The Journal of Wildlife Management*, **77**, 957–964.

Tigner, J., Bayne, E.M. & Boutin, S. (2014) Black bear use of seismic lines in Northern Canada. *The Journal of Wildlife Management*, **78**, 282–292.

Vierling, K.T., Vierling, L. a, Gould, W. a, Martinuzzi, S. & Clawges, R.M. (2008) Lidar: shedding new light on habitat characterization and modeling. *Frontiers in Ecology and the Environment*, **6**, 90–98.

Weclaw, P. & Hudson, R.J. (2004) Simulation of conservation and management of woodland caribou. *Ecological Modelling*, **177**, 75–94.

Whittington, J., Hebblewhite, M., DeCesare, N.J., Neufeld, L., Bradley, M., Wilmshurst, J. & Musiani, M. (2011) Caribou encounters with wolves increase near roads and trails: a time-to-event approach. *Journal of Applied Ecology*, **48**, 1535–1542.

Whittington, J., St.Clair, C. & Mercer, G. (2005) Spatial responses of wolves to roads and trails in mountain valleys. *Ecological Applications*, **15**, 543–553.

Wickham, H. (2009) *Ggplot2: Elegant Graphics for Data Analysis*. Springer, New York.