Assessing the Influence of Industrial Development on Caribou (*Rangifer tarandus*) in the Lower Athabasca Planning Region of Alberta

2011 Final Report

Prepared for the Ecological Monitoring Committee of the Lower Athabasca

by

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Executive Summary

Most boreal woodland caribou (*Rangifer tarandus*) populations are declining in Alberta. A key caribou conservation policy objective in Alberta is to maintain caribou distribution throughout its current range, which requires maintaining movement capabilities of this highly mobile mammal. The Ecological Monitoring Committee for the Lower Athabasca (EMCLA) initiated this project to address uncertainty over the effects of above-ground pipelines and associated linear features on caribou movement and the extent to which linear features may affect caribou populations.

We completed a review of the current state-of-knowledge regarding the influence of above-ground pipelines and associated linear features on caribou movement in the Lower Athabasca Planning Region (LAPR). An impact hypothesis diagram (IHD) was developed to illustrate the complex relationships that link linear features with caribou population dynamics. Although above-ground pipelines and associated linear corridors are known to affect caribou movement, a consensus was reached by industry, government and scientific representatives who attended a workshop commissioned for this project that based on current evidence from the literature and study area, as well as experience and professional judgment, the overall effect of above-ground pipelines and associated linear features on caribou is small relative to predation at current levels of development. They also concluded that it is unreasonable to expect to measure the influence of individual land use footprint types on caribou movement because of: 1) confounding factors; 2) small sample size from existing monitoring programs; and 3) cost of a directed research and monitoring program that would require extensive long-term monitoring of individual caribou.

Workshop participants agreed that further work should focus on spatially explicit mitigation strategies of entire in-situ developments, and on ways that all features within these intensive development areas can be planned, designed, operated, and restored to maintain range-scale caribou movements and distribution. We therefore compiled existing datasets that could be used to analyze current caribou movement patterns in the LAPR in relation to in-situ features, as well as other man-made and habitat landscape features.

We used existing GPS-telemetry data from adult female caribou to test whether large-scale caribou movement types could be identified and whether caribou selected and/or avoided specific habitat and land use features while making large-scale movements within ranges, using non-linear models and step selection functions (SSFs), respectively. We found that woodland caribou movement could be classified into two types: slow and fast, where slow movements represent small-scale movements and fast-movements represent large-scale movements. We found that caribou in northeast Alberta selected or avoided specific habitat and land use features while making large-scale movements. However, there was significant individual variability in the type and strength of relationships between caribou movement steps and landscape features.

There remains uncertainty as to the strength of scientifically credible support for adopting spatially-explicit mitigation strategies to minimize the influence of in-situ oil sands developments on caribou movement. We therefore propose the following work for 2012:

(1) Obtain accurate information on the location of in-situ footprint in the LAPR, particularly where they overlap with caribou telemetry data. Current footprint data does not allow us to differentiate between in-situ footprint and other types of

footprint (e.g., forestry roads, conventional oil and gas pipelines). Data on the spatial location, configuration and boundaries of in-situ developments is needed to accurately measure caribou movement in response to these features.

(2) Map the density of existing large-scale caribou movement steps within the WSAR, ESAR and Richardson caribou population ranges. This will provide a preliminary analysis of whether large-scale caribou movements in northeast Alberta are concentrated or dispersed within ranges. The map can be overlaid onto in-situ development maps to compare the location of existing caribou movement to in-situ development location.

(3) Complete the SSF analyses to define large-scale caribou movement response to in-situ oil sands developments. The final SSF model will measure caribou response to in-situ footprint versus habitat and other human land use types.

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Dr. Tyler Muhly developed the impact hypothesis material and conducted the statistical analysis with input from Terry Antoniuk, Dr. Jason Fisher and Dr. Cole Burton. Terry Antoniuk coordinated and consolidated information from the technical workshop. Tyler Muhly, Terry Antoniuk, Cole Burton, and Jason T. Fisher contributed to conceptual development and writing the report.

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1. Introduction

Most boreal woodland caribou (*Rangifer tarandus*) populations are declining in Alberta (Environment Canada 2011; Festa-Bianchet et al. 2011). Predation appears to be the dominant factor limiting caribou populations across North America (Bergerud and Ballard 1988; Seip 1992; Bergerud and Elliott 1986; Stuart-Smith et al*.* 1997; Bergerud and Elliott 1998; Rettie and Messier 1998; Schaefer et al. 1999; McLoughlin et al*.* 2003; Wittmer et al. 2005a). Research has also identified strong correlations between combined land use footprint (e.g., roads and clearings) on the landscape and caribou decline at the caribou range scale (Schaefer 2003; Wittmer et al. 2005b; Vistnes and Nellemann 2007; Vors et al. 2007; Bowman et al. 2010), including northeast Alberta (Sorensen et al. 2008; Schneider et al. 2010). The leading hypothesis for this negative relationship is that human-caused habitat change converts low-productivity vegetation (e.g., old growth forest) to high-productivity vegetation (e.g., young forest and agriculture). High-productivity vegetation increases populations of browsing ungulate species such as moose (*Alces alces)* and deer (*Odocoileus spp.*) (Fisher and Wilkinson 2005) which causes predator numbers to increase, particularly wolves (*Canis lupus*). This predator 'numerical response' (*sensu* Holling 1959), is referred to as "apparent competition" (Holt 1977, 1984; Holt and Kotler 1987), wherein an increase in density of moose and deer (the primary prey) causes a decline in caribou (the incidental prey) due to a shared predator (most often wolves; DeCesare et al. 2010). In addition, construction of linear features (i.e., roads, pipelines and seismic lines) makes it easier for predators to traverse the landscape, which increases predator-caribou encounter rates (i.e., a 'functional response' of predators; James and Stuart-Smith 2000; McLoughlin *et al.* 2003; Latham et al*.* 2011). Finally, there is also some evidence that climate change might be contributing to caribou decline in Alberta, with increasing temperatures at northern latitudes allowing white-tailed deer to expand their range north into caribou range (Dawe 2011).

Much research and conservation attention has focused on stabilizing and reversing caribou population declines in Alberta by reducing incremental habitat loss and predation through direct and indirect management actions. Wolf and other prey control, land-use planning to maintain high quality caribou habitat, and habitat restoration are the primary management options being proposed (Athabasca Landscape Team 2009; Environment Canada 2011). In addition, a key policy objective in Alberta is to maintain caribou distribution throughout its current range (Alberta Woodland Caribou Recovery Team 2005; D. Hervieux, Government of Alberta, pers. comm.).

Previous research from Alberta has suggested that large-scale caribou movements are highly variable with no obvious relationship to landscape features (Fuller and Keith 1981; Stuart-Smith et al*.* 1997; Bergman and Luttich 2000), with the implication that caribou movements are indiscriminately dispersed throughout a caribou population's range. Thus, there would be no distinct caribou movement areas to avoid by strategically placing land use linear features, facilities, and clearings within caribou ranges. However, there is uncertainty whether anthropogenic influences on caribou movement have implications for caribou population dynamics. It is unclear whether anthropogenic features that block caribou movements to a habitat patch or require caribou to move further distances to reach habitat patches could result in increased energy expenditure that negatively influences adult female reproduction and/or calf survival. It is unlikely that current levels of anthropogenic development are influencing caribou movement to such a large degree that it is indirectly influencing caribou population dynamics. However, anthropogenic development is expected to increase in the study area, and thus influence on caribou movement will likely increase. We acknowledge the uncertainty but potential importance of anthropogenic influence on caribou movement. Caribou selection or avoidance of habitat and land use features during large-scale movements has never explicitly been tested. Testing this hypothesis will allow us to determine if spatially-explicit management of habitat and land use within a caribou local population range could positively or negatively influence caribou movement patterns in that range.

1.1. Objectives

Approval conditions for in-situ bitumen projects in northeast Alberta require monitoring of caribou movement patterns and mitigating for the influence of above-ground pipelines on movement. However, there is uncertainty over the effects of linear features on caribou movement relative to other human and habitat factors, and the extent to which linear features may affect caribou populations. The EMCLA therefore initiated a research project to review the state-of-knowledge about the influence of above-ground pipelines and associated linear features on caribou movement. This project also collated existing data to conduct a preliminary analysis of caribou movement metrics in order to study the influence of habitat and human land use on large-scale caribou movements in northeast Alberta.

1.2. Report Outline

The intent of this non-technical summary report is to review the conclusions from the state-of-knowledge review about the influence of linear features on caribou movement (Section 2) and to present key preliminary results from the empirical analysis of caribou movement (Section 3). We then describe how results of this work can guide completion of a spatially explicit caribou movement model in 2012 (Section 4). Please refer to the Workshop Report for additional details on the effects of aboveground pipelines and associated linear features on caribou as well as the context of this work within caribou conservation and management, and the Technical Report for complete details on methods and results from the preliminary caribou movement analyses.

2. Effects of Aboveground Pipelines and Associated Linear Features on Caribou Movement and Population Dynamics

Impact hypothesis diagrams (IHDs) are used to help visualize and understand complex systems or relationships. An IHD relating linear features to caribou movement and population response is provided in Fig.1. Recent syntheses (Wolfe et al. 2000) suggest that the population-level effects of anthropogenic disturbance on caribou and reindeer are not clear, although woodland caribou local population growth appears to be inversely related to total disturbed footprint (Vors et al. 2007; Environment Canada 2008, 2011; Sorensen et al. 2008; Schneider et al. 2010). The influence of human land use features (including above-ground pipelines and roads) on caribou energetics, fitness, reproduction and survival has been identified as a major gap in caribou research (NCASI 2007; Festa-Bianchet et al. 2011).

We reviewed and summarized the current state-of-knowledge regarding the influence of above-ground pipelines and associated linear features on caribou movement in the LAPR. Based on results of a literature review, and expert and professional judgment of participants at a technical workshop held on May 12, 2011, a consensus was reached that

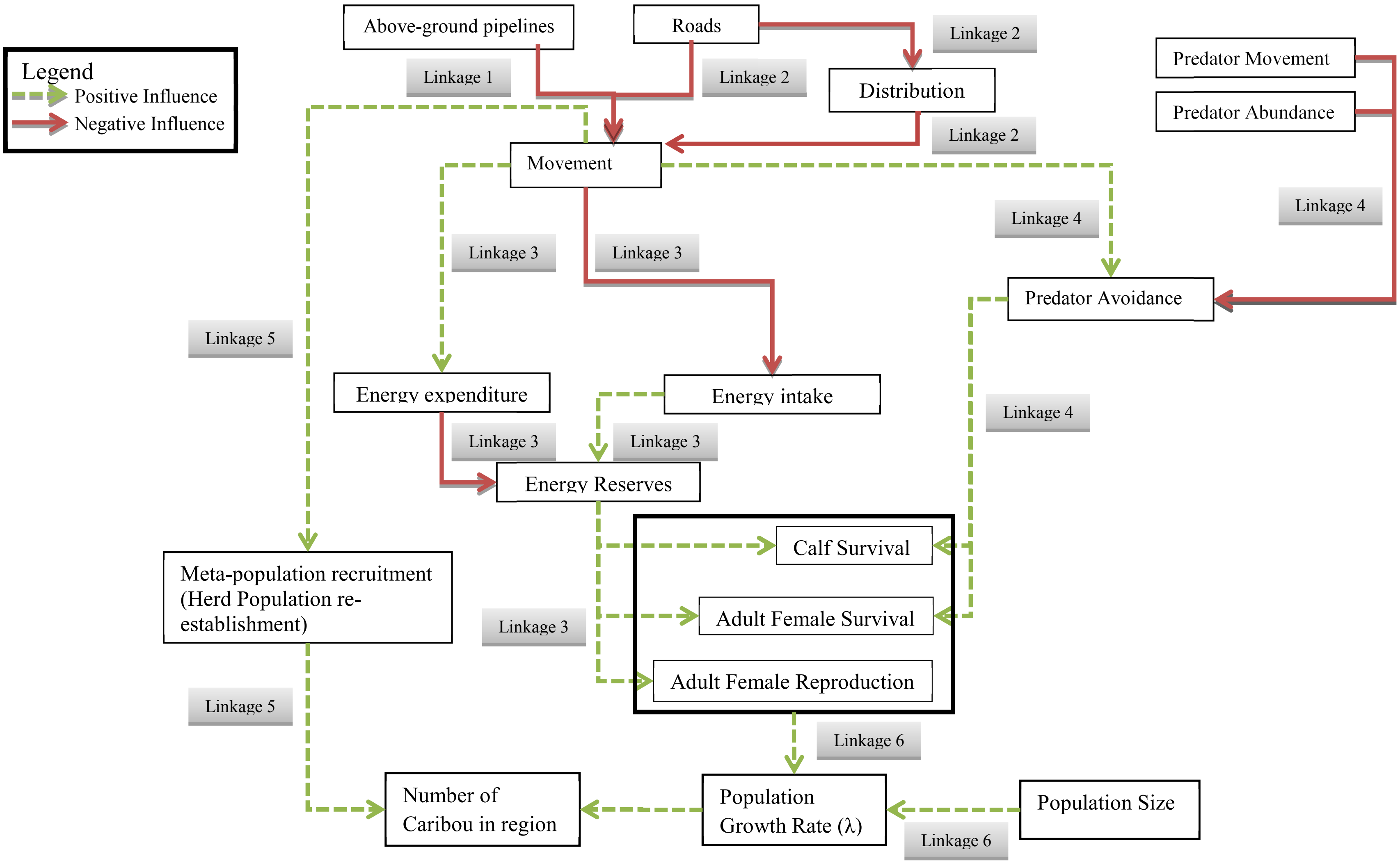

Figure 1. Impact hypothesis diagram (IHD) indicating key linkages between the influence of above-ground pipelines and associated linear features (i.e., roads) on caribou movement and population dynamics in northeast Alberta.

the overall effect of above-ground pipelines and associated linear features on caribou is small relative to predation at current levels of development. Workshop participants also concluded that it is unreasonable to expect to tease out the influence of individual footprint types (i.e., above-ground pipelines, roads, facilities) on caribou movement because of: 1) confounding factors; 2) small sample size from existing monitoring programs; and 3) cost of a directed research and monitoring program that would require extensive long-term monitoring of individual caribou (e.g., using Global Position System telemetry devices – see Walsh et al. 1995).

A defined goal of caribou management in the Lower Athabasca region is to maintain caribou distribution, which means that future range fragmentation should be avoided. However, as in-situ bitumen development proceeds, widespread barriers to caribou movement will likely arise. To reduce ongoing range fragmentation, landscape-scale mitigation strategies should consider entire in-situ project areas, and focus on ways that all features within these intensive development areas can be planned, designed, operated, and restored to maintain range-scale caribou movements and distribution. Additional information on caribou movement metrics is required to inform the design of these mitigation strategies. We therefore compiled existing datasets that could be used to analyze current caribou movement patterns in the LAPR in relation to linear features, as well as other man-made and habitat landscape features.

3. Modeling Large-scale Caribou Movements in Alberta

The purpose of this work was to develop a spatially explicit model of large-scale caribou movements in northeast Alberta using Global Positioning System (GPS)-telemetry data from 20 adult female caribou from northeast Alberta (a sub-sample of data from 89 caribou across Alberta). More specifically, we evaluated whether above-ground pipelines and associated linear features are likely to have a significant influence on caribou movement and population dynamics in the Lower Athabasca Planning Region (LAPR) using a three step process:

1. We collated Global Positioning System (GPS) telemetry data provided by Alberta Sustainable Resource Development (ASRD), Government of Alberta as described in Section 3.1.
2. We tested the hypothesis that boreal woodland caribou movement can be classified into two types: slow, small-scale, intra-patch movements within habitat patches (i.e., contiguous foraging areas), and fast, large-scale, inter-patch movements. We used GPS telemetry data and non-linear models (Sibly et al. 1990; Berdoy 1993; Johnson et al. 2002, 2006) to identify large-scale caribou movements. Results of these analyses are provided in Section 3.2.
3. We tested whether large-scale movements are influenced by specific habitat and land use features. We used GPS telemetry data and step selection functions (SSFs; Fortin et al. 2005) to model habitat and land use feature avoidance or selection along large scale movement steps. Results of these analyses are provided in Section 3.3.

3.1. GPS-telemetry data

We obtained GPS-telemetry data from ASRD, Government of Alberta. Hundreds of thousands of locations were collected at intervals ranging from 15 minutes to 6 hours, from 89 adult female caribou. Caribou had been collared between 1998 to 2000 and 2007 to

2011 from seven different boreal woodland caribou populations in Alberta: Little Smoky, Chinchaga, Red Earth, Richardson, East Side Athabasca River (ESAR), West Side Athabasca River (WSAR) and Nipisi. We analyzed data from 20 individuals collared in the Lower Athabasca Planning Region (LAPR) between 2008 and 2011, specifically within the ESAR (6 individuals) and Richardson (14 individuals) populations. We divided data into summer and winter seasons, where summer was defined as post-calving to rut (May 15 – September 30), and winter was defined as rut to post-calving (October 1 – May 14).

3.2. Identifying large-scale caribou movements from GPS-telemetry data

We found that caribou movement could be divided into two different types: slow, small-scale, intra-patch movements and fast, large-scale, inter-patch movements, consistent with the findings of Johnson et al. (2002). We observed a difference between high-frequency slow movements and low-frequency fast movements for most caribou during the summer and winter, as illustrated for caribou 1489 (Fig. 2). The statistical break point between these movement types was calculated (the 'scale criterion' [r_c]) to differentiate slow (movement rate$<r_c$) from fast (movement rate$\geq r_c$) movement types for each individual animal. Using caribou 1489 as an example, movements slower than 23.78 metres/minute were assumed to represent slow movements, and those faster than this rate represented large-scale movements (Fig. 2). To confirm that movement rate was a useful proxy of movement step length for the majority of caribou steps, we calculated a Spearman correlation between movement rate and step length across all animals and found a high correlation between them (r=0.948, P<0.0001).

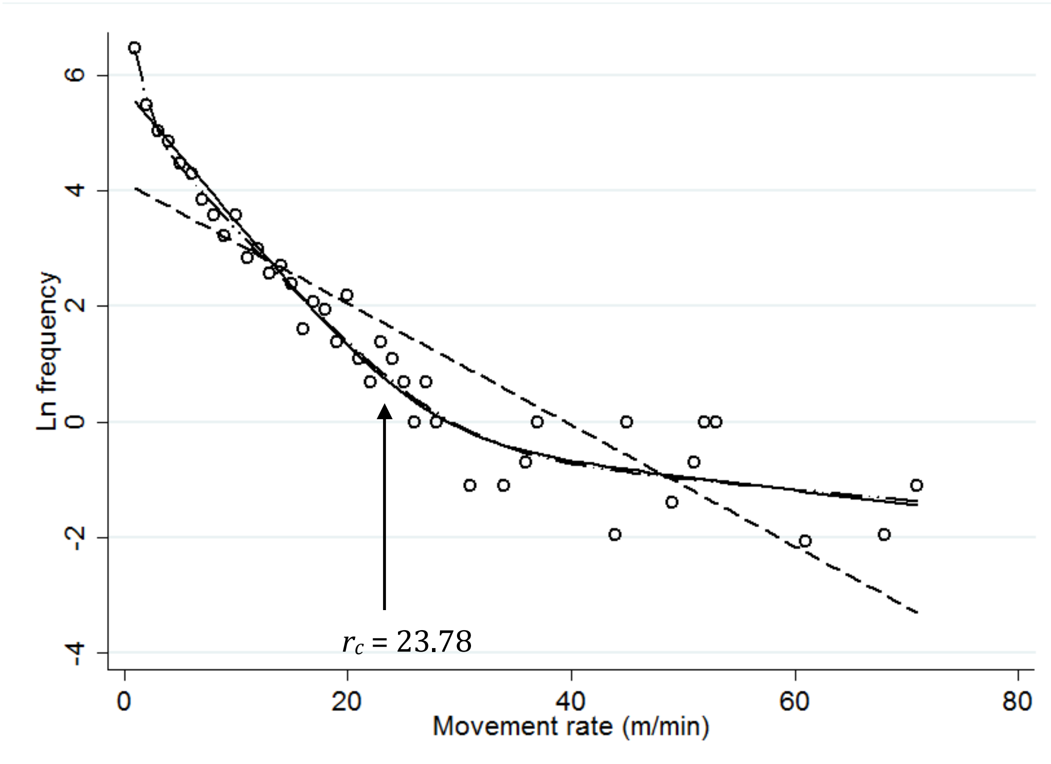

Figure 2. Example of $\log_e$ frequency distribution of movement rates by caribou 1489 during summer (May 15 – September 30). Three models were fit to the data: a null linear model where movement cannot be divided into different types (dashed line), a two-process model where movement can be divided into slow and fast types (solid line) and a three process model where movement can be divided into slow, fast and migratory types (dash-dot line). The two-process model best fit the data, therefore a scale criterion (r_c=23.78 m/min) to identify slow (r_c<23.78 m/min) versus fast (r_c≥23.78 m/min) movement types was calculated using parameters from the two-process model. The three-process model is shown to illustrate how the data over-fits the model, as the first breakpoint is fit to a small portion of the data (upper left).

3.3. Modeling the Influence of Habitat and Anthropogenic Features on Large-scale Caribou Movement

3.3.1. Habitat and anthropogenic footprint

We reviewed the literature on caribou habitat use and selection and identified several habitat and land use variables that might influence caribou movement. These broadly included avoidance of rugged terrain (Wasser et al. 2011), selection of wetlands (Bradshaw et al. 1995; Stuart-Smith et al. 1997; Rettie and Messier 2000; McLoughlin et al. 2005; Wasser et al. 2011), selection of conifer forest (Fuller and Keith 1981; Stuart Smith et al. 1997; Rettie and Messier 2000; Dzus 2001; Johnson et al. 2002; Apps and Mclellan 2006; Courbin et al. 2008; Fortin et al. 2009; Wasser et al. 2011), avoidance of deciduous forest (Fuller and Keith 1981; Rettie and Messier 2000; Courbin et al. 2009; Fortin et al. 2008), avoidance of recently burned areas (Sorensen et al. 2008; Fortin et al. 2008; Wasser et al. 2011) and avoidance of human land use features (James and Stuart-Smith 2000; Dyer et al. 2001, 2002; Apps and Mclellan 2006; Fortin et al. 2008; Courbin et al. 2009; Wasser et al. 2011). Habitat and land use footprint was measured along fast movement steps using various spatial datasets in a Geographic Information System (see Technical Report for details).

3.3.2. Caribou habitat and footprint selection along large-scale movement steps

We found that individual caribou did select or avoid habitat and land use features along fast movement steps (Table 1). However, there was a high degree of variability in which features individual caribou selected or avoided, perhaps due to variability in individual animal behaviour, habitat available to the individual caribou during its

Table 1. The top models of individual caribou (n=15) selection of habitat and human land use features along fast caribou movement steps during the summer in northeast Alberta. Grey highlight indicates the top statistical model and models that are statistically similar to the top model. Models were calculated using step selection functions (SSFs) and compared using corrected Akaike Information Criterion (ΔAIC_c) scores. Please refer to the Technical Report for more details on methods and results of the analysis.

	Model										
	Human Land Use					Habitat					
Individual	All Human[1]	Human Simple[2]	Human – Oil[3]	Human – Forestry[4]	Human – Activity5	AGCC Habitat	ABMI Habitat	AVI Habitat	Terrain only	Fire only	Fire and Terrain
1485	22	16	16	20	20	8	7	N/A	10	4	0
1486	26	15	16	26	22	6	0	N/A	11	N/A	13
1488	26	23	21	25	28	0	3	N/A	11	20	8
1489	2	10	9	0	8	13	8	N/A	6	9	8
1490	12	14	13	13	10	0	8	N/A	12	18	14
1492	1	8	6	3	1	0	14	N/A	7	11	7
1493	6	0	6	6	7	11	5	N/A	5	N/A	5
1494	106	105	107	105	105	0	29	N/A	79	101	78
1495	21	28	21	25	27	0	17	N/A	15	28	17
1504	14	11	14	12	11	0	9	2	12	7	11
1505	27	24	26	26	17	4	0	9	9	19	8
1506	98	90	93	95	98	0	25	35	82	96	84
1507	3	0	2	1	1	4	7	5	2	N/A	4
1509	24	21	21	20	22	22	8	0	18	21	20
1629	1	7	9	3	9	1	0	N/A	0	7	1

1. All human covariates (distance to unpaved road, distance to cutblock, distance to settlement, distance to well).
2. Distance to nearest anthropogenic footprint feature.
3. Distance to well, distance to unpaved road and interaction.
4. Distance to cutblock, distance to unpaved road and interaction.
5. Distance to settlement, distance to unpaved road and interaction.

movements, and the movement rate threshold (r_c) used to define fast caribou movements. Furthermore, we found that many land use variables along caribou steps were highly correlated with each other (e.g., distance to paved road and distance to well correlation: r_S= 0.887; distance to paved road and distance to pipeline correlation: r_S= 0.991).

Our analyses also show that it is highly unlikely that we will be able to disentangle the effect of some individual land use features (e.g., paved roads versus wells versus pipelines) on caribou movement, because their distribution and density on the landscape tends to be similar, and thus statistically related.

More complex ways of modeling movement to perhaps more realistically identify movement types (i.e., short- versus large-scale movements) are emerging, including Bayesian approaches (Morales et al. 2005, Fryxell et al. 2008), state-space models (Patterson et al. 2008), k-means cluster analyses (Van Moorter et al. 2010), and wavelet analyses (Wittemyer et al. 2008). These approaches typically use turning angle data, in addition to movement rate, to identify different movement types. We used a simpler approach (i.e., movement rate only) to model caribou movement in this preliminary analysis to test whether we could identify different caribou movement types. While our approach was successful, we found significant variability among individual caribou in how different movement types were classified. Additional work to consistently and more accurately represent short- versus large-scale caribou movement types across individual animals may be needed.

4. Implications of the Preliminary Results of the Caribou Movement Model

Our preliminary results suggest that fast caribou movements are influenced by habitat and land use features, providing a basis for exploring spatially-explicit mitigation strategies to minimize negative effects of oil sands development on caribou movement. The SSF movement models developed for this project can provide information on locations within caribou range that are more or less favorable to caribou movement as a function of the spatial arrangement of habitat and land use features on the landscape. Where consistent responses are observed, this information can be used to manage habitat and land use features to minimize adverse effects on caribou movement. However, we caution that a focus on caribou movement only may overlook the overriding influence of predation on caribou (see above) and the need for sufficient "critical habitat"[1] to maintain long-term caribou persistence in the Lower Athabasca planning region. Habitat selection is a multi-scale process, meaning that caribou make habitat selection decisions at all stages of their life history, for example, when establishing population ranges to selecting food items in a foraging area (Boyce 2006; Mayor et al. 2009; Gaillard et al. 2010). Our preliminary analysis focuses on large-scale movement only, which limits inferences we can make about caribou habitat selection in general and therefore inferences on how to minimize the influence of anthropogenic development on caribou, in general. Exclusively considering caribou movement in caribou conservation plans without considering other factors that negatively influence caribou distribution would be erroneous. A multi-scale approach to understanding caribou habitat (i.e. similar to what was done in British Columbia; Johnson

[1] i.e., habitat that is necessary for the survival or recovery of a wildlife species; (http://laws.justice.gc.ca/eng/acts/S-15.3/; Environment Canada (2011).

et al. 2004) would provide a more complete understanding of how anthropogenic activity might influence caribou habitat and ultimately their distribution on the landscape.

Our analytical approach is capable of producing models of caribou movement relative to landscape features. We could therefore simulate caribou movements throughout their range relative to current as well as simulated land use scenarios (e.g., one or more scenarios describing new land use and natural disturbance footprints, or alternative habitat restoration schemes), and ultimately calculate the expected density and location of caribou movements within a population range. However, preliminary results showed a high degree of individual variability in habitat selection, which suggests that all individuals of a caribou population may not use similar distinct movement paths in their range. High variability in habitat selection between individual animals may produce movement pathways that appear completely dispersed throughout caribou range. Furthermore, we were unable to distinguish the potential influence if in-situ oil sands developments, or features within these developments (e.g., pipelines, seismic lines, roads) on caribou movement. Thus, additional data and analyses are required to complete a useful and accurate SSF model.

4.1. Proposed 2012 Work Plan

Our initial analyses showed that it is feasible to produce a statistically rigorous spatially-explicit model of woodland caribou movement in relation to habitat and land use features. However, there remains some uncertainty about whether and how caribou respond to in-situ developments on the landscape. This information is necessary to ascertain the appropriateness of spatially-explicit mitigation of the influence of in-situ developments on caribou movement. To reduce the uncertainty regarding spatially-explicit mitigation strategies, we propose the following work for 2012:

1. Obtain accurate spatially-explicit information on in-situ development footprint in the LAPR, particularly where they overlap with caribou telemetry data. Current footprint data does not allow us to differentiate between in-situ footprint and other types of footprint (e.g., forestry roads, conventional oil and gas pipelines). Data on the spatial location and configuration and boundaries of in-situ developments is needed to accurately assess caribou movement in response to these features.
2. Map the density of existing fast and slow caribou movement steps within the WSAR, ESAR and Richardson caribou population ranges (i.e. the caribou ranges in northeast Alberta for which we currently have GPS-telemetry data). This will provide an important preliminary assessment of the degree to which caribou movements in northeast Alberta are concentrated within ranges. Concentration of movement implies that caribou repeatedly move through the same locations of the landscape. This map can be overlaid onto the in-situ development location data to compare caribou movement to in-situ development location.
3. Complete the SSF analyses to define caribou movement response to in-situ oils sands developments, including:
    a. Develop a final set of hypotheses (i.e., candidate SSF models) with the EMCLA to test the effects of habitat and footprint on caribou movement.
    b. Compare caribou habitat selection during fast movements to caribou habitat selection during slow movements and other scales of selection, if

possible. Examining caribou habitat selection at multiple scales will provide a more comprehensive analysis of how in-situ oils sands developments influence caribou distribution and movement.

c. Model resource selection as a function of total anthropogenic footprint within caribou population ranges to measure how caribou habitat use changes as the amount of human footprint changes (e.g., Mauritzen et al. 2003; Hebblewhite and Merrill 2008; Matthiopoulos et al. 2011). For example, caribou avoidance of in-situ development may change as the amount of in-situ development changes. Validate SSF models, with independent caribou telemetry data if possible.

d. Develop mitigation products with the EMCLA, based on results of the analysis, and evaluate how results of the model could advise future caribou monitoring in the LAPR.

Literature Cited

Alberta Woodland Caribou Recovery Team. 2005. Alberta woodland caribou recovery plan 2004/05-2013/14. Alberta Sustainable Resource Development, Fish and Wildlife Division, Alberta Species at Risk Recovery Plan No. 4. Edmonton, AB. 48 pp.

Apps, C.D., & McLellan, B.N. (2006) Factors influencing the dispersion and fragmentation of endangered mountain caribou populations. Biological Conservation, 130, 84-97.

Athabasca Landscape Team (2009). Athabasca Caribou Landscape Management Options Report. Prepared for Alberta Caribou Committee Governance Board. 99 pp.

Berdoy, M. (1993) Defining bouts of behaviour: a three-process model. Animal Behaviour, 46, 387-396.

Bergerud, A.T. & Ballard, W.B. (1988) Wolf predation on caribou: the Nelchina herd case history, a different interpretation. The Journal of Wildlife Management, 52, 344-357.

Bergerud, A.T. & Elliot, J.P. (1986) Dynamics of caribou and wolves in northern British Columbia. Canadian Journal of Zoology, 64, 1515-1529.

Bergerud, A.T. & Elliott, J.P. (1998) Wolf predation in a multiple-ungulate system in northern British Columbia. Canadian Journal of Zoology, 76, 1551-1569.

Bowman, J., Ray, J.C., Magoun, A.J., Johnson, D.S. & Dawson, F.N. (2010) Roads, logging, and the large-mammal community of an eastern Canadian boreal forest. Canadian Journal of Zoology, 88, 454-467.

Bradshaw, C.J.A., Hebert, D.M., Rippin, A.B. & Boutin, S. (1995) Winter peatland habitat selection by woodland caribou in northeastern Alberta. *Canadian Journal of Zoology*, **73**, 1567-1574.

Courbin, N., Fortin, D., Dussault, C. & Courtois, R. (2009) Landscape management for woodland caribou: the protection of forest blocks influences wolf-caribou co-occurrence. Landscape Ecology, 24, 1375-1388.

Dawe, K.L. (2011) Factors driving range expansion of white-tailed deer, *Odocoileus virginianus*, in the boreal forest of northern Alberta, Canada. Dissertation, University of Alberta.

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.

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

Dyer, S.J., O'Neill, J.P., Wasel, S.M. & Boutin, S. (2002) Quantifying barrier effects of roads and seismic lines on movements of female woodland caribou in northeastern Alberta. Canadian Journal of Zoology, 80, 839-845.

Dzus, E. 2001. Status of the Woodland Caribou (Rangifer tarandus caribou) in Alberta. Alberta Environment, Fisheries and Wildlife management Division, and Alberta Conservation Association, Wildlife Status Report No. 30, Edmonton, AB. 47 pp.

Environment Canada. 2008. Scientific Review for the Identification of Critical Habitat for Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population, in Canada, August 2008. Ottawa, Ontario.

Environment Canada. 2011. Recovery Strategy for the Woodland Caribou, Boreal population (*Rangifer tarandus caribou*) in Canada [Proposed]. Species at Risk Act Recovery Strategy Series. Environment Canada, Ottawa. vi + 55 pp.

Festa-Bianchet, M., Ray, J.C., Boutin, S. & Gunn, A. (2011) Conservation of caribou (*Rangifer tarandus*) in Canada: an uncertain future. Canadian Journal of Zoology, 89, 419-434.

Fisher, J.T., and Wilkinson, L (2005). The response of mammals to forest fire and timber harvesting in the North American boreal forest. Mammal Review, 35(1), 51-81.

Fortin, D., Beyer, H.L., Boyce, M.S., Smith, D.W., Duchesne, T. & Mao, J.S. (2005) Wolves influence elk movements: behavior shapes a trophic cascade in Yellowstone National Park. Ecology, 86, 1320-1330.

Fortin, D., Courtois, R., Etcheverry, P., Dussault, C., & Gingras, A. (2008). Winter selection of landscapes by woodland caribou: behavioural response to geographical gradients in habitat attributes. Journal of Applied Ecology, 45, 1392-1400.

Fryxell, J. M., M. Hazell, L. Borger, B. D. Dalziel, D. T. Haydon, J. M. Morales, T. Mcintosh, and R. C. Rosatte. (2008) Multiple Movement Modes by Large Herbivores at Multiple Spatiotemporal Scales. Proceedings of the National Academy of Sciences of the United States of America, 105, 19114-19119.

Fuller, T.K. & Keith, L.B. (1981) Woodland caribou population dynamics in northeastern Alberta. The Journal of Wildlife Management, 45, 197-213.

Hebblewhite, M. & Merrill, E. H. (2008) Modelling wildlife-human relationships for social species with mixed-effects resource selection models. Journal of Applied Ecology, 45, 834–844.

Holling, C. S. (1959) The components of predation as revealed by a study of small-mammal predation of the European pine sawfly. Canadian Entomologist 91, 293–320.

Holt, R.D. (1977). Predation, apparent competition, and the structure of prey communities. Theoretical Population Biology, 12, 197–229.

Holt, R.D. (1984). Spatial heterogeneity, indirect indirections, and the coexistence of prey species. The American Naturalist, 124(3), 377-406.

Holt, R.D., and Kotler, B.P. (1987). Short-term apparent competition. The American Naturalist, 130(3), 412-430.

James, A.R.C. & Stuart-Smith, A.K. (2000) Distribution of caribou and wolves in relation to linear corridors. The Journal of Wildlife Management, 64, 154-159.

Johnson, C.J., Parker, K.L., Heard, D.C. & Gillingham, M.P. (2002) A multiscale behavioral approach to understanding the movements of woodland caribou. Ecological Applications, 12, 1840-1860.

Johnson, C. J., Seip, D.R., & Boyce, M.S. (2004) A quantitative approach to conservation planning: using resource selection functions to map the distribution of mountain caribou at multiple spatial scales. Journal of Applied Ecology, 41, 238-251.

Johnson, C.J., Parker, K.L., Heard, D.C. & Gillingham, M.P. (2006) Unrealistic animal movement rates as behavioural bouts: a reply. Journal of Animal Ecology, 75, 303-308.

Latham, A.D.M., Latham, M.C., McCutchen, N.A. & Boutin, S. (2011) Invading white-tailed deer change wolf-caribou dynamics in northeastern Alberta. The Journal of Wildlife Management, 75, 204-212.

Matthiopoulos, J., Hebblewhite, M., Aarts, G., & Fieberg, J. (2011) Generalised functional responses for species distributions. Ecology, 92, 583-589.

Mauritzen, M., Belikov, S.E., Boltunov, A.N., Derocher, A.E., Hansen, E., Ims, R.A., Wiig, O., & Yoccoz, N. (2003) Functional responses in polar bear habitat selection. Oikos, 100, 112-124.

McLoughlin, P.D., Dzus, E., Wynes, B., & Boutin, S. (2003) Declines in populations of woodland caribou. The Journal of Wildlife Management, 67, 755-761.

Morales, J. M., D. T. Haydon, J. Frair, K. E. Holsinger, and J. M. Fryxell. (2005) Extracting more from relocation data: building movement models as mixtures of random walks. Ecology, 85, 2436-2445.

National Council for Air and Stream Improvement, Inc. (NCASI). (2007) *State of knowledge and analysis of current research on woodland caribou in Canada: technical bulletin no. 939*. Research Triangle Park, N.C.

Nams, V.O. (2006) Animal movement rates as behavioural bouts. Journal of Animal Ecology, 75, 298–302.

Patterson, T. A., L. Thomas, C. Wilcox, O. Ovaskainen, and J. Matthiopoulos. (2008) State-space models of individual animal movement. Trends in Ecology & Evolution, 23, 87-94.

Rettie, W.J. & Messier, F. (1998) Dynamics of woodland caribou populations at the southern limit of their range in Saskatchewan. Canadian Journal of Zoology, 76, 251-259.

Schaefer, J.A., Veitch, A.M., Harrington, F.H., Brown, W.K., Theberge, B., & Luttich, S.N. (1999) Demography of decline of the Red Wine Mountains caribou herd. The Journal of Wildlife Management, 63, 580-587.

Schaefer, J.A. (2003) Long-term range recession and the persistence of caribou in the taiga. Conservation Biology, 17, 1435-1439.

Schneider, R.R., Hauer, G., Adamowicz, W.L. & Boutin, S. (2010) Triage for conserving populations of threatened species: The case of woodland caribou in Alberta. Biological Conservation, 143, 1603-1611.

Seip, D.R. (1992) Factors limiting woodland caribou populations and their interrelationships with wolves and moose in southeastern British Columbia. Canadian Journal of Zoology, 70, 1494-1503.

Sibly, R., Nott, H. & Fletcher, D. (1990) Splitting behaviour into bouts. Animal Behaviour, 39, 63-69.

Sorensen, T., McLoughlin, P.D., Hervieux, D., Dzus, E., Nolan, J., Wynes, B. & Boutin, S. (2008) Determining sustainable levels of cumulative effects for boreal caribou. Journal of Wildlife Management, 72, 900-905.

Stuart-Smith, A.A.K., Bradshaw, C.J.A., Boutin, S., Hebert, D.M. & Rippen, A.B. (1997) Woodland caribou relative to landscape patterns in northeastern Alberta. The Journal of Wildlife Management, 61, 622-633.

Turchin, P. (1998) *Quantitative analysis of movement: measuring and modeling population redistribution in animals and plants*. Sinauer Associates, Sunderland, Massachusetts, USA.

Van Moorter, B., D. R. Visscher, C. L. Jerde, J. L. Frair, and E. H. Merrill. (2010) Identifying Movement States From Location Data Using Cluster Analysis. Journal of Wildlife Management, 74, 588-594.

Vistnes, I. & Nellemann, C. (2007) Impacts of human activity on reindeer and caribou: The matter of spatial and temporal scales. Rangifer, 12, 47-56.

Vors, L.S., Schaefer, J.A, Pond, B.A, Rodgers, A.R. & Patterson, B.R. (2007) Woodland caribou extirpation and anthropogenic landscape disturbance in Ontario. Journal of Wildlife Management, 71, 1249-1256.

Walsh, N.E., Griffith, B. & McCabe, T.R. (1995) Evaluating growth of the porcupine caribou herd using a stochastic model. The Journal of Wildlife Management, 59, 262-272.

Wasser, S.K., Keim, J.L., Taper, M.L. & Lele, S.R. (2011) The influences of wolf predation, habitat loss, and human activity on caribou and moose in the Alberta oil sands. Frontiers in Ecology and the Environment, 110621062742041.

Wittmer, H.U., Sinclair, A.R.E., &McLellan, B.N. (2005a) The role of predation in the decline and extirpation of woodland caribou. Ecology, 144, 257-267.

Wittmer, H.U., McLellan, B.N., Seip, D.R., Young, J.A., Kinley, T.A., Watts, G.S. & Hamilton, D. (2005b) Population dynamics of the endangered mountain ecotype of woodland caribou (*Rangifer tarandus caribou*) in British Columbia , Canada. Canadian Journal of Zoology, 83, 407-418.

Wittemyer, G., Polansky, L., Douglas-Hamilton, I. & Getz, W.M. (2008) Disentangling the effects of forage, social rank, and risk on movement autocorrelation of elephants using Fourier and wavelet analyses. Proceedings of the National Academy of Sciences of the United States of America, 105, 19108-13.

Wolfe, S.A., Griffith, B. & Wolfe, C.A.G. (2000) Response of reindeer and caribou to human activities. Polar Research, 19, 63-73.

Developing a Model of Large-Scale Caribou (*Rangifer tarandus*) Movement in the Lower Athabasca Planning Region of Alberta

2011 Final Technical Report

Prepared for the Ecological Monitoring Committee of the Lower Athabasca

by

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Executive Summary

Most boreal woodland caribou (*Rangifer tarandus*) populations are declining in Alberta. A key caribou conservation policy objective in Alberta is to maintain caribou distribution throughout its current range, which requires maintaining movement capabilities of this highly vagile mammal. We used existing GPS-telemetry data from 89 adult female caribou and tested whether large-scale caribou movement types could be identified and whether caribou selected and/or avoided specific habitat and anthropogenic landscape features while making large-scale movements, using non-linear models and step selection functions (SSFs), respectively.

We found that woodland caribou movement could be classified into two types: slow and fast, where fast movements are equivalent to large-scale movements. We found that caribou in northeast Alberta selected or avoided specific habitat and anthropogenic landscape features while making fast movements. However, there was significant individual variability in the type and strength of relationships between caribou movement steps and landscape features. For 2012, we recommend the following work:

1. Obtain accurate spatially explicit information on in-situ development footprint in the Lower Athabasca Planning Region, particularly where they overlap with caribou telemetry data. Current footprint data does not allow us to differentiate between in-situ footprint and other types of footprint (e.g., forestry roads, conventional oil and gas pipelines). Data on the spatial location and configuration and boundaries of in-situ developments is needed to accurately assess caribou movement in response to these features.
2. Map the density of existing fast and slow caribou movement steps within the WSAR, ESAR and Richardson caribou population ranges (i.e. the caribou ranges in northeast Alberta for which we currently have GPS-telemetry data). This will provide an important preliminary assessment of the degree to which caribou movements in northeast Alberta are

concentrated within ranges. Concentration of movement implies that caribou repeatedly move through the same locations of the landscape. This map can be overlaid onto the in-situ development location data to compare caribou movement to in-situ development location.

3. Complete the SSF analyses to define caribou movement response to in-situ oils sands developments, and evaluate how results of the model could advise future caribou monitoring in the LAPR.

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Introduction

Most boreal woodland caribou (*Rangifer tarandus*) populations are declining in Alberta (Environment Canada 2011; Festa-Bianchet et al. 2011). The decline of caribou populations in northeast Alberta appears to be linked to low calf recruitment rate, likely due to predation (McLoughlin et al*.* 2003), a dominant factor limiting caribou populations in North America (Bergerud and Ballard 1988; Seip 1992; Bergerud and Elliott 1986; Stuart-Smith et al*.* 1997; Bergerud and Elliott 1998; Rettie and Messier 1998; Schaefer et al*.* 1999; McLoughlin et al*.* 2003; Wittmer et al. 2005a). Research has also identified strong correlations between anthropogenic footprint (e.g., roads) on the landscape and caribou decline at the caribou range scale (Schaefer 2003; Wittmer et al. 2005b; Vistness and Nelleman 2007; Vors et al. 2007; Bowman et al. 2010), including northeast Alberta (Sorensen et al. 2008). The leading hypothesis for this negative relationship is that anthropogenic-caused habitat change converts low- productivity vegetation (e.g., old growth forest) to high-productivity vegetation (e.g., early seral forest and agriculture); this increases populations of browsing ungulates species such as moose (*Alces alces)* and deer (*Odocoileus spp.*) (Fisher and Wilkinson 2005). The increase in ungulate prey species increases predator density (particularly wolves, *Canis lupus*) effecting a numerical response of predators (*sensu* Holling 1959). The result is apparent competition (Holt 1977, 1984; Holt and Kotler 1987), wherein an increase in density of moose and deer causes a decline in caribou that is caused by wolves, their shared predator (DeCesare et al. 2010). In addition, construction of linear features (i.e., roads, pipelines and seismic lines) makes it easier for predators to traverse the landscape, which increases predator-caribou encounter rates (i.e., a functional response of predators; James and Stuart-Smith 2000; McLoughlin *et al.* 2003; Latham et al*.* 2011). Finally, there is also some evidence that climate change might be contributing to the apparent competition driven caribou decline in Alberta, with increasing temperatures at northern latitudes allowing white-tailed deer to expand their range north into caribou range (Dawe 2011).

Much research and conservation attention has focussed on stabilizing and reversing caribou population declines in Alberta by reducing predation through direct and indirect management actions. Wolf control, land-use planning to minimize destruction of caribou habitat and habitat restoration are the primary management options being proposed (Environment Canada 2011). In addition to limiting caribou mortality due to elevated predation, a key policy objective in Alberta is to maintain caribou distribution throughout its current range (Alberta Woodland Caribou Recovery Team 2005; D. Hervieux, Government of Alberta, pers. comm.), which necessarily requires maintaining movement patterns of this highly vagile mammal. Animal movement is a key link between individual behaviour and population dynamics (Turchin 1998; Nams 2006), so anthropogenic restrictions of caribou movement may play an important role in caribou declines.

Relatively little research attention has been given to understanding what factors influence boreal woodland caribou movement in Alberta. Research from British Columbia found that caribou may select movement pathways with the lowest energetic cost during the winter (Johnson et al*.* 2002). Previous research from Alberta has suggested that large-scale caribou movements are highly variable with no obvious relationship to landscape features (Fuller and Keith 1981; Stuart-Smith et al*.* 1997; Bergman and Luttich 2000), but caribou use or avoidance of habitat and anthropogenic landscape features during large-scale movements has never explicitly been tested. There is uncertainty whether anthropogenic influences on caribou movement have implications for caribou population dynamics. It is unclear whether anthropogenic features that block caribou movements to a habitat patch or require caribou to move further distances to reach habitat patches could result in increased energy expenditure that negatively influences adult female reproduction and/or calf survival. It is unlikely that current levels of anthropogenic development are influencing caribou movement to such a large degree that it is indirectly influencing caribou population dynamics. However, anthropogenic development is expected to increase in the study area, and thus influence on caribou movement will likely increase. We acknowledge the uncertainty but potential importance of anthropogenic influence on caribou movement.

We caution that a focus on caribou movement only may overlook the overriding influence of predation on caribou (see above) and the need for sufficient "critical habitat"[1] to maintain long-term caribou persistence in the Lower Athabasca planning region. Habitat selection is a multi-scale process, meaning that caribou make habitat selection decisions at all stages of their life history, for example, when establishing population ranges to selecting food items in a foraging area (Boyce 2006; Mayor et al. 2009; Gaillard et al. 2010). Our preliminary analysis focuses on large-scale movement only, which limits inferences we can make about caribou habitat selection in general and therefore inferences on how to minimize the influence of anthropogenic development on caribou, in general. Exclusively considering caribou movement in caribou conservation plans without considering other factors that negatively influence caribou distribution would be erroneous. A multi-scale approach to understanding caribou habitat (i.e. similar to what was done in British Columbia; Johnson et al. 2004) would provide a more complete understanding of how anthropogenic activity might influence caribou habitat and ultimately their distribution on the landscape.

The purpose of this work is to develop a spatially explicit model of large-scale caribou movements in northeast Alberta. We test the hypothesis that caribou are influenced by specific habitat and anthropogenic footprint features when making large-scale movements between habitat patches (i.e., contiguous foraging areas). We use Global Positioning System (GPS) telemetry data and non-linear models (Sibly et al. 1990; Berdoy 1993; Johnson et al. 2002, 2006) to identify fast caribou movements, which can be considered large-scale movements, and use step selection functions (SSFs; Turchin 1998, Fortin et al. 2005) to model habitat and anthropogenic footprint avoidance or selection along movement steps.

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[1] i.e., habitat that is necessary for the survival or recovery of a wildlife species; (http://laws.justice.gc.ca/eng/acts/S-15.3/; Environment Canada (2011).

Our results may suggest what habitats could be avoided by industrial developments to minimize negative influences on caribou moving between habitat patches. In addition, if caribou avoid anthropogenic footprint while moving, industrial activities could be designed to minimize total footprint. SSFs can also potentially be used to identify areas within caribou range that are more or less favourable to caribou movement. We acknowledge that results of movement analysis should be kept in the context of "critical habitat" needs of caribou for their long-term persistence on the landscape (Environment Canada 2011). Just as underestimating the importance of anthropogenic and habitat influences on caribou movement might have negative implications for caribou conservation, exclusively considering the importance of caribou movement without considering other factors that negatively influence caribou habitat selection would be erroneous.

The intent of the work described in this report is to determine if available data to and the proposed analytical approach can produce a statistically rigorous and ecologically rational model of caribou movement. Results of this work will inform whether and how to complete a spatially explicit caribou movement model in 2012.

Methods

Caribou telemetry data

We obtained GPS-telemetry data from Alberta Sustainable Resource Development (ASRD), Government of Alberta. Hundreds of thousands of locations were collected at intervals ranging from 15 minutes to 6 hours, from 89 adult female caribou. Caribou had been collared between 1998 to 2000 and 2007 to 2011 from seven different boreal woodland caribou populations in Alberta: Little Smoky, Chinchaga, Red Earth, Richardson, East Side Athabasca River (ESAR), West Side Athabasca River (WSAR) and Nipisi (Appendix A). Data were collected from 20 individuals in the Lower Athabasca Planning Region (LAPR), specifically within the ESAR (6 individuals) and Richardson (14 individuals) populations in 2008-2011. Only data from the LAPR were used in the SSF analysis. We divided data into summer and winter seasons for movement and SSF analysis, where summer is defined as post-calving to rut (May 15 – September 30), and winter is defined as rut to post-calving (October 1 – May 14). Raw data were screened to remove inaccurate locations by removing all locations with a 2-dimensional fix and a horizontal dilution of precision > 12 (M. Russell, Government of Alberta, pers. comm.). We did not screen the data for consistent fix rate and therefore used all data in the analyses.

Identifying large-scale caribou movements from GPS-telemetry data

We were interested in identifying directed, relocating movements between foraging patches (Owen–Smith et al. 2010), as we hypothesized that habitat and anthropogenic development may be affecting these movements (Appendix A). We used a non-linear curve fitting procedure (Sibly et al. 1990; Berdoy 1993) to identify fast (i.e., large-scale or inter-patch) caribou movements within the GPS-telemetry data (Johnson et al. 2002, 2006; Chetkiewicz et al. 2006). The model identifies whether the frequency of caribou movement rates (distance divided by time) calculated from caribou GPS-telemetry location data are best fit by a linear or non-linear, i.e., two-process (Sibly et al. 1990) or three-process (Berdoy 1993), model. Data that are best fit by linear models suggest that caribou movement follows a linear, scale- independent behavioural process where there is no difference between short and long movements (Johnson et al. 2002). Data fit by a two-process model indicate that caribou movements can be categorized as frequent slow (intra-patch) and infrequent fast (inter-patch) movements (Johnson et al. 2002, 2006; Chetkiewicz et al. 2006). Data fit by a three-process model suggest caribou movements can be categorized as small-, large- and migratory-scale movements (Johnson et al., 2002). In the case of two- and three-process models, a scale criterion (r_c) can be calculated to specify the threshold at which caribou movement rate can be characterized into small-, large- and migratory-scale movements.

We used movement rate, as opposed to step distance (step = straight-line path between two successive GPS-locations), to standardize variation in the location sampling interval resulting from failure of telemetry-collars to acquire GPS locations for each scheduled attempt, differences in scheduled location acquisition, and differences in acquisition times. Substituting movement rate for step distance is a current practice (Johnson et al. 2002, 2006) and necessary to minimise error associated with inaccurate step distances. To confirm that movement rate was a useful proxy of movement step length for the majority of caribou steps, we calculated a Spearman correlation between movement rate and step length across all animals. The high correlation between the distance and rate (see Results) indicated the movement rate was in fact a useful proxy of movement distance.

We calculated the natural log of the frequency of movement rates between GPS-telemetry locations in 1 metre/minute frequency bins for each individual caribou, by each season (Johnson et al. 2002; Johnson et al. 2006). We identified the best-fitting model (linear, two-process or three-process) using Akaike Information Criterion scores corrected for small sample size (AIC_c; Burnham and Anderson 1998) and F-statistics (Sibly et al. 1990; Johnson et al. 2002). Models that fit the data (F-statistic) and had the lowest AIC_c value were considered the most parsimonious and the best-supported by the evidence for identifying the caribou movement process. Linear models were fit using STATA 10 “regress” command. Non-linear models were fit using the SAS 9.2 PROC NLIN procedure with equations and derivatives provided by Sibly et al. (1990) and Berdoy (1993) for the two- and three-process models, respectively.

To identify if movement rates differed between seasons or caribou populations, we tested for differences in r_c with repeated-measures Analysis of Variance (ANOVA), and Mann-Whitney U tests. Different movement rates across seasons or populations suggest that movement rates should not be pooled in analysis; otherwise, pooling data is supported and can increase our statistical power to detect relationships between movement and habitat features.

Spatial habitat and anthropogenic footprint data

We reviewed the literature on caribou habitat use and selection and identified several habitat and human footprint covariates that might influence caribou movement (Appendix B); these broadly included avoidance of rugged terrain (Wasser et al. 2011), selection of wetlands (Bradshaw et al. 1995; Stuart-Smith et al. 1997; Rettie and Messier 2000; McLoughlin et al. 2005; Wasser et al. 2011), selection of conifer forest (Fuller and Keith 1981; Stuart Smith et al. 1997; Rettie and Messier 2000; Dzus 2001; Johnson et al. 2002; Apps and Mclellan 2006; Courbin et al. 2008; Fortin et al. 2009; Wasser et al. 2011), avoidance of deciduous forest (Fuller and Keith 1981; Rettie and Messier 2000; Courbin et al. 2009; Fortin et al. 2008), avoidance of recently burned areas (Sorensen et al. 2008; Fortin et al. 2008; Wasser et al. 2011) and avoidance of anthropogenic features (James and Stuart-Smith 2000; Dyer et al. 2001, 2002; Apps and Mclellan 2006; Fortin et al. 2008; Courbin et al. 2009; Wasser et al. 2011). Previous research studied caribou habitat use and selection in general, as opposed to along fast movements specifically. Caribou may use similar or different types of habitat and anthropogenic landscape features when moving, and therefore mitigating negative anthropogenic influences on caribou movement may be similar or different.

A digital elevation model (DEM) obtained from Natural Resources Canada, Government of Canada, was used to measure elevation. Terrain ruggedness was calculated by measuring the dispersion of vectors orthogonal to the terrain surface, extrapolated from the DEM (Sappington et al. 2007). We calculated the length-weighted mean, maximum and minimum values of terrain ruggedness and elevation along each caribou movement step, and terrain ruggedness and elevation values at the beginning and end of each step.

A reliable, high resolution GIS layer describing land cover features across caribou range in Alberta does not yet exist. We therefore obtained three datasets of vegetation and land cover representing the best information in the study area: the Alberta Ground Cover Characterization (AGCC; Sánchez-Azofeifa et al. 2003), the Alberta Vegetation Inventory (AVI; Alberta Environmental Protection 1991) and the Alberta Biodiversity Monitoring Institute (ABMI) wall-to-wall vegetation classification dataset. AGCC is derived from Landsat 7 ETM (i.e., it is in raster format with 30 m spatial resolution), has near complete coverage of Alberta, and identifies 99 different land cover types. AVI data provides detailed information on forest cover type and age, is in vector format, and is based on photo-interpretation; however it is limited in extent and therefore does not cover much of caribou range in Alberta. ABMI data is derived from AGCC data; however, it has fewer classes (n=23) to reduce misclassification errors, it covers the entire province of Alberta, and is in vector format rather than raster format. A classification accuracy assessment has not been completed for any of the land cover data. AGCC, AVI and ABMI data were re-classified into the following non-exclusive vegetation cover classes hypothesized to be important to caribou movement (Appendix B): wetland, forest, closed forest, conifer forest, mixed/deciduous forest, closed conifer forest, mature conifer forest and mature closed conifer forest. Cover types were re-classified from each data set (where applicable). Furthermore, we obtained spatial data on historical fires from ASRD and created GIS datasets of recent fire (i.e., <50 years old) for each year for which we had caribou telemetry data. We calculated the proportion of each land cover type along each fast caribou movement step.

We obtained human footprint data from ASRD base layers (linear features, wells, cutblocks, and settlements; http://www.altalis.com/). We used the time stamp of when the data was entered into the database to create annual footprint layers for each year that caribou were collared. We then attributed the anthropogenic data to each caribou step that was from the same year as when the caribou step occurred. We calculated length-weighted mean, maximum and minimum values of distance to each anthropogenic footprint type along each movement step, and distance to each anthropogenic footprint type at the beginning and end of each step. We then calculated the distance to the closest anthropogenic footprint of any type and calculated length-weighted mean, maximum value and minimum value along each step. Finally, because caribou use or avoidance of anthropogenic features is expected to vary with degree of human activity (e.g., Wasser et al. 2011), we calculated two-way interaction terms by multiplying each of: (1) distance to cutblock and distance to unpaved road, (2) distance to well and distance to unpaved road, and (3) distance to settlement and distance to unpaved road. Unpaved roads were used because of the high-correlation among linear anthropogenic feature types and because unpaved roads were most correlated with observed caribou movements (see below).

Caribou habitat selection along large-scale movement steps

We measured habitat selection along summer fast movement steps (defined above) by 15 caribou in the ESAR and Richardson populations by calculating step-selection functions (SSFs; Turchin 1998, Fortin et al. 2005) for each individual caribou. We conducted SSF analysis on caribou in the ESAR and Richardson herds in this preliminary work because these are the populations that occurred in the LAPR study area. SSFs use conditional logistic regression and a case-control design to compare habitat and anthropogenic footprint measured along observed caribou steps to a random sample of "available" steps from the same starting point (Fortin et al. 2005). We generated 100 random steps from each observed starting point at randomly drawn turning angles generated from the observed frequency of turning angles for the individual caribou during the summer (Fortin et al. 2005). Random step lengths were equal to observed step lengths.

SSF analyses were conducted for each individual of the 15 animals using conditional logistic regression in STATA 10. A candidate set of habitat and anthropogenic footprint models were created (Appendix C) that included only habitat and anthropogenic footprint covariates, respectively. Prior to conditional logistic regression, covariates were screened for co-linearity using Spearman correlation (Hosmer and Lemeshow 2000). When covariates had $r > 0.7$ then the covariate least correlated with observed movement steps was removed from the analysis. Statistical significance of covariates included in the model was assessed using t-tests (Hosmer and Lemeshow 2000).

Model fits were compared using AIC_c (Burnham and Anderson 1998), where models with the lowest AIC_c are considered the best-supported by the evidence of all models in the set. Best-supported models are the most parsimonious models that fit caribou movement relative to landscape features. All models with a difference in AIC_c value (ΔAIC) < 2 could be also reasonably be considered as good as the top model (Burnham and Anderson 2002), assuming it included >1 covariate than the top model (Arnold 2010). Standard errors of SSF parameters were obtained using a Huber-White sandwich estimate of the co-variance matrix (Pendergast et al. 1996), as successive steps were likely not independent from one another, which can bias the standard errors (Nielson et al. 2002; Fortin et al. 2005; Gillies et al. 2006). Land cover types were compared from each spatial dataset (AGCC, ABMI, AVI) independently to assess whether measures of caribou habitat selection during movement were consistent across data sources. Different vegetation cover types were generated for each data source, depending on details available. Specifically, only AVI provided data on forest age, and therefore included mature conifer forest as a covariate in the model. We also re-iterate that some habitat covariates were highly correlated with each other, and some habitat classes may have been removed from habitat models using one dataset, but not necessarily another.

Results

Identifying large-scale caribou movements

We found that the two-process model better fit the movement rate log frequency distribution for the majority of caribou in the summer (65 of 71 individuals) and winter (84 of 89 individuals) (Table 1). We observed a difference between high-frequency slow (i.e., small-scale intra-patch) movements and low-frequency fast (i.e., large-scale inter-patch) movements for most caribou during the summer and winter, as illustrated for caribou 1489 (Fig. 1). We found similar problems as Johnson et al. (2002) with fitting a three-process model to the data. The majority of models (40 of 72) failed to converge or in cases where they did converge, the models appeared to over-fit the data. In addition, we randomly selected 10 individuals from the winter season dataset and attempted to fit three-process models. We found that three of the ten failed to converge, or converged to a two-process model. Of the seven that converged, five had lower AIC_c values than the two-process model, indicating a three-process model was a better fit to these data than a two-process model. However, the three-process model appeared to overfit these data as well.

We calculated scale criteria (r_c) for two-process models (Table 1) using the equation provided by Sibly et al. (1990) to identify the threshold for fast movements (i.e., movement rates > r_c ; Fig. 1). These fast movements were used in the SSF analysis. For individuals where a linear model best fit the data, all movement data were used in the SSF analysis. We found that movement rate was highly correlated with step length (r=0.948, P<0.0001).

There were no significant differences in r_c between the summer (Mean=11.65, SD=7.80) and winter (Mean=11.32, SD=6.43; Fig. 2). However, there were significant differences between populations (F=2.95, P=0.015; Fig. 3). Specifically, we found significant differences during the summer between mean values of Richardson (Mean=12.80, SD=6.26) and WSAR (Mean=8.42, SD=5.40; z=2.405, P=0.016) and Chinchaga (Mean=17.83, SD=10.67) and WSAR (z=3.363, P<0.001) populations.

Caribou habitat selection along large-scale movement steps

We found that beginning, end and length-weighted mean/proportion values of each habitat and anthropogenic footprint covariate along caribou steps were typically highly correlated with each other (i.e., r>0.7). We removed correlated variables and kept the variable that was most correlated to the observed steps in the analysis. We were initially concerned that wetland was confounded with terrain ruggedness and elevation, as wetlands typically occur in lower areas. We found that length-weighted mean elevation and proportion of wetland (as classified by the ABMI vegetation cover dataset) along each step were positively correlated (r=0.300, P<0.0001) and length-weighted mean terrain ruggedness and proportion of wetland along each step were negatively correlated (r=-0.369, P<0.0001), although the degree of correlation coefficients was acceptable (i.e., r<0.7) and therefore all three covariates were kept in the SSF analysis.

Habitat, including land cover, terrain and fire, was a better predictor than anthropogenic footprint of caribou movements in twelve of the fifteen individuals (Table 2). Of the vegetation cover models, AGCC covariates were selected as the top model for eight individuals and ABMI covariates were selected for three individuals. We re-iterate that candidate models using different land cover data sets used different covariates because they had different information in each, therefore it is difficult to compare results of different models. Furthermore, candidate models included all uncorrelated habitat covariates and we did not compare models with different combinations of covariates. Elevation and terrain ruggedness covariates and the combination of these and fire covariates were in top models for two of the caribou.

Among the 15 caribou assessed, there was not a clear indication that individuals consistently responded more to certain types of footprint (Table 2). Distance to nearest human footprint was the top model for two individuals. Anthropogenic footprints related to forestry (i.e., distance to unpaved road and distance to cutblock) were in the top model for two individuals and anthropogenic footprints related to human activity (i.e., distance to unpaved road and distance to settlement) were in the top model for one individual. A combination of all anthropogenic covariates was in the top model for two individuals.

Significant covariates in the top SSF model for each individual caribou (Table 3) indicate a high degree of variability in how individuals selected habitat and anthropogenic footprint features of the landscape. For example, two individuals selected higher, and one selected lower, elevation at the end of the step, five individuals avoided and one selected rugged terrain along the step, and four individuals avoided and two selected, areas burned in the last 50 years at the end of step. Of the three models that indicate anthropogenic footprint was more important than habitat features at explaining caribou movement, two of the three had distance to nearest anthropogenic footprint as the top model. However, the coefficient was not significant in either model. In the third model that included distance to cutblock and distance to unpaved road covariates, the individual avoided unpaved roads when near cutblocks.

Discussion and Recommendations

We found that caribou movement could be divided into two different types: slow, small-scale, intra-patch movements and fast, large-scale, inter-patch movements (Fig. 1), consistent with the findings of Johnson et al. (2002). We also found that individual caribou selected or avoided habitat and anthropogenic landscape features along fast movement steps (Table 2), however there were no clear patterns in what features they selected or avoided (Table 3). Our preliminary results suggest that fast caribou movements are not independent of habitat or anthropogenic features, providing a basis for exploring spatial mitigation strategies to minimize negative anthropogenic influence on caribou. However, preliminary results also suggest that a caribou population may not use distinct movement paths in their range, as there was a high degree of variability in individual habitat selection. Implications of this result are that movement pathways will appear completely dispersed throughout caribou range. However, additional analyses are necessary prior to making an ultimate conclusion on this result.

Habitat and anthropogenic footprint influences caribou movement

Our results suggest that habitat and anthropogenic footprint likely influence individual caribou habitat selection along fast movement steps. Model selection indicated that for most caribou, habitat was generally a better predictor of caribou movement than was anthropogenic footprint. In general caribou we modelled seemed to avoid making fast movements through wetlands and mixed/deciduous forest, although there was variability in selection among individuals. Avoidance of wetlands is inconsistent with previous research that has indicated that caribou select wetlands (Bradshaw et al. 1995; Stuart-Smith et al. 1997; Rettie and Messier 2000; McLoughlin et al. 2005; Wasser et al. 2011). Different results from these studies compared to ours may be due to different definitions of wetland in land cover data, or that despite their apparent preference for wetlands in general, caribou may avoid wetlands when making fast movements. Terrain ruggedness also influenced fast movements by individual caribou, which is similar to results found for caribou in British Columbia (Johnson et al. 2002). However, terrain is generally flat in the study area, and therefore its influence on caribou movement requires further investigation by modeling the effect size. The digital elevation model used to derive terrain had a coarse spatial accuracy (250 m) and therefore may poorly represent terrain complexity. Terrain ruggedness may also be confounded with wetlands, since they were negatively correlated (r=-0.369, P<0.0001). We recommend further investigation of whether Light Detection and Ranging (LiDAR) data, which provides higher spatial resolution, could be acquired to more accurately model terrain ruggedness. In general we caution that the selection coefficients, and the variables identified as important predictors of caribou movement, resulting from SSF models are likely to change in population-scale models.

We found considerable variability in individual response to habitat and anthropogenic footprint, which may be due to variability in several factors, including individual animal behaviour, quality of the habitat data (i.e., accuracy), habitat available to the individual caribou, and the movement rate threshold (r_c) used to define fast caribou movements. The latter two explanations require further examination with additional analyses. Caribou selection of habitat is a function of the habitat that was available to the caribou at the time (Aebischer et al. 1993). This functional relationship can be examined by modelling selection coefficients as a function of available habitat for each individual animal, or using random effects in multi-individual models (Gillies et al. 2006; Hebblewhite et al. 2008; Fieberg et al. 2010). Including more individuals in the analysis would improve statistical power to model these relationships.

The implication of caribou avoiding or selecting habitat and anthropogenic footprint along fast movement steps is that spatial mitigation of industrial development might be a strategy for minimizing negative anthropogenic influences (e.g., habitat removal and/or displacement of caribou) on caribou movement, with the optimal strategy being to avoid habitat that caribou select (or conversely, concentrate footprint in the habitat that caribou avoid). Although there was individual variability in responses to habitat and anthropogenic footprint, some habitat selection patterns were emerging (e.g., avoidance of mixed deciduous forest and selection of less rugged terrain), suggesting we can adequately statistically model caribou habitat selection along fast movements at a population scale. However, we again caution that habitat availability is an important consideration in this outcome, as selected habitats (e.g., wetlands) may be ubiquitous throughout a caribou population's range. Therefore, more analyses are needed prior to concluding on mitigation strategies.

Pooling data across seasons and populations to increase SSF statistical power

Our analysis divided data by individual and by season to test for variability in movement rates and habitat selection. The strength of this approach is that it allowed us to identify any unusual outliers in the data (i.e., counter-intuitive habitat selection, unusual movement patterns, etc.). However, we are losing statistical power in the SSF analysis as a result, since some individuals have only a few fast steps (particularly those with large r_c values), reducing the sample size of steps to analyse.

We found no significant difference in movement rate between seasons, but found that on average, individuals within the WSAR population had significantly slower movements than in the Chinchaga and Richardson populations. Our results suggest that, based on movement rates, data from summer and winter could be pooled in analysis, but that data from different populations should not. Results from the summer SSF of individuals from ESAR and Richardson populations suggest habitat selection may be similar between populations, however, this is difficult to determine due to high variability in selection coefficients between individuals within a population. Available habitat differed among these individuals (unpublished data). It is therefore likely that available habitat differs significantly between populations and pooling data across herds may be inappropriate due to differences in movement patterns and available habitat within a range.

Finally it should be recognized that there is measurement error associated with GPS telemetry data. This error has been reduced since satellite-based locations ceased to be artificially varied for security reasons in the early 2000's, but still exists (D'Eon and Delparte 2005; Hansen and Riggs 2008). GPS measurement error is not equal across habitat types, so may bias the results of telemetry-based habitat selection studies (D'Eon 2003; Frair et al. 2004). Measurement error and has been shown to erode the detection of scale-dependent thresholds associated with movement data (Bradshaw et al. 2007). Increasing sample size and spatial resolution in future analyses, thereby averaging error across multiple individuals, may reduce any bias in step-length analysis and subsequent SSF's.

Recently developed habitat selection statistics such as generalized linear mixed models (GLMMs) or generalized estimating equations (GEEs), may allow us to hierarchically pool data but still account for correlation at the step, individual and population level (Gillies et al. 2006; Bolker at al. 2009; Koper and Manseau 2009; Fieberg et al. 2010). We recommend that future analysis pool data across seasons for individuals in a two-stage analysis, where models are produced for individuals and model results averaged to obtain population estimates for each caribou population (Fieberg et al. 2010). We also recommend exploring the feasibility of doing an analysis that pools all data and uses GLMMs or GEEs with random effects to account for correlation within steps, individuals and populations (Bolker at al. 2009; Koper and Manseau 2009). Both approaches would increase the power of the analysis.

Identifying large-scale caribou movements using movement rate frequency

The method for identifying fast caribou movements described by Johnson et al. (2002) assumes that caribou movement rate is a biological proxy for movement distance (i.e., step length). However, it is possible that caribou move long distances slowly, and some long and slow directed large-scale movements may be missed when using movement rate to identify fast movements. There may be biological differences between "fast" large-scale movements as opposed to "slow" large-scale movements; if so, measuring habitat selection only along "fast" large-scale movements may limit the inferences we can make about the effects of habitat and anthropogenic footprint on caribou movement. For example, faster movements may be caused by encounters with predators or human activity, and slower movements by some other mechanism. However, we found that movement rate and step length were highly correlated (r=0.948, P<0.0001), suggesting that only a very small proportion of large-scale caribou movements occur at slow rates. Therefore, we accept that some slow large-scale movements may be excluded from the caribou step selection function analysis. However, we maintain that these are relatively rare movement events that likely do not impact observed trends.

A more important and challenging issue with using movement rate (or step length) is identifying how to define large-scale movements. We used Johnson et al.'s (2002) empirically-based approach. However, for some individual animals r_c could not be identified, and we observed significant variability in individual r_c for those that could be identified. For example, visual verification of whether large-scale movement telemetry steps were accurately identified by the scale criteria suggested that large values of r_c may fail to identify what appear to be large-scale movement steps, and small values for r_c may include steps that appear to be small-scale movements. An alternative solution to Johnson et al.'s (2002) empirical approach is to visually identify larger- versus smaller-scale movements from telemetry data. However, this approach is subjective and thus difficult to repeat or scientifically defend. There may also be other empirical ways to classify large- versus small-scale movements. For example, methods to identify "clusters" of telemetry locations to identify predator kill sites (e.g., Webb et al. 2008; Tambling et al. 2010) may be useful for identifying clusters of telemetry locations that likely represent shorter intra-patch movements, where large-scale movement steps are unlikely to be clustered in space. However, ultimately this approach may suffer from the same issue as the Johnson et al. (2002) approach, where variability among individual animals or site conditions could produce variable results, thus requiring that models be refined with independent data to validate the model (e.g., Webb et al. 2008).

The use of Johnson et al.'s (2002) analysis of movement rates also assumes that the time between steps is exponentially distributed, and the null hypothesis of a single-process model yields a decreasing linear relationship between the frequency of movement events and time; the alternative two-process model yields a monotonically decreasing curve with an inflection point, r_c. However, Nams (2006) analysed this method using simulated data in complex and simple 'habitats' and found: (1) the method failed because movement rates were not exponentially distributed; (2) the distribution of movement rates changed markedly with sampling interval; and most importantly, (3) deviations from a linear relationship (1-process model) can be caused by factors other than a scaled movement response (see also Nams 2005). Johnson et al. (2006) evaluated Nams' (2006) criticisms using actual movement data from three different species, including caribou, and found that distribution of movement rates and sampling interval had little influence on the criterion used to identify scales of movement. The difference in results was likely due to simulated data not reflecting actual movement behaviours of ungulates (Johnson et al. 2006). Therefore, we applied the analysis of Johnson et al. (2002, 2006).

Variability in r_c identified for individual caribou could influence habitat selection coefficients calculated by the SSF analysis. For future analyses we recommend using a population mean r_c of individual animals for classifying large- vs. small-scale movements. We will visually examine whether the population averaged r_c identifies the majority of large-scale movements. If it does not, then we will consider alternative solutions, such as the cluster analysis indicated above. Regardless, it is likely that some slow large-scale movements will be omitted from analysis. However, we believe these movements are likely to be rare and thus have limited implications for mitigating industrial influences on caribou movement.

More complex ways of modelling movement to perhaps more realistically identify movement types (i.e., short- versus large-scale movements) are emerging, including Bayesian approaches (Morales et al. 2005, Fryxell et al. 2008), state-space models (Patterson et al. 2008), k-means cluster analyses (Van

Moorter et al. 2010), and wavelet analyses (Wittemyer et al. 2008). These approaches typically use turning angle data, in addition to movement rate, to identify different movement types. We used a simpler approach (i.e., movement rate only) to model caribou movement in this preliminary analysis to test whether we could identify different caribou movement types. While our approach was successful, we found significant variability among individual caribou in how different movement types were classified. Additional work to consistently and more accurately represent short- versus large-scale caribou movement types across individual animals may be needed.

Anthropogenic footprint and habitat covariates to include in future SSFs

We found that distance to anthropogenic footprint type (e.g., roads, wells, seismic lines) were typically highly correlated (r>0.7) between years and with each other (Appendix D). An important implication of this result is that we were unable to disentangle the influence of different types of anthropogenic footprint on caribou movement. It is unlikely that we will be able to model caribou response to different types of footprints in future analyses, with the exception of some broad classifications (e.g., linear features, cutblocks, settlements and well sites).

The annual timestamp in the footprint data that we used in the ASRD base data likely did not accurately reflect when the feature was built. An alternative dataset, digital integrated dispositions (DIDS) data, provides an accurate timestamp of when a license was given by the Government of Alberta to build a footprint on public land (e.g., LOC for roads, EZE for powerlines, PLA for pipelines, and MSL and PIL for wells and oil and gas facilities). However, the DIDS data does not provide as accurate description of the type of footprint (e.g., gravel versus paved road), nor does it indicate when the feature was built. Nevertheless, it can provide information on linear (i.e., LOC, EZE and PLA) versus polygonal (i.e., MSL and PIL) footprint types and provides a more accurate indication of when a feature was built than the ASRD base data, which indicated when the feature was entered into the database. We recommend further analyses using DIDS to create anthropogenic footprint covariates. Distance to linear footprint and distance to polygonal footprint by year, in addition to distance to cutblock and distance to settlement, should be included as covariates in the analysis. Given the high correlation between anthropogenic footprint features that we found, modelling caribou response to the broad categories of footprint described by DIDS may be as accurate as is feasible with the SSF analysis described here.

In this analysis we simplified land cover to four or five classes. If data are pooled in future analyses it would be reasonable to include more land cover classes in the analysis as statistical power should improve. Reducing the number of land cover classes tends to increase habitat classification accuracy (G. Castilla, University of Calgary, pers. comm.). However, this may also result in reduced precision in our ability to identify important habitat features to caribou movement. Therefore, we recommend that future analysis include all 23 ABMI land cover classes. Including more classes may be more appropriate in a population-scale analysis where sample size is larger. However, if using many classes results in weak statistical relationships, we recommend a second stage of analysis with the following nine classes, derived from ABMI classes: developed, shrub, wetland, herb/grassland, agriculture, conifer forest, deciduous forest, mixed-wood forest, water and other (i.e., rock/ice, cloud, and barren land, which are <5% of the landscape). We also recommend using the proportion of each cover type along a step in the model rather than that and another covariate for cover type at the end of the step. Although these may have two different biological meanings (encountering habitat along a step versus habitat at the destination, respectively) in general we found these two covariates highly correlated (r>0.7) and therefore it is reasonable to exclude one.

Conclusions and Recommendations

It is feasible to use SSFs to produce a statistically rigorous spatial model of woodland caribou movement in relation to habitat and anthropogenic features throughout boreal Alberta. Evidence from analysis of individual animals from the ESAR and Richardson populations suggests that fast, inter-patch caribou movements are not random, but instead are associated with habitat features and anthropogenic footprint. SSFs, once refined, could provide information to help inform spatial mitigation strategies by policymakers and landscape managers. However, we also documented high variability in individual caribou response to habitat and anthropogenic features. Therefore, we are not certain whether population-scale models will indicate clear and consistent relationships between caribou movement steps and habitat and anthropogenic landscape features. To reach a clear conclusion we recommend the following steps:

1. Obtain accurate spatially-explicit information on in-situ development footprint in the LAPR, particularly where they overlap with caribou telemetry data. Current footprint data does not allow us to differentiate between in-situ footprint and other types of footprint (e.g., forestry roads, conventional oil and gas pipelines). Data on the spatial location and configuration and boundaries of in-situ developments is needed to accurately assess caribou movement in response to these features.
2. Map the density of existing fast and slow caribou movement steps within the WSAR, ESAR and Richardson caribou population ranges (i.e. the caribou ranges in northeast Alberta for which we currently have GPS-telemetry data). This will provide an important preliminary assessment of the degree to which caribou movements in northeast Alberta are concentrated within ranges. Concentration of movement implies that caribou repeatedly move through the same locations of the landscape. This map can be overlaid onto the in-situ development location data to compare caribou movement to in-situ development location.
3. Complete the SSF analyses to define caribou movement response to in-situ oils sands developments, including:
    a. Develop a final set of hypotheses (i.e., candidate SSF models) with the EMCLA to test the effects of habitat and footprint on caribou movement.

b. Compare caribou habitat selection during fast movements to caribou habitat selection during slow movements and other scales of selection, if possible. Examining caribou habitat selection at multiple scales will provide a more comprehensive analysis of how in-situ oils sands developments influence caribou distribution and movement.
c. Model resource selection as a function of total anthropogenic footprint within caribou population ranges to measure how caribou habitat use changes as the amount of human footprint changes (e.g., Mauritzen et al. 2003; Hebblewhite and Merrill 2008; Matthiopoulos et al. 2011). For example, caribou avoidance of in-situ development may change as the amount of in-situ development changes.
d. Validate SSF models, with independent caribou telemetry data if possible.
e. Develop mitigation products with the EMCLA, based on results of the analysis, and evaluate how results of the model could advise future caribou monitoring in the LAPR.

Tables

Table 1. Scale criteria (r_c) calculated using a two-process model used to differentiate slow from fast movements by caribou during winter and summer seasons in Alberta. Results illustrate comparison to one-process (linear) models, where R^2 values and F-statistics represent model fit, AICΔ represents the difference between the Akaike's information criteria value of the one- and two-process models, and NF (no fit) represents r_c values that could not be calculated because of poor model fit. Scale criteria were calculated as m/min. Models were all statistically significant ($P < 0{\cdot}001$).

				R^2		F-statistic		AIC_c		
Season	Population	Caribou	Scale Criteria (r_c)	One-Proc.	Two-Proc.	One-Proc.	Two-Proc.	One-Proc.	Two-Proc.	$AIC_c\Delta$
Summer	Red Earth	1753	-	-	-	-	-	-	-	-
Winter			6.60	0.710	0.908	95	121	114	45	69
Summer	Red Earth	1752	-	-	-	-	-	-	-	-
Winter			12.82	0.730	0.900	95	99	109	28	81
Summer	Red Earth	1750	-	-	-	-	-	-	-	-
Winter			10.47	0.522	0.886	44	98	150	25	125
Summer	Red Earth	1749	-	-	-	-	-	-	-	-
Winter			6.85	0.601	0.892	27	44	71	6	65
Summer	Red Earth	1747	-	-	-	-	-	-	-	-
Winter			3.06	0.731	0.927	33	42	46	4	42
Summer	Red Earth	1744	-	-	-	-	-	-	-	-
Winter			6.50	0.636	0.876	52	66	99	21	78
Summer	Richardson	1630	11.51	0.905	0.978	210	293	39	59	20
Winter			12.20	0.901	0.967	209	203	53	40	14
Summer	Richardson	1629	13.52	0.846	0.933	104	79	44	27	17
Winter			6.90	0.773	0.906	116	102	96	33	63

				R^2		F-statistic		AIC_c		
Season	Population	Caribou	Scale Criteria (r_c)	One-Proc.	Two-Proc.	One-Proc.	Two-Proc.	One-Proc.	Two-Proc.	$AIC_c\Delta$
Summer	Little Smoky	1524	NF	0.660	NF	25	NF	47	NF	N/A
Winter			4.26	0.736	0.947	45	83	56	17	39
Summer	Chinchaga	1523	15.63	0.852	0.965	230	349	113	62	51
Winter			13.67	0.762	0.934	163	231	159	55	104
Summer	Chinchaga	1522	12.83	0.872	0.975	210	384	84	59	25
Winter			11.11	0.826	0.944	256	290	157	61	95
Summer	Chinchaga	1521	28.36	0.876	0.951	169	142	66	29	37
Winter			16.23	0.715	0.932	108	187	151	37	114
Summer	Chinchaga	1520	38.95	0.551	0.929	47	157	162	20	142
Winter			14.37	0.770	0.956	174	364	169	69	100
Summer	ESAR	1509	8.47	0.754	0.960	49	113	62	15	47
Winter			NF	0.866	NF	129	NF	60	NF	N/A
Summer	ESAR	1507	9.80	0.699	0.966	51	192	88	27	61
Winter			9.81	0.802	0.964	97	196	84	29	55
Summer	ESAR	1506	NF	0.850	NF	119	NF	57	NF	N/A
Winter			2.47	0.930	0.976	253	235	42	35	7
Summer	ESAR	1505	13.36	0.892	0.955	239	191	71	39	33
Winter			12.90	0.866	0.962	214	261	92	47	45
Summer	ESAR	1504	11.46	0.766	0.955	82	163	84	31	53
Winter			9.62	0.880	0.964	198	226	73	39	34
Summer	Richardson	1495	14.07	0.833	0.927	179	143	96	38	59
Winter			12.18	0.883	0.971	226	314	82	49	33
Summer	Richardson	1494	5.41	0.963	0.979	699	381	34	59	25
Winter			6.48	0.904	0.952	310	205	74	45	29
Summer	Richardson	1493	9.11	0.539	0.886	22	44	79	4	75
Winter			6.87	0.788	0.931	107	121	80	37	43
Summer	Richardson	1492	21.35	0.888	0.962	261	263	74	59	15
Winter			4.01	0.939	0.983	491	586	53	82	29
Summer	Richardson	1491	-	-	-	-	-	-	-	-
Winter			4.99	0.718	0.921	51	70	63	22	42

				R^2		F-statistic		AIC_c		
Season	Population	Caribou	Scale Criteria (r_c)	One-Proc.	Two-Proc.	One-Proc.	Two-Proc.	One-Proc.	Two-Proc.	$AIC_c\Delta$
Summer	Richardson	1490	14.21	0.717	0.928	68	108	100	16	84
Winter			10.16276591	0.756	0.906	140	138	140	33	107
Summer	Richardson	1489	23.78	0.787	0.944	144	209	122	45	77
Winter			12.16	0.815	0.938	202	224	130	54	76
Summer	Richardson	1488	11.07	0.905	0.962	210	171	54	30	24
Winter			11.76	0.861	0.952	192	191	87	36	51
Summer	Richardson	1486	9.33	0.788	0.906	100	80	80	21	59
Winter			15.27	0.840	0.962	210	325	112	64	48
Summer	Richardson	1485	14.98	0.831	0.944	103	108	68	18	50
Winter			11.67	0.785	0.951	117	193	102	40	61
Summer	Richardson	1484	0.90	0.937	0.943	518	182	56	48	7
Winter			7.34	0.876	0.951	310	272	107	62	45
Summer	ESAR	1420	-	-	-	-	-	-	-	-
Winter			2.38	0.609	0.923	16	32	47	2	45
Summer	Richardson	1416	8.46	0.717	0.972	38	151	62	19	43
Winter			3.62	0.731	0.867	52	37	62	6	56
Summer	Nipisi	1240	4.19	0.911	0.943	329	166	67	40	28
Winter			10.83	0.811	0.924	219	200	150	45	105
Summer	Chinchaga	1238	20.73	0.783	0.958	83	159	77	29	48
Winter			6.09	0.691	0.948	45	110	71	25	46
Summer	Chinchaga	1237	4.00	0.933	0.973	195	145	30	23	7
Winter			8.80	0.583	0.850	32	40	84	7	78
Summer	Chinchaga	1236	2.14	0.926	0.951	510	252	75	60	15
Winter			6.67	0.868	0.927	314	196	114	53	62
Summer	Chinchaga	1235	NF	0.949	NF	392	NF	30	NF	NF
Winter			9.31	0.850	0.942	244	224	112	54	59
Summer	Chinchaga	1234	12.95	0.825	0.947	203	243	121	55	66
Winter			4.88	0.897	0.945	453	287	108	75	33
Summer	Chinchaga	1233	36.79	0.772	0.963	138	341	140	56	84
Winter			4.47	0.935	0.976	796	724	97	117	20

				R^2		F-statistic		AIC_c		
Season	Population	Caribou	Scale Criteria (r_c)	One-Proc.	Two-Proc.	One-Proc.	Two-Proc.	One-Proc.	Two-Proc.	$AIC_c\Delta$
Summer	Chinchaga	1232	-	-	-	-	-	-	-	-
Winter			7.95	0.735	0.925	91	127	103	35	68
Summer	Chinchaga	1231	-	-	-	-	-	-	-	-
Winter			5.99	0.688	0.930	44	80	66	23	43
Summer	Chinchaga	1230	18.80	0.819	0.957	194	308	134	55	79
Winter			8.51	0.872	0.970	320	491	123	83	41
Summer	Chinchaga	1229	23.50	0.878	0.952	323	283	118	55	63
Winter			30.31	0.464	0.909	47	172	226	27	199
Summer	Chinchaga	1228	14.24	0.751	0.933	130	190	143	39	105
Winter			15.91	0.790	0.938	233	301	191	64	126
Summer	Chinchaga	1227	-	-	-	-	-	-	-	-
Winter			8.91	0.769	0.926	123	145	108	42	67
Summer	Chinchaga	1226	17.68	0.792	0.927	187	199	148	45	103
Winter			17.06	0.796	0.947	234	344	182	72	110
Summer	Chinchaga	1225	13.86	0.758	0.933	129	180	139	34	105
Winter			33.20	0.656	0.914	97	174	195	25	170
Summer	Chinchaga	1224	7.05	0.900	0.955	376	281	94	61	33
Winter			7.242	0.895	0.966	445	470	119	90	28
Summer	Little Smoky	1092	10.53	0.617	0.953	42	161	108	25	83
Winter			8.62	0.703	0.957	45	127	81	13	68
Summer	Little Smoky	1090	8.26	0.780	0.954	82	145	80	25	54
Winter			6.84	0.817	0.933	111	108	80	19	61
Summer	Little Smoky	1089	13.18	0.733	0.957	55	134	77	20	58
Winter			7.53	0.858	0.964	157	216	74	39	35
Summer	WSAR	174	9.03	0.899	0.959	331	271	83	57	26
Winter			9.46	0.840	0.960	147	210	77	45	32
Summer	WSAR	173	4.34	0.910	0.957	335	230	68	52	16
Winter			4.09	0.897	0.937	279	150	67	42	25
Summer	WSAR	172	3.84	0.742	0.955	46	99	56	20	36
Winter			10.14	0.625	0.943	32	94	77	17	60

				R^2		F-statistic		AIC_c		
Season	Population	Caribou	Scale Criteria (r_c)	One-Proc.	Two-Proc.	One-Proc.	Two-Proc.	One-Proc.	Two-Proc.	$AIC_c\Delta$
Summer	WSAR	171	-	-	-	-	-	-	-	-
Winter			8.00	0.802	0.913	118	95	87	21	66
Summer	ESAR	170	10.64	0.873	0.947	219	180	78	44	34
Winter			12.72	0.784	0.922	167	174	143	38	105
Summer	WSAR	169	3.43	0.569	0.900	18	36	61	1	60
Winter			5.34	0.818	0.957	135	208	81	51	29
Summer	WSAR	168	2.45	0.857	0.943	114	93	51	22	29
Winter			10.81	0.733	0.933	82	131	86	44	42
Summer	WSAR	167	3.10	0.872	0.954	143	132	51	32	20
Winter			8.62	0.781	0.938	114	151	88	46	42
Summer	WSAR	166	NF	0.842	NF	144	NF	76	NF	N/A
Winter			7.16	0.830	0.926	137	109	82	23	58
Summer	WSAR	165	7.54	0.833	0.939	150	143	82	36	46
Winter			10.09	0.742	0.923	75	95	83	25	58
Summer	WSAR	164	2.04	0.895	0.939	178	98	46	26	20
Winter			8.13	0.744	0.911	75	82	85	19	66
Summer	WSAR	163	5.16	0.872	0.921	203	110	70	31	39
Winter			9.19	0.776	0.916	187	189	165	45	120
Summer	WSAR	162	9.22	0.867	0.931	195	126	78	29	49
Winter			16.64	0.646	0.920	98	199	196	42	154
Summer	WSAR	161	-	-	-	-	-	-	-	-
Winter			9.76	0.630	0.965	31	146	69	29	40
Summer	WSAR	160	3.84	0.689	0.958	24	68	45	10	36
Winter			6.51	0.645	0.911	56	99	98	37	61
Summer	WSAR	159	26.82	0.604	0.908	73	151	187	23	164
Winter			13.68	0.839	0.960	220	321	114	68	46
Summer	WSAR	157	10.83	0.784	0.936	131	166	109	40	69
Winter			9.15	0.755	0.921	83	97	81	28	53
Summer	WSAR	156	8.30	0.882	0.964	97	99	38	16	22
Winter			5.05	0.814	0.940	92	99	63	23	40

				R^2		F-statistic		AIC_c		
Season	Population	Caribou	Scale Criteria (r_c)	One-Proc.	Two-Proc.	One-Proc.	Two-Proc.	One-Proc.	Two-Proc.	$AIC_c\Delta$
Summer	WSAR	154	7.61	0.794	0.909	104	83	78	23	55
Winter			6.83	0.875	0.950	140	115	53	24	28
Summer	WSAR	153	12.69	0.611	0.911	52	106	130	16	114
Winter			8.96	0.694	0.918	77	119	120	25	95
Summer	WSAR	152	14.44	0.759	0.938	126	192	133	39	94
Winter			18.70	0.818	0.938	184	196	116	47	69
Summer	WSAR	151	0.28	0.894	0.933	134	65	31	22	9
Winter			7.77	0.832	0.951	168	206	82	68	14
Summer	WSAR	150	6.30	0.818	0.935	139	140	90	33	57
Winter			9.76	0.699	0.950	35	83	53	19	34
Summer	WSAR	149	17.50	0.842	0.965	198	325	111	54	57
Winter			18.17	0.693	0.910	104	149	167	23	144
Summer	WSAR	148	11.32	0.826	0.956	200	292	119	62	57
Winter			6.79	0.885	0.952	324	266	93	66	27
Summer	WSAR	147	13.30	0.718	0.925	109	170	145	37	108
Winter			12.08	0.781	0.918	118	116	104	25	79
Summer	WSAR	146	8.67	0.761	0.927	102	127	93	39	53
Winter			29.73	0.610	0.920	74	173	174	38	137
Summer	WSAR	145	2.14	0.833	0.943	115	115	65	27	38
Winter			NF	0.831	NF	108	NF	57	NF	N/A
Summer	WSAR	144	4.80	0.911	0.960	327	240	67	52	15
Winter			11.96	0.716	0.913	131	176	168	44	124
Summer	WSAR	143	6.81	0.772	0.906	190	174	156	56	100
Winter			7.05	0.848	0.959	145	186	76	35	41
Summer	WSAR	141	8.63	0.833	0.926	194	154	103	42	60
Winter			4.86	0.856	0.954	172	185	71	47	24
Summer	WSAR	140	9.99	0.872	0.961	178	195	75	32	43
Winter			20.19	0.530	0.897	50	122	180	16	164
Summer	WSAR	139	8.92	0.775	0.915	138	127	114	39	75
Winter			30.30	0.696	0.942	94	211	154	34	120

				R^2		F-statistic		AIC_c		
Season	Population	Caribou	Scale Criteria (r_c)	One-Proc.	Two-Proc.	One-Proc.	Two-Proc.	One-Proc.	Two-Proc.	$AIC_c\Delta$
Summer	WSAR	138	11.81	0.840	0.935	189	164	96	41	55
Winter			13.88	0.696	0.928	119	215	181	46	135

Table 2. Difference in corrected Akaike Information Criterion (ΔAIC_c) values from the top step selection function (SSF) models of caribou (n=15) selection of habitat and anthropogenic footprint landscape features along fast caribou movement steps during the summer in northeast Alberta. Grey highlight indicates top-model (i.e., lowest AIC_c value) and models with $AIC_c \leq 2$ from the top model.

	Model										
	Anthropogenic					Habitat					
Individual	All Human[1]	Human Simple[2]	Human – Oil[3]	Human – Forestry[4]	Human – Activity5	AGCC Habitat	ABMI Habitat	AVI Habitat	Terrain only	Fire only	Fire and Terrain
1485	22	16	16	20	20	8	7	N/A	10	4	0
1486	26	15	16	26	22	6	0	N/A	11	N/A	13
1488	26	23	21	25	28	0	3	N/A	11	20	8
1489	2	10	9	0	8	13	8	N/A	6	9	8
1490	12	14	13	13	10	0	8	N/A	12	18	14
1492	1	8	6	3	1	0	14	N/A	7	11	7
1493	6	0	6	6	7	11	5	N/A	5	N/A	5
1494	106	105	107	105	105	0	29	N/A	79	101	78
1495	21	28	21	25	27	0	17	N/A	15	28	17
1504	14	11	14	12	11	0	9	2	12	7	11
1505	27	24	26	26	17	4	0	9	9	19	8
1506	98	90	93	95	98	0	25	35	82	96	84
1507	3	0	2	1	1	4	7	5	2	N/A	4
1509	24	21	21	20	22	22	8	0	18	21	20
1629	1	7	9	3	9	1	0	N/A	0	7	1

1. All human covariates (distance to unpaved road, distance to cutblock, distance to settlement, distance to well).
2. Distance to nearest anthropogenic footprint feature.
3. Distance to well, distance to unpaved road and interaction.
4. Distance to cutblock, distance to unpaved road and interaction.
5. Distance to settlement, distance to unpaved road and interaction.

Table 3. Coefficients of the fast movement step selection function (SSF) models of fifteen individual caribou during the summer in northeast Alberta. Significant covariates (P<0.05) are highlighted in grey.

	Population	Richardson										ESAR				
	Individual	1629	1485	1486	1488	1490	1492	1493	1494	1495	1489	1504	1505	1506	1507	1509
	Covariate	β-coefficient										β-coefficient				
	$Elev_{end}$	-0.690	-0.056	0.019	0.001	0.062	0.048	-	0.008	-0.005	-	0.004	-0.002	-0.027	-	-0.093
	TRI_{lwm}	11,612.260	5,962.613	-52,820.000	-17,991.130	-25,185.650	-5,395.634	-	-4,349.649	-25,423.200	-	-4,671.279	-7,196.380	-11,627.130	-	33,194.240
	$Fire_{prop}$	27.450	-2.773	-8.217	0.521	14.411	0.285	-	0.028	-0.108	-	-1.549	-0.962	-8.964	-	-25.863
															-	
AGCC	CF_{prop}	-	-	-	1.100	2.186	-9.246	-	-0.177	4.040	-	0.145	-	0.297	-	-
	CF_{end}	-	-	-	0.071	1.505	-2.034	-	-0.134	-0.065	-	1.019	-	1.017	-	-
	W_{prop}	-	-	-	1.963	7.956	-9.110	-	-0.030	2.919	-	-5.180	-	0.188	-	-
	W_{end}	-	-	-	-1.050	-16.173	-1.862	-	-0.594	-0.993	-	0.317	-	-0.401	-	-
	MDF_{prop}	-	-	-	-17.312	0.808	-541.855	-	-232.509	11.138	-	-8.794	-	-0.358	-	-
	MDF_{end}	-	-	-	-12.008	0.305	-13.277	-	-11.097	-0.194	-	-13.098	-	0.345	-	-
ABMI	CCF_{prop}	12.213	-	1.544	-	-	-	-	-	-	-	-	-0.059	-	-	-
	CCF_{end}	-24.466	-	-0.843	-	-	-	-	-	-	-	-	-0.900	-	-	-
	MDF_{prop}	-13.187	-	-23.894	-	-	-	-	-	-	-	-	-3.372	-	-	-
	MDF_{end}	1.800	-	1.999	-	-	-	-	-	-	-	-	-2.140	-	-	-
	F_{prop}	2,582.008	-	2.815	-	-	-	-	-	-	-	-	1.967	-	-	-
	F_{end}	8.301	-	0.196	-	-	-	-	-	-	-	-	0.734	-	-	-
AVI	MCF_{prop}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-11,551.830
	MCF_{end}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-2.783
	F_{end}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.793
	CF_{prop}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-43.287
	CF_{end}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.892
	MDF_{prop}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-5.232
	MDF_{end}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-24.136
	DHF_{lwm}	-	-	-	-	-	-	-0.0005	-	-	-	-	-	-	-0.0001	-
	DC_{lwm}	-	-	-	-	-	-	-	-	-	0.0001	-	-	-	-	-
	DUR_{lwm}	-	-	-	-	-	-	-	-	-	0.001	-	-	-	-	-
	DC x DUR	-	-	-	-	-	-	-	-	-	-0.00000001	-	-	-	-	-

Notes: Covariates included in the SSFs are elevation ($Elev_{end}$) and habitat type (wetland[W_{end}], coniferous forest [CF_{end}], mixed deciduous forest [MDF_{end}], closed coniferous forest [CCF_{end}], forest [F_{end}], and mature coniferous forest [MCF_{end}]) at which the step ended, terrain ruggedness index (TRI_{lwm}), distance to human footprint (DHF_{lwm}), distance to cutblock (DC_{lwm}) and distance to unpaved road (DUR_{lwm}) length-weighted mean along the step, and proportion of step consisting of areas burned in the last fifty years ($Fire_{prop}$), coniferous forest (CF_{prop}), wetland (W_{prop}), mixed deciduous forest (MDF_{prop}), closed coniferous forest (CCF_{prop}), forest (F_{prop}), and mature coniferous forest (MCF_{prop}). AGCC is vegetation type derived from Alberta Ground Cover Characterization (AGCC), ABMI is vegetation type derived from Alberta Biodiversity Monitoring Institute and AVI is vegetation derived from Alberta Vegetation Inventory.

Figures

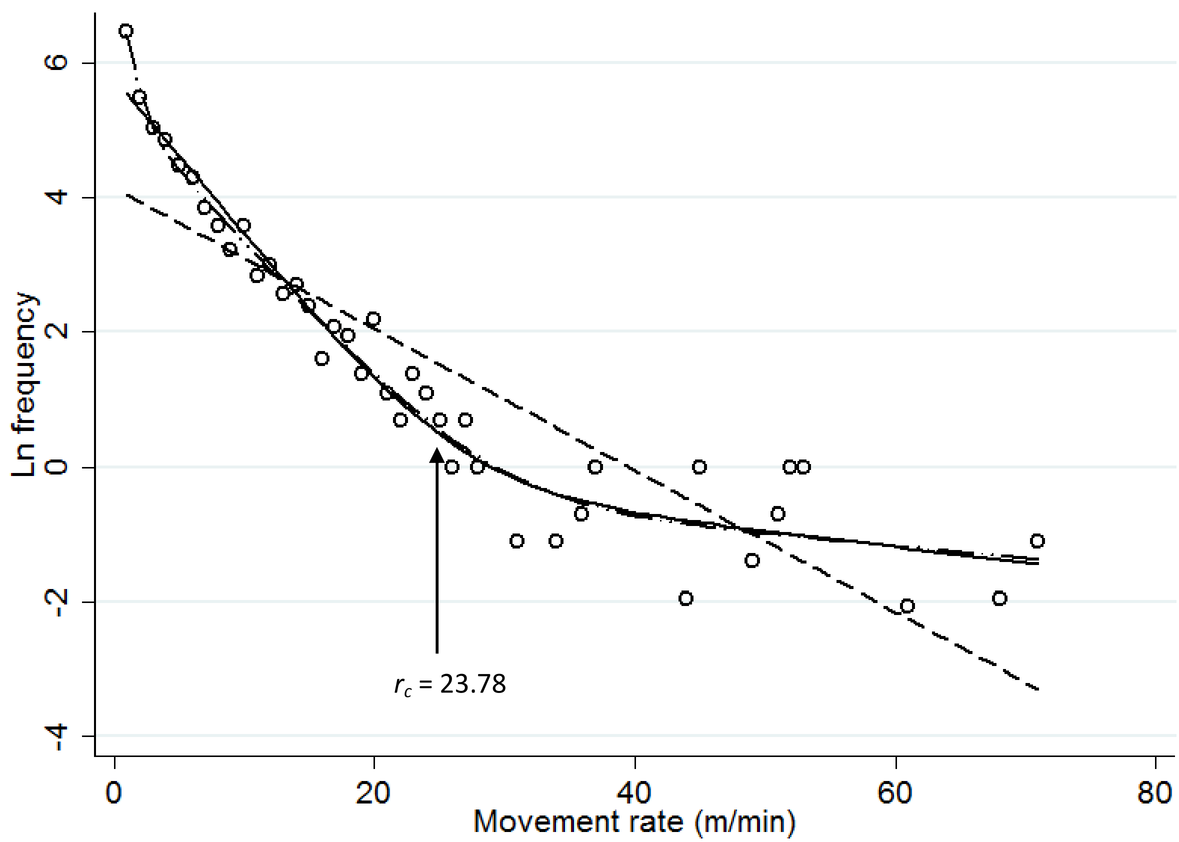

Figure 1. Example of $\log_e$ frequency distribution of movement rates by caribou 1489 during summer (May 15 – September 30) fit with equation of the null linear model of non-scalar response (dashed line), two-process model (solid line) and three process model (dash-dot line). A scale criterion (r_c=23.78 m/min) was calculated using parameters from the two-process model. The three-process model is shown to illustrate how the data over-fits the model, as the first breakpoint is fit to a small portion of the data (upper left).

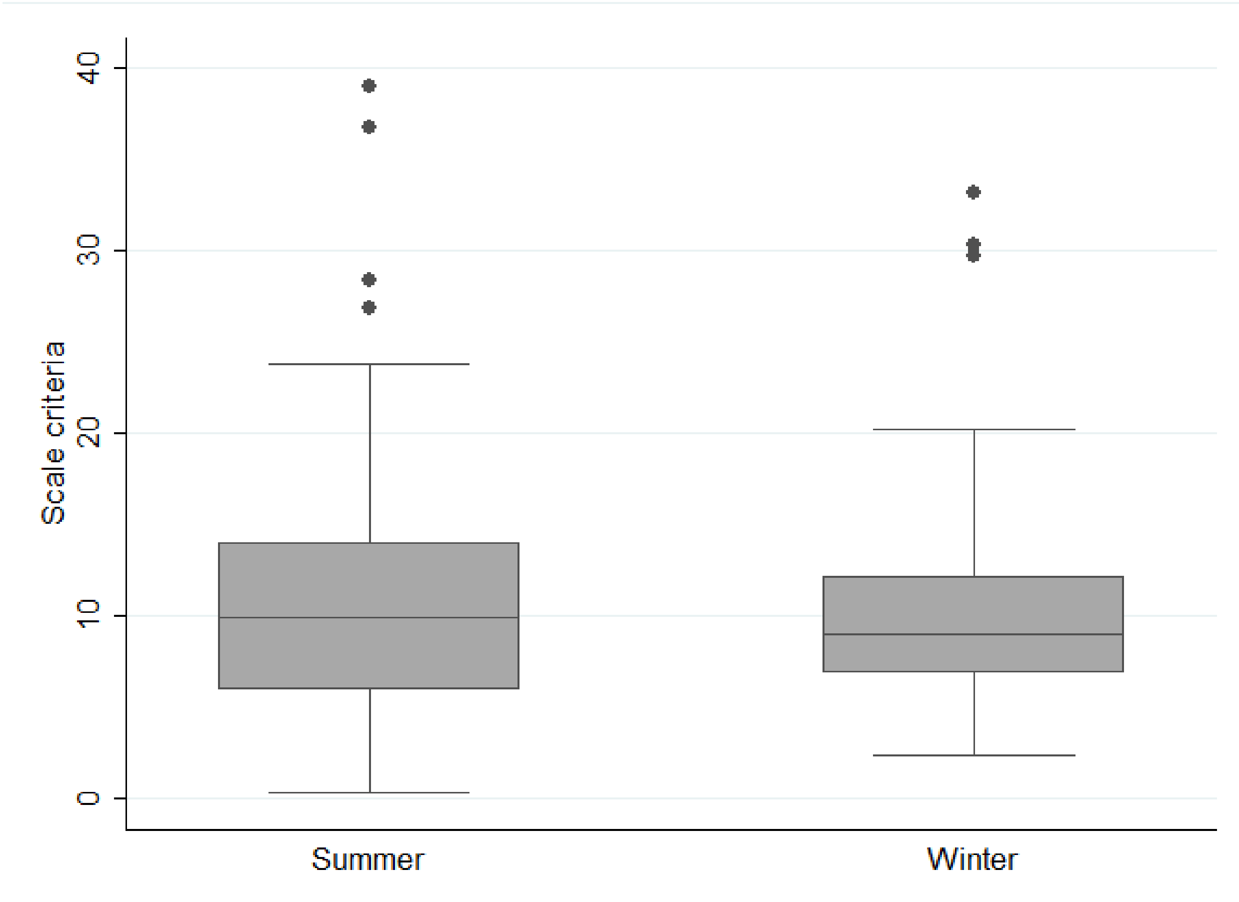

Figure 2. Box plots (middle line=median, box = 25th and 75th percentiles, ends of the whiskers = 5th and 95th percentile) of the distribution of scale criteria (r_c) for defining slow and fast summer and winter caribou movements in Alberta, Canada.

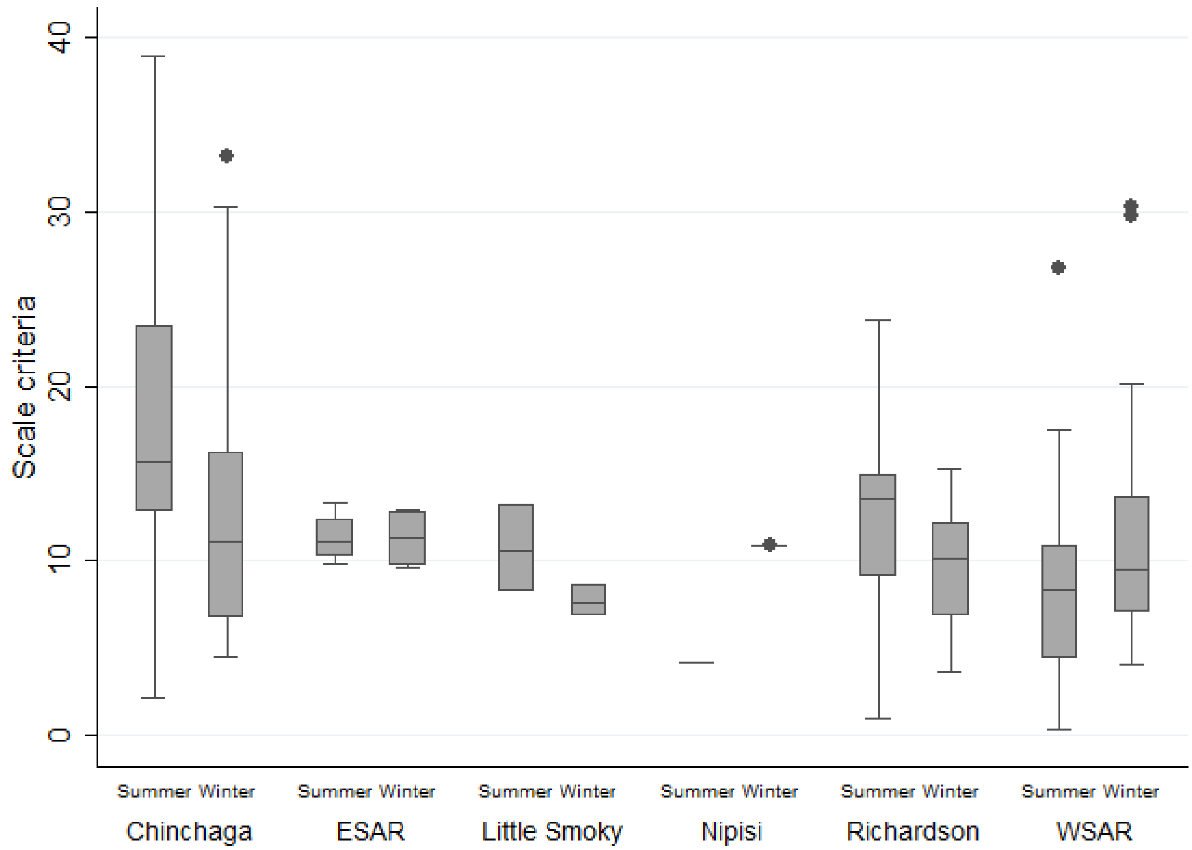

Figure 3. Box plot (middle line=median, box = 25th and 75th percentiles, ends of the whiskers = 5th and 95th percentile) of the distribution of scale criteria (r_c) for defining small- and large- scale caribou movements in summer and winter, by caribou population in Alberta, Canada. Sample size for each population in summer and winter is: Chinchaga n_s=15, n_w=18; ESAR n_s=5, n_w=5; Little Smoky n_s=3, n_w=4; Richardson n_s=13, n_w=14; WSAR n_s=31, n_w=32; Nipisi n_s=1, n_w=1.

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Literature Cited

Aebischer, N.J., Robertson, P.A., and Kenward, R.E. (1993) Compositional analysis of habitat use from animal radio-tracking data. Ecology, 74(5), 1313-1325.

Alberta Environmental Protection. 1991. Alberta Vegetation Inventory Standards Manual, version 2.1. Government of Alberta. 52 pp.

Alberta Sustainable Resource Development and Alberta Conservation Association. 2010. Status of the Woodland Caribou (*Rangifer tarandus caribou*) in Alberta: Update 2010. Alberta Sustainable Resource Development. Wildlife Status Report No. 30 (Update 2010). Edmonton, AB. 88 pp.

Alberta Woodland Caribou Recovery Team. 2005. Alberta woodland caribou recovery plan 2004/05-2013/14. Alberta Sustainable Resource Development, Fish and Wildlife Division, Alberta Species at Risk Recovery Plan No. 4. Edmonton, AB. 48 pp.

Apps, C.D., & McLellan, B.N. (2006) Factors influencing the dispersion and fragmentation of endangered mountain caribou populations. Biological Conservation, 130, 84-97.

Arnold, T.W. (2010) Uninformative parameters and model selection using Akaike's Information Criterion. Journal of Wildlife Management 74(6):1175–1178.

Berdoy, M. (1993) Defining bouts of behaviour: a three-process model. Animal Behaviour, 46, 387-396.

Bergerud, A.T. & Ballard, W.B. (1988) Wolf predation on caribou: the Nelchina herd case history, a different interpretation. The Journal of Wildlife Management, 52, 344-357.

Bergerud, A.T. & Elliot, J.P. (1986) Dynamics of caribou and wolves in northern British Columbia. Canadian Journal of Zoology, 64, 1515-1529.

Bergerud, A.T. & Elliott, J.P. (1998) Wolf predation in a multiple-ungulate system in northern British Columbia. Canadian Journal of Zoology, 76, 1551-1569.

Bergerud, A.T., Jakimchuk, R.D. & Carruthers, D.R. (1984) The buffalo of the north: Caribou (Rangifer tarandus) and human developments. Arctic, 37, 7-22.

Bolker, B. M., Brooks, M. E., Clark, C. J., Geange, S. W., Poulsen, J. R., Stevens, M. H. H. & White, S. S. (2009) Generalized linear mixed models: a practical guide for ecology and evolution. Trends Ecol. Evol. 24, 127–135.

Bowman, J., Ray, J.C., Magoun, A.J., Johnson, D.S. & Dawson, F.N. (2010) Roads, logging, and the large-mammal community of an eastern Canadian boreal forest. Canadian Journal of Zoology, 88, 454-467.

Boyce, M.S. (2006) Scale for resource selection functions. Diversity and Distributions, 12, 269-276.

Bradshaw, C.J.A., Sims, D.W., & Hays, G.C. (2007) Measurement error causes scale-dependent threshold erosion of biological signals in animal movement data. Ecological Applications, 17, 628-638.

Bradshaw, C.J.A., Boutin, S. & Hebert, D.M. (1998) Energetic implications of disturbance caused by petroleum exploration to woodland caribou. Canadian Journal of Zoology, 76, 1319-1324.

Bradshaw, C.J.A., Hebert, D.M., Rippin, A.B. & Boutin, S. (1995) Winter peatland habitat selection by woodland caribou in northeastern Alberta. *Canadian Journal of Zoology*, **73**, 1567-1574.

Burnham, K.P. & Anderson, D.R. (1998) Model Selection and Inference a Practical Information–Theoretic Approach. Springer-Verlag, New York.

Cameron, R.D. & Ver Hoef, J.M. (1994) Predicting parturition rate of caribou from autumn body mass. The Journal of Wildlife Management, 58, 674-679.

Chetkiewicz, C.-L.B., St. Clair, C.C. & Boyce, M.S. (2006) Corridors for Conservation: Integrating Pattern and Process. Annual Review of Ecology, Evolution, and Systematics, 37, 317-342.

Courbin, N., Fortin, D., Dussault, C. & Courtois, R. (2009) Landscape management for woodland caribou: the protection of forest blocks influences wolf-caribou co-occurrence. *Landscape Ecology*, **24**, 1375-1388.

Dawe, K.L. (2011) Factors driving range expansion of white-tailed deer, *Odocoileus virginianus*, in the boreal forest of northern Alberta, Canada. Dissertation, University of Alberta.

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.

D'Eon, R.G., & Delparte, D. (2005) Effects of radio-collar position and orientation on GPS collar performance, and the implications of PDOP in data screening. Journal of Applied Ecology, 42, 383-388.

D'Eon, R.G. (2003) Effects of a stationary GPS fix-rate bias on habitat-selection analysis. Journal of Wildlife Management, 67, 858-863.

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

Dyer, S.J., O'Neill, J.P., Wasel, S.M. & Boutin, S. (2002) Quantifying barrier effects of roads and seismic lines on movements of female woodland caribou in northeastern Alberta. Canadian Journal of Zoology, 80, 839-845.

Dzus, E. 2001. Status of the Woodland Caribou (Rangifer tarandus caribou) in Alberta. Alberta Environment, Fisheries and Wildlife management Division, and Alberta Conservation Association, Wildlife Status Report No. 30, Edmonton, AB. 47 pp.

Environment Canada. 2008. Scientific Review for the Identification of Critical Habitat for Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population, in Canada. August 2008. Ottawa: Environment Canada. 72 pp. plus 180 pp Appendices.

Environment Canada. 2011. Recovery Strategy for the Woodland Caribou, Boreal population (*Rangifer tarandus caribou*) in Canada [Proposed]. Species at Risk Act Recovery Strategy Series. Environment Canada, Ottawa. vi + 55 pp.

Festa-Bianchet, M., Ray, J.C., Boutin, S. & Gunn, A. (2011) Conservation of caribou (*Rangifer tarandus*) in Canada: an uncertain future. Canadian Journal of Zoology, 89, 419-434.

Fieberg, J., Matthiopoulos, J., Hebblewhite, M., Boyce, M.S. & Frair, J.L. (2010) Correlation and studies of habitat selection: problem, red herring or opportunity? Phil. Trans. R. Soc. B, 365, 2233-2244.

Fisher, J.T., and Wilkinson, L (2005). The response of mammals to forest fire and timber harvesting in the North American boreal forest. Mammal Review, 35(1), 51-81.

Forester, J.D., Ives, A.R., Turner, M.G., Anderson, D.P., Fortin, D., Beyer, H.L., Smith, D.W. & Boyce, M.S. (2007) State–space models link elk movement patterns to landscape characteristics in Yellowstone National Park. *Ecological Monographs*, **77**, 285-299.

Fortin, D., Beyer, H.L., Boyce, M.S., Smith, D.W., Duchesne, T. & Mao, J.S. (2005) Wolves influence elk movements: behavior shapes a trophic cascade in Yellowstone National Park. Ecology, 86, 1320-1330.

Fortin, D., Courtois, R., Etcheverry, P., Dussault, C., & Gingras, A. (2008). Winter selection of landscapes by woodland caribou: behavioural response to geographical gradients in habitat attributes. Journal of Applied Ecology, 45, 1392-1400.

Frair, J.L., Nielsen, S.E., Merrill, E.H., Lele, S.R., Boyce, M.S., Munro, R.H.M., Stenhouse, G.B., & Beyer, H.L. (2004) Removing GPS collar bias in habitat selection studies. Journal of Applied Ecology, 41, 201-212.

Fryxell, J. M., Mosser, A., Sinclair, A. R. E. and Packer, C. (2007) Group formation stabilizes predator–prey dynamics. Nature 449, 1041–1044.

Fryxell, J. M., M. Hazell, L. Borger, B. D. Dalziel, D. T. Haydon, J. M. Morales, T. Mcintosh, and R. C. Rosatte. (2008) Multiple Movement Modes by Large Herbivores at Multiple Spatiotemporal Scales. Proceedings of the National Academy of Sciences of the United States of America, 105, 19114-19119.

Fuller, T.K. & Keith, L.B. (1981) Woodland caribou population dynamics in northeastern Alberta. The Journal of Wildlife Management, 45, 197-213.

Gaillard, J.-M., Hebblewhite, M., Loison, A., Fuller, M., Powell, R., Basille, M., & Van Moorter, B. (2010) Habitat–performance relationships: finding the right metric at a given spatial scale. Philosophical Transactions of the Royal Society B: Biological Sciences, 365, 2255-2265.

Gillies, C. S., Hebblewhite, M., Nielsen, S. E., Krawchuk, M. A., Aldridge, C. L., Frair, J. L., Saher, J., Stevens,C. E. & Jerde, C. L. (2006) Application of random effects to the study of resource selection by animals. Journal of Animal Ecology, 75, 887–898.

Hansen, M.C., & Riggs, R.A. (2008) Accuracy, precision, and observation rates of global positioning system telemetry collars. Journal of Wildlife Management, 72, 518-526.

Haskell, S.P., Nielson, R.M., Ballard, W.B., Cronin, M.A. & McDonald, T.L. (2006) Dynamic responses of calving caribou to oilfields in northern Alaska. Arctic, 59, 179-190.

Hebblewhite, M. & Merrill, E. H. (2008) Modelling wildlife-human relationships for social species with mixed-effects resource selection models. Journal of Applied Ecology, 45, 834–844.

Holling, C. S. (1959) The components of predation as revealed by a study of small-mammal predation of the European pine sawfly. Canadian Entomologist 91, 293–320.

Holt, R.D. (1977). Predation, apparent competition, and the structure of prey communities. Theoretical Population Biology, 12, 197–229.

Holt, R.D. (1984). Spatial heterogeneity, indirect indirections, and the coexistence of prey species. The American Naturalist, 124(3), 377-406.

Holt, R.D., and Kotler, B.P. (1987). Short-term apparent competition. The American Naturalist, 130(3), 412-430.

Hosmer, D.W. and Lemeshow, S. (1989) *Applied logistic regression*. John Wiley and Sons.

James, A.R.C. & Stuart-Smith, A.K. (2000) Distribution of caribou and wolves in relation to linear corridors. The Journal of Wildlife Management, 64, 154-159.

Johnson, C.J., Parker, K.L., Heard, D.C. & Gillingham, M.P. (2002) A multiscale behavioral approach to understanding the movements of woodland caribou. Ecological Applications, 12, 1840-1860.

Johnson, C. J., Seip, D.R., & Boyce, M.S. (2004) A quantitative approach to conservation planning: using resource selection functions to map the distribution of mountain caribou at multiple spatial scales. Journal of Applied Ecology, 41, 238-251.

Johnson, C.J., Parker, K.L., Heard, D.C. & Gillingham, M.P. (2006) Unrealistic animal movement rates as behavioural bouts: a reply. Journal of Animal Ecology, 75, 303-308.

Koper, N. & Manseau, M. L. 2009 Generalized estimating equations and generalized linear mixed-effects models for modeling resource selection. J. Appl. Ecol. 46, 590–599.

Latham, A.D.M., Latham, M.C., McCutchen, N.A. & Boutin, S. (2011) Invading white-tailed deer change wolf-caribou dynamics in northeastern Alberta. The Journal of Wildlife Management, 75, 204-212.

Luick, B.R., & White, R.G. (1986) Oxygen consumption for locomotion by caribou calves. The Journal of Wildlife Management, 50, 148-152.

Matthiopoulos, J., Hebblewhite, M., Aarts, G., & Fieberg, J. (2011) Generalised functional responses for species distributions. Ecology, 92, 583-589.

Mauritzen, M., Belikov, S.E., Boltunov, A.N., Derocher, A.E., Hansen, E., Ims, R.A., Wiig, O., & Yoccoz, N. (2003) Functional responses in polar bear habitat selection. Oikos, 100, 112-124.

Mayor, S.J., Schneider, D.C., Schaefer, J.A. & Mahoney, S.P. (2009) Habitat selection at multiple scales. Ecoscience, 16, 238-247.

McLoughlin, P.D., Dunford, J.S., & Boutin, S. (2005) Relating predation mortality to broad-scale habitat selection. Journal of Animal Ecology, 74, 701-707.

McLoughlin, P.D., Dzus, E., Wynes, B., & Boutin, S. (2003) Declines in populations of woodland caribou. The Journal of Wildlife Management, 67, 755-761.

Morales, J. M., D. T. Haydon, J. Frair, K. E. Holsinger, and J. M. Fryxell. (2005) Extracting more from relocation data: building movement models as mixtures of random walks. Ecology, 85, 2436-2445.

Nielsen, S. E., Boyce, M. S., Stenhouse, G. B. & Munro R. H. M. (2002) Modeling grizzly bear habitats in the Yellowhead ecosystem of Alberta: taking autocorrelation seriously. Ursus, 13, 45–56.

Owen-Smith, N., Fryxell, J.M. & Merrill, E.H. (2010) Foraging theory upscaled: the behavioural ecology of herbivore movement. Philosophical Transactions of the Royal Society B: Biological Sciences, 365, 2267-2278.

Patterson, T. A., L. Thomas, C. Wilcox, O. Ovaskainen, and J. Matthiopoulos. (2008) State-space models of individual animal movement. Trends in Ecology & Evolution, 23, 87-94.

Pendergast, J.F., Gange, S.J., Newton, M.A., Lindstrom, M.J., Palta, M. & Fisher, M.R. (1996) A survey of methods of analyzing clustered binary response data. International Statistics Review, 64, 89–118.

Rettie, W.J. & Messier, F. (1998) Dynamics of woodland caribou populations at the southern limit of their range in Saskatchewan. Canadian Journal of Zoology, 76, 251-259.

Rettie, W.J., & Messier, F. (2000) Hierarchical habitat selection by woodland caribou: its relationship to limiting factors. Ecography, 23, 466-478.

Sánchez-Azofeifa et al., G.A. Sánchez-Azofeifa, M. Kachmar, M. Kalacska and S. Hamilton, (2003) Experiences in field data collection in support of land use and land cover change classification in boreal and tropical environments, Remote Sensing of Forest Environments: Concepts and Case Studies, Kluwer Academic Publishers, pp. 433–446.

Sappington, J. M., Longshore, K. M. & Thompson, D. B. (2007) Quantifying landscape ruggedness for animal habitat analysis: a case study using bighorn sheep in the Mojave Desert. The Journal of Wildlife Management, 71, 1419-1426.

Schaefer, J.A., Veitch, A.M., Harrington, F.H., Brown, W.K., Theberge, B., & Luttich, S.N. (1999) Demography of decline of the Red Wine Mountains caribou herd. The Journal of Wildlife Management, 63, 580-587.

Schaefer, J.A. (2003) Long-term range recession and the persistence of caribou in the taiga. Conservation Biology, 17, 1435-1439.

Seip, D.R. (1992) Factors limiting woodland caribou populations and their interrelationships with wolves and moose in southeastern British Columbia. Canadian Journal of Zoology, 70, 1494-1503.

Sibly, R., Nott, H. & Fletcher, D. (1990) Splitting behaviour into bouts. Animal Behaviour, 39, 63-69.

Sorensen, T., McLoughlin, P.D., Hervieux, D., Dzus, E., Nolan, J., Wynes, B. & Boutin, S. (2008) Determining sustainable levels of cumulative effects for boreal caribou. Journal of Wildlife Management, 72, 900-905.

Stuart-Smith, A.A.K., Bradshaw, C.J.A., Boutin, S., Hebert, D.M. & Rippen, A.B. (1997) Woodland caribou relative to landscape patterns in northeastern Alberta. The Journal of Wildlife Management, 61, 622-633.

Tambling, C. J., Cameron, E. Z., Du Toit, J. T. & Getz, W. M. (2010) methods for locating African lion kills using global positioning system movement Data. Journal of Wildlife Management, 74, 549–556.

Turchin, P. (1998) *Quantitative analysis of movement: measuring and modeling population redistribution in animals and plants*. Sinauer Associates, Sunderland, Massachusetts, USA.

Van Moorter, B., D. R. Visscher, C. L. Jerde, J. L. Frair, and E. H. Merrill. (2010) Identifying Movement States From Location Data Using Cluster Analysis. Journal of Wildlife Management, 74, 588-594.

Vistnes, I. & Nellemann, C. (2007) Impacts of human activity on reindeer and caribou: The matter of spatial and temporal scales. Rangifer, 12, 47-56.

Vors, L.S., Schaefer, J.A, Pond, B.A, Rodgers, A.R. & Patterson, B.R. (2007) Woodland caribou extirpation and anthropogenic landscape disturbance in Ontario. Journal of Wildlife Management, 71, 1249-1256.

Wasser, S.K., Keim, J.L., Taper, M.L. & Lele, S.R. (2011) The influences of wolf predation, habitat loss, and human activity on caribou and moose in the Alberta oil sands. Frontiers in Ecology and the Environment, 110621062742041.

Webb, N. F., Hebblewhite, M. & Merrill, E. H. (2008) Statistical methods for identifying wolf kill sites using global positioning system locations. Journal of Wildlife Management, 72, 798–807.

Wittmer, H.U., Sinclair, A.R.E., &McLellan, B.N. (2005a) The role of predation in the decline and extirpation of woodland caribou. Ecology, 144, 257-267.

Wittmer, H.U., McLellan, B.N., Seip, D.R., Young, J.A., Kinley, T.A., Watts, G.S. & Hamilton, D. (2005b) Population dynamics of the endangered mountain ecotype of woodland caribou (*Rangifer tarandus caribou*) in British Columbia , Canada. Canadian Journal of Zoology, 83, 407-418.

Wittemyer, G., Polansky, L., Douglas-Hamilton, I. & Getz, W.M. (2008) Disentangling the effects of forage, social rank, and risk on movement autocorrelation of elephants using Fourier and wavelet analyses. Proceedings of the National Academy of Sciences of the United States of America, 105, 19108-13.

Appendix A: Details of caribou GPS-telemetry data obtained from the Government of Alberta

GPS-telemetry data by individual adult female caribou

Individual ID	Population	Start Date	End Date	# steps	# summer steps	# winter steps
138	WSAR	22/02/1998	01/02/2000	5,781	2,354	3,427
139	WSAR	22/02/1998	01/02/2000	5,366	2,141	3,225
140	WSAR	22/02/1998	01/02/2000	6,288	2,811	3,477
141	WSAR	22/02/1998	11/09/1998	2,520	1,598	922
143	WSAR	22/02/1998	23/07/1999	5,099	2,541	2,558
144	WSAR	22/02/1998	01/02/2000	6,127	2,644	3,484
145	WSAR	22/02/1998	24/09/1998	2,522	1,607	915
146	WSAR	21/01/1999	01/02/2000	3,556	1,330	2,226
147	WSAR	22/02/1998	19/12/1999	6,026	3,142	2,884
148	WSAR	22/02/1998	01/02/2000	6,490	2,945	3,545
149	WSAR	22/02/1998	01/02/2000	6,173	2,991	3,182
150	WSAR	22/02/1998	05/09/1998	2,523	1,603	920
151	WSAR	22/02/1998	22/06/1998	1,369	449	920
152	WSAR	22/02/1998	31/01/2000	6,218	2,974	3,244
153	WSAR	22/02/1998	09/09/1999	2,843	1,230	1,613
154	WSAR	22/02/1998	12/08/1998	1,655	777	878
155	WSAR	22/02/1998	03/07/1998	1,480	555	925
156	WSAR	22/02/1998	31/07/1998	1,770	849	921
157	WSAR	22/02/1998	22/11/1998	2,531	1,411	1,120
158	WSAR	22/02/1998	20/05/1998	985	71	914
159	WSAR	22/02/1998	17/01/2000	4,245	1,843	2,402
160	WSAR	22/02/1998	23/07/1998	1,171	276	895
161	WSAR	18/01/1999	21/04/1999	1,084	0	1,084
162	WSAR	18/01/1999	01/02/2000	3,560	1,313	2,247
163	WSAR	18/01/1999	01/02/2000	3,526	1,318	2,208
164	WSAR	18/01/1999	04/08/1999	2,235	881	1,354
165	WSAR	20/01/1999	26/01/2000	2,550	1,271	1,279
166	WSAR	20/01/1999	19/12/1999	2,934	1,300	1,634
167	WSAR	20/01/1999	02/09/1999	2,514	1,180	1,334
168	WSAR	20/01/1999	09/08/1999	2,279	941	1,338
169	WSAR	21/01/1999	25/06/1999	1,441	383	1,058
170	ESAR	21/01/1999	01/02/2000	3,541	1,310	2,231
171	WSAR	21/01/1999	26/04/1999	1,101	0	1,101
172	WSAR	22/01/1999	29/06/1999	1,765	454	1,311
173	WSAR	22/02/1998	20/12/1998	2,940	1,658	1,282
174	WSAR	22/02/1998	28/12/1998	3,040	1,641	1,399
1089	Little Smoky	12/02/2009	19/12/2010	3,658	1,415	2,243
1090	Little Smoky	24/01/2007	29/12/2007	3,745	1,444	2,301
1092	Little Smoky	26/01/2007	08/08/2008	6,403	2,505	3,898
1224	Chinchaga	12/01/2008	15/11/2010	8,990	3,647	5,344

1225	Chinchaga	12/01/2008	09/03/2010	9,266	3,247	6,019
1226	Chinchaga	12/01/2008	09/03/2010	9,191	3,186	6,005
1227	Chinchaga	12/01/2008	01/05/2008	1,309	0	1,309
1228	Chinchaga	12/01/2008	09/03/2010	9,230	3,219	6,011
1229	Chinchaga	12/01/2008	12/11/2010	12,118	4,877	7,241
1230	Chinchaga	12/01/2008	09/03/2010	9,216	3,209	6,007
1231	Chinchaga	12/01/2008	14/04/2008	1,108	0	1,108
1232	Chinchaga	10/01/2008	11/04/2008	1,089	0	1,089
1233	Chinchaga	10/01/2008	12/11/2010	12,187	4,854	7,333
1234	Chinchaga	06/04/2007	19/01/2009	7,195	2,945	4,250
1235	Chinchaga	22/03/2007	11/05/2008	3,036	1,046	1,990
1236	Chinchaga	06/04/2007	08/07/2008	5,420	2,259	3,161
1237	Chinchaga	22/03/2007	23/08/2007	1,825	1,197	628
1238	Chinchaga	22/03/2007	01/08/2007	1,565	934	631
1240	Nipisi	15/01/2008	14/02/2010	8,987	3,258	5,729
1416	Richardson	11/03/2008	14/09/2008	1,095	716	379
1420	ESAR	16/03/2008	26/04/2008	242	0	242
1484	Richardson	12/01/2009	28/02/2011	4,567	1,608	2,959
1485	Richardson	12/01/2009	18/01/2011	4,402	1,662	2,741
1486	Richardson	12/01/2009	19/12/2010	4,045	1,510	2,535
1488	Richardson	12/01/2009	23/11/2010	4,005	1,618	2,387
1489	Richardson	12/01/2009	20/01/2011	4,305	1,615	2,690
1490	Richardson	12/01/2009	18/01/2011	4,358	1,649	2,709
1491	Richardson	12/01/2009	10/03/2009	338	0	338
1492	Richardson	12/01/2009	23/11/2010	4,033	1,644	2,389
1493	Richardson	12/01/2009	29/08/2009	1,290	570	720
1494	Richardson	12/01/2009	18/01/2011	4,285	1,591	2,694
1495	Richardson	12/01/2009	25/06/2010	3,154	1,069	2,085
1504	ESAR	14/01/2009	17/01/2011	4,214	1,538	2,676
1505	ESAR	14/01/2009	24/11/2010	3,891	1,517	2,375
1506	ESAR	13/01/2009	08/08/2010	3,399	1,329	2,070
1507	ESAR	21/01/2009	24/11/2010	3,972	1,618	2,354
1509	ESAR	13/01/2009	24/11/2010	4,014	1,620	2,394
1520	Chinchaga	17/02/2009	20/02/2011	8,199	3,061	5,138
1521	Chinchaga	17/02/2009	17/04/2010	4,913	1,632	3,281
1522	Chinchaga	17/02/2009	20/02/2011	8,481	3,227	5,254
1523	Chinchaga	05/06/2009	15/11/2010	6,103	2,950	3,153
1524	Little Smoky	12/02/2009	07/08/2009	966	459	507
1629	Richardson	06/03/2010	23/11/2010	1,029	374	655
1630	Richardson	06/03/2010	23/11/2010	1,536	806	730
1744	Red Earth	01/03/2011	12/05/2011	862	0	862
1745	Red Earth	01/03/2011	29/03/2011	341	0	341
1746	Red Earth	01/03/2011	05/03/2011	49	0	49
1747	Red Earth	01/03/2011	03/04/2011	400	0	400
1748	Red Earth	01/03/2011	05/03/2011	55	0	55
1749	Red Earth	01/03/2011	14/04/2011	535	0	535
1750	Red Earth	01/03/2011	13/05/2011	876	0	876
1752	Red Earth	01/03/2011	13/05/2011	872	0	872
1753	Red Earth	01/03/2011	11/05/2011	840	0	840

GPS-telemetry data by year

Year	Population	Number of Individuals
1998+	WSAR	23
1999+	WSAR, ESAR	25
2000*+	WSAR, ESAR	13
2007	Chinchaga**	5
	Little Smoky	2
2008	Chinchaga	13
	ESAR	1
	Little Smoky	1
	Nipisi	1
	Richardson**	1
2009	Chinchaga	12
	ESAR	5
	Little Smoky	2
	Nipisi	1
	Richardson	11
2010	Chinchaga	11
	ESAR	5
	Little Smoky	1
	Nipisi	1
	Richardson	11
2011	Chinchaga	2
	ESAR	1
	Red Earth	9
	Richardson	5

GPS-telemetry data by herd

Population	Years
WSAR	1998, 1999, 2000
Chinchaga**	2007,2008,2009,2010,2011
Little Smoky	2007,2008,2009,2010
ESAR	1999, 2000, 2008,2009,2010,2011
Nipisi	2008,2009,2010
Richardson**	2008,2009,2010,2011
Red Earth	2011

** Limited to early winter only*

*** Some data from the "border" populations may be lost if animal spends time in B.C. or Saskatchewan*

+ This data from Dyer et al. 2001, 2002 work.

NOTE: Does not include "proprietary" data. Potentially data from Slave Lake, Nipisi and Bistcho to come; more records from LS and Chin potentially to come too.

Appendix B: Proposed habitat/footprint Covariates to analyzed in step selection function analysis

Covariate (Hypothesized relationship)	Reference from Literature	Metric	GIS Data Source (Year)
Habitat Covariates			
Terrain ruggedness (Avoid rugged)	Wasser et al. 2011	Mean along step	Sappington et al. 2007 terrain ruggedness index derived from digital elevation model (DEM)
Elevation	N/A	Mean along step	From DEM
Wetland (Select)	Bradshaw et al. 1995; Stuart-Smith et al. 1997; Rettie and Messier 2000; McLoughlin et al. 2005; Wasser et al. 2011	Start/end point Mean (Proportion)	AGCC – reclass all wetland, riparian, wet and black spruce types ABMI w2w(Guillermo) – reclass wetland types (80-83) AVI –ABMI reclass wetland classes (9001, 9002, 9003, 9004, 9010, 9011)
Forest (Select/Avoid)	Fuller and Keith 1981; Rettie and Messier 2000; Wasser et al. 2011	Start/end point Mean (Proportion)	AGCC – reclass all closed and open forest types ABMI w2w(Guillermo) – reclass forest types AVI – ABMI reclass Forest Classes (Canopy Cover >6%)
Closed Forest (Select/Avoid)	Fuller and Keith 1981; Rettie and Messier 2000; Wasser et al. 2011	Start/end point Mean (Proportion)	AGCC – reclass all closed forest types ABMI w2w(Guillermo) – reclass closed forest types AVI – ABMI reclass Closed Forest Classes (Canopy Cover >50%)

Covariate (Hypothesized relationship)	Reference from Literature	Metric	GIS Data Source (Year)
Conifer forest (Select)	Fuller and Keith 1981; Stuart Smith et al. 1997; Rettie and Messier 2000; Dzus 2001; Johnson et al. 2002; Apps and Mclellan 2006; Courbin et al. 2008; Fortin et al. 2009; Wasser et al. 2011	Start/end point Mean (Proportion)	AGCC – reclass all conifer forest types ABMI w2w(Guillermo) – reclass conifer forest types AVI – ABMI Coniferous Dominated Forest Classes (Canopy Cover >6%, >80% of stand is conifer)
Mixed/deciduous forest (Avoid)	Fuller and Keith 1981; Rettie and Messier 2000; Courbin et al. 2009; Fortin et al. 2008	Start/end point Mean (Proportion)	AGCC – reclass all mixed/deciduous forest types ABMI w2w(Guillermo) – reclass mixed/deciduous forest types AVI – ABMI Deciduous and Mixed-Wood Dominated Forest Classes (<80% of stand is conifer)
Closed Conifer Forest (Select)		Start/end point Mean (Proportion)	AVI ONLY - ABMI Closed (Canopy Cover >50%) Coniferous Dominated (>80% of stand) Forest Classes ABMI w2w(Guillermo) – reclass closed conifer forest types
Mature Conifer Forest (Select)	Fuller and Keith 1981; Stuart Smith et al. 1997; Rettie and Messier 2000; Dzus 2001; Johnson et al. 2002; Apps and Mclellan 2006; Courbin et al. 2009; Fortin et al. 2008; Wasser et al. 2011	Start/end point Mean (Proportion)	AVI ONLY - ABMI >80 Years Old Coniferous Dominated (>80% of stand) Forest Classes

Covariate (Hypothesized relationship)	Reference from Literature	Metric	GIS Data Source (Year)
Mature Closed Conifer Forest (Select)		Start/end point Mean (Proportion)	AVI ONLY - ABMI >80 Years Old Closed (Canopy Cover >50%) Coniferous Dominated (>80% of stand) Forest Classes
Recent fire (Avoid)	Sorensen et al. 2008 (≤50 yrs); Fortin et al. 2008; Wasser et al. 2011 (<40 yrs)	Start/end point Mean (Proportion)	ASRD Historical fire data: reclass by year of fire (≤50 yrs; for 1998, 1999, 2000, 2007, etc.)
Footprint Covariates			
Distance to paved road (Avoid)	James and Stuart-Smith 2000; Fortin et al. 2008; Wasser et al. 2011	Avg. along step Cross yes/no	ABMI 2010 base layers; reclass by year using capture date as cut-off; however, this may not be accurate pre-2000 data looks suspect, as some roads that are there based on valtus are not digitized – looks like major update in entering data in ~2000

Covariate (Hypothesized relationship)	Reference from Literature	Metric	GIS Data Source (Year)
Distance to unpaved road (Select/Avoid)	James and Stuart-Smith 2000; Dyer et al. 2002; Fortin et al. 2008; Wasser et al. 2011	Avg. along step Cross yes/no	ABMI 2010 base layers; reclass by year using capture date as cut-off; however, this may not be accurate pre-2007 data looks suspect, as some roads that are there based on valtus are not digitized– looks like major update in entering data in ~2000
Distance to pipeline (Select/Avoid)	Dyer et al. 2001; Wasser et al. 2011	Avg. along step Cross yes/no	ABMI 2010 base layers; reclass by year using capture date as cut-off; however, this may not be accurate pre-2007 data looks suspect, as some roads that are there based on valtus are not digitized– looks like major update in entering data in ~2000
Distance to seismic line (Select/Avoid)	Dyer et al. 2001; Wasser et al. 2011	Avg. along step Cross yes/no	ABMI 2010 base layers; reclass by year using capture date as cut-off; however, this may not be accurate pre-2007 data looks suspect, as some roads that are there based on valtus are not digitized– looks like major update in entering data in ~2000
Distance to human settlement (Avoid)	Apps and Mclellan 2006	Avg. along step	ABMI HF_V2; Distance to urban[1101]/rural[1102]/high density heavy industry[1204] feature (2007) *2010 base layers?* *Dyer ~2000??*

Covariate (Hypothesized relationship)	**Reference from Literature**	**Metric**	**GIS Data Source (Year)**
Distance to cutblock (Avoid)	Courbin et al. 2009	Avg. along step	ABMI HF_V2; Distance to managed forest[3000] (2007) ABMI Crown Cutblock (2010) *Not time stamped, so problem with year*
Distance to wellsite (Avoid)	Dyer et al. 2001	Avg. along step	ABMI HF_V2; Distance to low density heavy industry[1205] feature Reclass by age , But to 2007 only
Interaction and Other Covariates			
Distance to road x Distance to human settlement (Avoid)	Dyer et al. 2001; Wasser et al. 2011	Avg. along step	
Step distance	Forester et al. 2009	N/A	

Appendix C. Candidate models used to investigate the relationship between caribou movement and habitat and anthropogenic footprint.

Model	Sub-model	Covariates	Covariate Names
Human	All Human	distance to well, distance to unpaved road, distance to settlement, distance to cutblock	dwell10lwm, duprd10lw, dcublkmin, dsettlemax,
	Human - Simple	distance to nearest human activity	dhuman10_minlwm
	Human - Oil	distance to well, distance to unpaved road, distance to well x distance to unpaved road	dwell10lwm, duprd10lwm, upvrdxwellmin10
	Human - Forestry	distance to unpaved road, distance to cutblock, distance to unpaved road x distance to cutblock	dcutblkmin, duprd10lwm, upvrdxctblkmin10
	Human - Activity	distance to unpaved road, distance to settlement, distance to settlement x distance to unpaved road	dsettlemax, duprd10lwm, upvrdxsettlemin10
Habitat	AGCC Habitat	elevation, conifer forest, mixed deciduous forest, wetland, aspect, terrain ruggedness, fire	elevEND, fire10END, tri_sapLWM, agcnfrV1, agcnfrend, agwtldV1, agwtldEND, agmdfrv1,agmdfrend
	ABMI Habtiat	elevation,terrain ruggedness, fire, closed conifer forest, mixed deciduous forest, forest	elevEND, fire10END, tri_sapLWM, abccfrV1, abccfrend, abmdfrV1, abmdfrend, abfrstV1, abfrstEND
	AVI Habitat	elevation, terrain ruggedness, fire, mature conifer forest, forest (end only), conifer forest, mixed deciduous forest	elevEND, fire10END, tri_sapLWM, avmcfrV1, avmcfrEND, avfrEND, avcnfrV1, avcnfrEND, avmdfrV1, avmdfrEND
	Terrain only	elevation terrain ruggedness	elevEND, tri_sapLWM
	Fire only	fire	fire10END
	Fire + Terrain	elevation terrain ruggedness, fire	elevEND, tri_sapLWM,fire10END

Appendix D. Covariates considered in the step selection function analysis that were removed because of high Spearman correlations(r>0.7).

- Elevation covariates correlated with each other – retained the elevation at the end of the step as most correlated with "used" steps
- Fire in 2009 and 2010 are completed correlated, and all fire covariates are correlated – retained 2010 fire at the end of the step as most correlated with "used" steps
- Terrain ruggedness lwm, max and end are correlated – retained tri_saplwm
- AGGC forest and AGCC coniferous forest proportion, beginning and end are highly correlated- retained coniferous forest proportion, beginning and end as most correlated with "used" steps
- AGCC proportion of and beginning peatland and wetland are highly correlated- retained wetland as most correlated with "used" steps
- ABMI wetland, closed coniferous forest and closed forest proportion, beginning and end are highly correlated - retained closed coniferous forest as most correlated with "used" steps
- AVI proportion of mixed deciduous forest and closed forest are highly correlated – retained mixed deciduous forest
- AVI proportion of mature conifer forest and mature closed conifer forest are highly correlated – retained mature conifer forest
- AVI proportion, beginning and end forest are highly correlated – retained end forest
- AVI proportion of conifer forest, and closed conifer forest are highly correlated – retained conifer forest
- AVI conifer forest and closed forest at beginning are highly correlated – retained conifer forest
- 2010 distance to well lwm, beg, end, min, max are highly correlated – retained dwell10lwm
- 2010 distance to well (all) and distance to pipeline (all) are highly correlated – retained dwell10lwm
- 2010 distance to well (all) and distance to paved road (all) are highly correlated – retained dwell10lwm
- 2010 distance to unpaved road lwm, beg, end, min, max are highly correlated – retained duprd10lwm
- Paved roads 2007 to 2010 are highly correlated – retain 2010 paved road
- 2010 and 2009 unpaved roads are highly correlated - retain 2010 unpaved road
- Pipelines 2007 to 2010 are highly correlated – retain 2010 pipelines
- 2010 and 2000 wellsites are highly correlated – retain 2010 data
- 2009 to 2007 seismic linear are correlated – retain 2009 seismic
- 2009 sesismic and 2010 well are correlated – retain distance to well
- Distance to cutblock lwm, min, max, beg, end correlated – retain min
- Distance to settlement lwm, min, max, beg, end correlated – retain max
- Distance to well, cutblock and settlement are correlated – retain well for all human and oil, retain cutblock for forestry and retain settlement for human activity

Assessing the Influence of Above-Ground Pipelines and Associated Linear Features on Caribou (*Rangifer tarandus*) in the Lower Athabasca Planning Region of Alberta

INTERIM REPORT

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Ecological Monitoring Committee
for the Lower Athabasca Planning Region

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EXECUTIVE SUMMARY

There is increasing concern about the influence of ongoing human activities on biodiversity and wildlife in northeastern Alberta. The Ecological Monitoring Committee for the Lower Athabasca (EMCLA) was established in 2010 to improving the quality of monitoring that takes place to fulfill wildlife and biodiversity clauses in project approvals. The EMCLA initiated this boreal caribou range fragmentation project to address uncertainty over the effects of above-ground pipelines and associated linear features on ungulate movement relative to other human and natural factors, and the extent to which linear features may affect caribou populations. This interim report provides conclusions on our current state of knowledge based on the preliminary literature review and professional judgment of expert participants who attended a workshop convened in May 2011.

A network of above-ground pipelines and associated linear features (i.e., roads and powerlines) are required for bitumen production within in-situ development areas. The width and height of above-ground pipelines can represent a complete or partial barrier to medium to large animals. In addition, pipeline barrier effects can be compounded by the presence of nearby or parallel roads. Crossing structures or sections of elevated pipeline are provided to allow animals to cross, and successful caribou crossings at both crossing ramps and elevated sections have been documented in the Lower Athabasca region.

The first objective of the caribou range fragmentation project commissioned by the Ecological Monitoring Committee for the Lower Athabasca region was to review and summarize the current state-of-knowledge regarding the influence of above-ground pipelines and associated linear features on caribou movement in the Lower Athabasca Planning Region. A simplified Impact hypothesis diagrams (IHD) was developed for this project (Figure E-1) to help visualize and understand the complex relationships that link linear features with caribou population dynamics and to provide a rigorous and transparent way to evaluate these cause-effect linkages. Recent syntheses suggest that the population-level effects of human habitat alteration and disturbance on caribou and reindeer are not clear, although woodland caribou local population growth appears to be inversely related to total disturbed footprint.

Six key linkages were identified and discussed:

1. Above-ground pipelines affect caribou movement.
2. Roads affect caribou movement and distribution.
3. Changes to movement patterns alter individual energy reserves which affects population dynamics (survival and reproduction).
4. Changes to movement patterns and distribution alter predation rates.
5. Changes in distribution and movement alter meta-population interchange frequency and rates.
6. Changes in survival, reproduction, and local population size affect population growth rate.

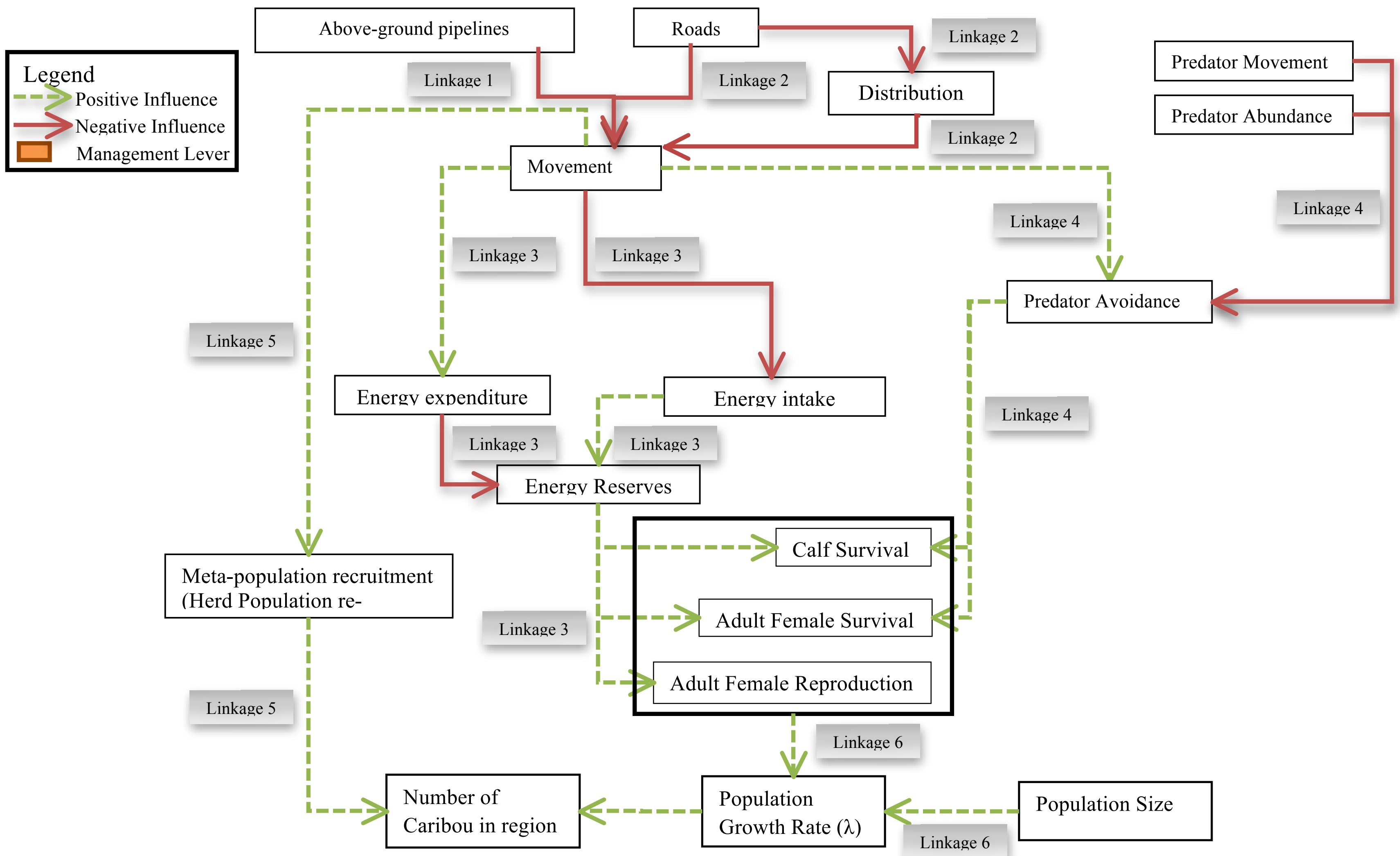

Figure E-1. Impact Hypothesis Diagram showing linkages between linear features, other factors, and caribou population growth

These linkages were concluded to be valid. Although above-ground pipelines and associated linear corridors are known to affect caribou movement, no scientific consensus exists about the relative influence of altered movement on caribou population growth, and there is little data specific to the Lower Athabasca region or woodland caribou. In contrast, there is scientific consensus that predation risk has been elevated by combined human and natural disturbance, that population growth is inversely related to combined disturbance, and that increased predation is the proximate cause of observed declines in boreal caribou populations.

Workshop participants reached consensus based on current evidence from the literature and study area (described in report Section 2), as well as their experience and professional judgment (summarized in report Section 3), that the overall effect of above-ground pipelines and associated roads on caribou is small relative to predation at current levels of development (roughly 400 km of above ground pipelines in total).

They also concluded that it is unreasonable to expect to tease out the influence of individual footprint types (i.e., above-ground pipelines, roads, facilities) because of: 1) confounding factors; 2) small sample size from existing monitoring programs; and 3) cost of a directed research and monitoring program that would require extensive long-term monitoring of individual caribou (e.g., using Global Position System telemetry devices – see Walsh *et al.* 1995). Further work to finalize a detailed literature review (as stipulated in the original project scope of work) was therefore determined to be unnecessary.

Finally, workshop participants also agreed that further work should focus on caribou distribution at the range scale (i.e., change focus from animal movement to range fragmentation). The following logic was applied:

- it can be assumed that individual in-situ projects represent complete barriers to caribou movement because of the intensity of development and human activity during construction and operations and because it is unreasonable to expect to tease out the influence of individual infrastructure (footprint) types because of confounding factors, small sample size and cost. Evaluating and monitoring at the scale of entire developments (i.e., intensive development areas) is therefore most appropriate;
- while the direct effect of above-ground pipelines and associated linear features may be comparatively small, they contribute to cumulative effects on caribou populations, so management of all activities at the range scale is still required;
- a reasonable alternative approach might be to stop mitigation in intensive development areas and instead, set aside no development areas or undertake more intensive mitigation in corridors that will maintain range-scale movement opportunities for caribou; and
- additional analyses on caribou movement patterns and information on future development scenarios will be required to evaluate the potential feasibility and benefits of this alternative approach.

There was general agreement to revise the original 2011 project work scope to obtain and analyze available GPS monitoring data to evaluate caribou movements relative to habitat and land use variables.

ACKNOWLEDGMENTS

This interim report reflects the combined efforts of a knowledgeable and enthusiastic team. The authors would like to thank the Ecological Monitoring Committee for the Lower Athabasca (EMCLA), in particular project sponsors Paul MacMahon (Alberta Sustainable Resources Development) and Tyler Colberg (Imperial Oil Ltd.), for initiating and directing this project. Susanne Cote (EMCLA Coordinator) and Dr. Dan Farr (Alberta Biodiversity Monitoring Institute) provided logistical and project management support to keep the project on track despite a major change in focus early on. Dr. Jason Fisher (Alberta Innovates Technology Futures) and Dr. Cole Burton (Alberta Biodiversity Monitoring Institute) provided thoughtful advice and comments that have substantially improved this report and the project approach. Technical advisors Dr. Stan Boutin (University of Alberta and Alberta Biodiversity Monitoring Institute), Dave Hervieux (Alberta Sustainable Resources Development), and Dr. Elston Dzus (Alberta-Pacific Forest Industries) challenged the team to focus on work that would significantly increase the amount of credible scientific information available to support sound environmental management. Finally, and most importantly, the authors would like to thank the following participants of the May 12 technical workshop who volunteered their experience and expertise:

Paula Bentham, Golder Associates Ltd. (Golder)
Dr. Stan Boutin, U of A/ Alberta Biodiversity Monitoring Institute (ABMI)
Dr. Cole Burton, ABMI
Dr. Tyler Colberg, Imperial Oil Ltd./EMCLA
Susanne Cote, ABMI/EMCLA
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Dave Hervieux, Alberta Sustainable Resource Development (ASRD)
Paul MacMahon, ASRD/EMCLA
Amit Saxena, Devon Canada Corp.

Dr. Tyler Muhly developed the impact hypothesis material included in Section 2 with input from Dr. Jason Fisher and Dr. Cole Burton. Terry Antoniuk coordinated the technical workshop described in Section 3 and consolidated available information in interim report format.

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GLOSSARY

Criteria: a series of questions used to provide a consistent evaluation of the significance of an individual linkage or overall impact hypothesis.

Impact hypothesis diagram: a set of linkages that describe and help visualize the cause-effect relationships between development activities and species or indicators of social, cultural, or management interest (LGL et al. 1986).

Linkage: the cause-effect relationship between a natural process or human activity (including development infrastructure and disturbance) and a biological response.

Local Population: a group of interacting individuals of the same species in a defined area distinguished by a distinct gene pool, distinct physical characteristics, or distinct habitat use. The local population is the designated management unit for boreal caribou in Canada (EC 2011). In this report, local population and range are used interchangeably.

Monitoring: a test of an impact hypothesis designed to: 1) measure environmental effects; 2) analyze cause-effect relationships; or 3) provide feedback on the success of impact management measures. As defined here, it is a scientific process designed to test specific hypotheses or linkages on the cause of environmental effects and how they are expressed in the environment (LGL et al. 1986).

Range: in Alberta, individual caribou within a given range generally have no, or infrequent, interaction with caribou in other ranges (ASRD 2005). The Lower Athabasca planning area includes three ranges: Richardson, East Side Athabasca River (ESAR), and Cold Lake Air Weapons Range – Alberta (CLAWR). These ranges were defined by ASRD? using both habitat mapping and telemetry data. In this report, range and local population are used interchangeably.

ACRONYMS

ABMI	Alberta Biodiversity Monitoring Institute
AITF	Alberta Innovates Technology Futures
ASRD	Alberta Sustainable Resource Development
EMCLA	Ecological Monitoring Committee for the Lower Athabasca
GOA	Government of Alberta
IHD	Impact Hypothesis Diagram
SAGD	Steam Assisted Gravity Drainage
UofA	University of Alberta

1. INTRODUCTION

There is increasing concern about the influence of ongoing human activities on biodiversity and wildlife in northeastern Alberta (GOA 2011). Oil sands operators have a regulatory responsibility to monitor biodiversity and effects on wildlife species of management concern. While industry has expended much effort to date, the value of the monitoring program designs and efforts of individual companies would be enhanced by greater coordination, enabling regional- or provincial-scale adaptive resource management. The Ecological Monitoring Committee for the Lower Athabasca (EMCLA) was established in 2010 to improving the quality of monitoring that takes place to fulfill wildlife and biodiversity clauses in *Environmental Protection and Enhancement Act* approvals for oil sands developments. EMCLA's goal is to move beyond the current focus on individual development projects to the design and implementation of a coordinated, integrated regional biodiversity and wildlife monitoring program that is effective, efficient, credible, and standardized both regionally and provincially. This monitoring program will provide better information for resource management by improving knowledge of the status and trends of species, the effects of human activities, and the success of mitigation efforts. The EMCLA is composed of representatives from the hydrocarbon industry and the provincial and federal government, with scientific and administrative support provided by the Alberta Biodiversity Monitoring Institute (ABMI).

The EMCLA identified three priorities for 2011 (year 1) activities. These involve consolidating existing data to: 1) design a rare plant monitoring program; 2) design a rare animal monitoring program; and 3) assess the influence of habitat fragmentation caused by industrial activities, particularly above-ground pipelines and associated linear features, on caribou (*Rangifer tarandus*) movement and distribution.

1.1 CARIBOU RANGE FRAGMENTATION PROJECT

This report addresses priority 3: caribou movement and distribution (hereafter referred to as caribou range fragmentation). Approval conditions for in-situ bitumen projects require monitoring of caribou movement patterns and mitigating for the influence of above-ground pipelines on movement. However, there is uncertainty over the effects of linear features on ungulate movement relative to other human and natural factors, and the extent to which linear features may affect caribou populations. The EMCLA therefore initiated the range fragmentation project with the following objectives:

1. Review and summarize the current state-of-knowledge regarding the influence of linear features on caribou movement in the Lower Athabasca Planning Region. This will also consider:
   a) Other types of human activities (e.g., forest harvesting, hunting, and recreation) and natural factors (e.g., predators, climate and habitat) that may also be affecting movement.

    b) The relationship between movement and local population dynamics.

2. Identify and where possible compile existing datasets that could be used to identify current caribou movement patterns in the Lower Athabasca Planning Region in relation to linear features, as well as other man-made and natural factors.
3. Provide recommendations for research and monitoring initiatives to be implemented in 2012 that will provide information on the influence of linear features on caribou movements, relative to other factors.
    a) For example, assess the feasibility of monitoring caribou movement in areas characterized by different densities of linear features (i.e., areas with minimal compared to high densities of development).

1.2 REPORT OUTLINE

This document presents conclusions for the current state-of-knowledge about the influence of linear features on caribou movement (objective 1). A preliminary review of relevant literature is provided in Section 2. Section 3 provides conclusions of a technical workshop held in May 2011 to discuss the literature-based state-of-knowledge. It also describes recommended modifications to project objectives including emphasizing data collation and analysis of caribou movement metrics. Section 4 provides conclusions on our current state of knowledge based on the preliminary literature review and professional judgment of workshop participants.

2. INFLUENCE OF LINEAR FEATURES ON CARIBOU MOVEMENT

2.1 LINEAR FEATURES FOR IN-SITU BITUMEN PRODUCTION

Much of the commercial bitumen reserve in northeastern Alberta can only be recovered through in-situ operations. In-situ Steam Assisted Gravity Drainage (SAGD) and Cyclic Steam Stimulation (CSS) operations require the use of pipelines to carry steam to the well, which is then pumped into the ground to melt the bitumen. The liquefied bitumen is then pumped back to a central facility for processing. Each SAGD well usually requires road access, electrical power, and pipelines for: steam; steam produced emulsion (i.e., oil and water); produced vapours; and fuel gas. The steam pipeline remains warm year round and expands and contracts as the temperature changes, so burying this line for long stretches is not feasible, and above-ground pipelines are constructed between wells. This creates a network of above-ground pipelines and associated linear features (i.e., roads and powerlines) within SAGD in-situ development areas (Golder 2004; Figure 1).

Figure 1. Aerial view of an in-situ bitumen project showing well, facility, and linear corridor network.

Average above-ground pipeline height is approximately 1.0 m (range 0.3 to 2.2 m) to the bottom of the pipe. In some developments, up to five 34- to 50-cm diameter pipelines are bundled together on supported racks, with combined pipeline widths averaging 1.8 m (range 0.3 to 6.0 m) (Golder 2004; Figure 2). As described in more detail below, the width and height of these structures could therefore represent a complete or partial barrier to medium to large animals. In addition, pipeline barrier effects can be compounded by the presence of nearby or parallel roads (Murphy and Curatolo 1987).

Figure 2. Typical aboveground in-situ pipeline in northeast Alberta.

Golder (2004) discusses the designs that have been used to mitigate impacts on movement. In most cases, crossing structures (Figure 3) or sections of elevated pipeline are provided to allow animals to cross. Successful caribou crossings at both crossing ramps and elevated sections have been documented (Golder 2004).

Figure 3. Culvert crossing strucuture in northeast Alberta.

2.2 IMPACT HYPOTHESIS

Impact hypothesis diagrams (IHD) are used to help visualize and understand complex systems or relationships. By providing a rigorous and transparent way to evaluate cause-effect linkages, they establish a foundation for monitoring program design and adaptive management (LGL *et al.* 1986). The IHD relating linear features to caribou population response is provided in Figure 4.

Woodland caribou (boreal and mountain ecotypes), barren-ground caribou, and reindeer are considered to be the same species, although their life history and ecological context differs. Research on woodland (boreal) caribou in northeast Alberta has not been completed for all linkages, so relevant information for barren-ground caribou and reindeer is included in the discussion of each linkage below. Managers and researchers must be cautious about applying research and monitoring results for barren-ground caribou and reindeer to woodland caribou (Festa-Bianchet *et al.* 2011), so the relevant subspecies/ecotype is noted below for specific research and monitoring conclusions.

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Lower Athabasca Caribou Range Fragmentation

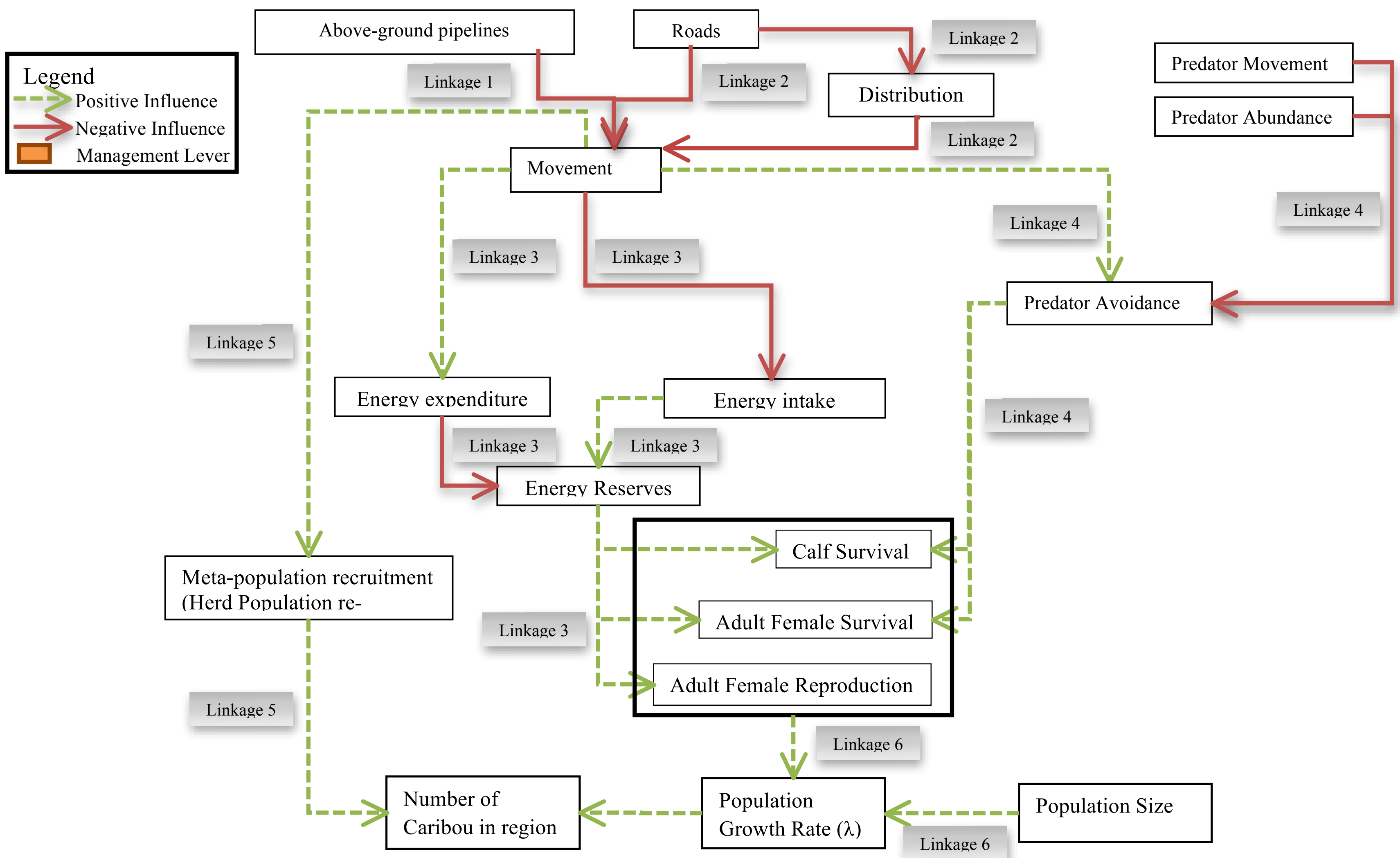

Figure 4. Impact hypothesis diagram (IHD) indicating key linkages between the influence of above-ground pipelines and

Recent syntheses (Wolfe *et al.* 2000) suggest that the population-level effects of anthropogenic disturbance on caribou and reindeer are not clear, although woodland caribou local population growth appears to be inversely related to total disturbed footprint (Vors *et al.* 2007; Environment Canada 2008; Sorensen *et al.* 2008; Schneider *et al.* 2010; Environment Canada 2011). The influence of anthropogenic footprint (including above-ground pipelines and roads) on caribou energetics, fitness, reproduction and survival has been identified as a major gap in caribou research (NCASI 2007; Festa-Bianchet *et al.* 2011).

2.2.1 Linkage 1: Above-ground pipelines affect caribou movement

Absolute barrier

Although the influence of above-ground pipelines on barren-ground caribou in northern Alaska has received much research interest, no research has specifically investigated woodland caribou movement relative to above-ground pipelines. However, evidence and knowledge of caribou movement ecology suggests that certain configurations of above-ground pipelines (i.e., multiple parallel pipelines as shown in Figure 2) may create blockages whereas others are unlikely to block woodland caribou movements (i.e., pipelines raised high above stream valleys). Disentangling the contribution of various types of above-ground pipelines and associated linear features on caribou movement is complex because of many confounding factors that influence both local movements and range-scale distribution.

Above-ground pipelines that are not raised may present an absolute barrier to caribou movement, as the pipeline structure averages 1.8 m in width (Golder 2004; Dunne and Quinn 2008), although there is a high degree of variability (from 0.3 m to 6 m; Golder 2004). No research was located indicating the maximum width of a pipeline over which a caribou will not cross, or the minimum height above the ground under which a caribou will not pass below a pipeline. Barren-ground caribou are physically able to cross underneath pipelines with an above- ground height of 1.5 m to the bottom of the pipe (Smith and Cameron 1985; Curatolo and Murphy 1986), although other factors described below affect short-term crossing success and longer-term permeability to movement.

Semi-permeable barrier (filter)

Overview

Crossing structures that facilitate caribou movement over the top of above-ground pipelines are a possible mitigation to above-ground pipeline barriers. Specific questions related to technical aspects of how to best mitigate for above-ground pipelines to allow for caribou movement (e.g., minimum height necessary for crossing, crossing structures vs. raised pipelines) are being addressed by a group of scientists working with the Canadian Association of Petroleum Producers (CAPP; Tyler Colberg, Imperial Oil Ltd., pers. comm.).

Raising or building crossing structures over the top of above-ground pipelines has been shown to create some permeability for caribou movement. However, there appears to be a high degree of variability in the permeability of raised above-ground pipelines to barren-ground caribou movement, especially when factors such as herd size, age, season, and sex structure are considered (Wolfe *et al.* 2000). For example, Smith and Cameron (1985) found it took ≥26 attempts for ≥46% of two large (≥655) insect-harassed caribou herds in Alaska to cross a pipeline that was ≥1.5 m above-ground and closely paralleled an active road. Some of the caribou that did not cross the pipeline trotted or ran parallel to the pipeline for 32 km (Smith and Cameron 1985). Similarly in Alaska, Fancy (1983) found that of 99 groups of caribou that approached within 500 m of a road, pipeline (all pipelines were ≥2.0m in height) or well pad, 71% crossed, 19% detoured and 10% reversed direction. Other research in Alaska found that most caribou successfully crossed underneath pipelines raised to ≥1.5 m (Curatolo and Murphy 1986) and ≥1.8 m in height (Carruthers and Jakimchuk 1987). However, in all of these barren-ground caribou studies, sampling design was not sufficiently robust to account for all potentially confounding influences, nor to provide information on energetic or population-scale implications.

There has been no test of whether partially restricted movement impeded ecological functions requiring caribou movement across pipelines; nor is there published data from Alberta indicating whether, or to what degree, raised above-ground pipelines or crossing structures partially block caribou movement. Relevant information on crossing structures and raised pipeline segments is provided below.

Benefits of Above-Ground Pipeline Crossing Structures

There are at least two types of above-ground pipeline crossing structures used in northeast Alberta: (1) a wooden deck overpass that is 5.5 m wide and 9 m long on either side; and (2) a culvert-style overpass that is 2.5 to 3.7 m wide (Figure 3; Golder 2004). Provincial regulators recommend one crossing structure for every 200 m of above-ground pipeline (Golder 2004).

Each design's ability to increase caribou movement across above-ground pipelines has not been tested. In addition, there is no research indicating the minimum distance between crossing structures along pipelines required to facilitate caribou movement across these potential barriers. Finally, there has been no research to identify the best locations to place crossing structures (e.g., based on vegetation cover and topography), to restore altered caribou movement pathways.

There is evidence that woodland caribou use crossing structures in northeast Alberta (Golder 2004), but the degree to which crossing structures increase caribou's ability to move across above-ground pipelines relative to raised pipelines or no crossing structure appears to be unknown. A monitoring program using remote camera traps was implemented at the Suncor Firebag in-situ development site in 2004/2005 (Golder 2004). The goal was to measure what species of ungulates use crossing structures and what proportion of animals that encountered the pipeline crossed the pipeline using the structure, but no results have ever been published. Some evidence from Alaska suggests that caribou might prefer crossing above-ground pipeline at buried sections or crossing structures (ramps over the top of pipelines) rather than crossing underneath a raised pipeline, perhaps because both are less of a visual barrier than raised pipelines (Smith and

Cameron 1985; Curatolo and Murphy 1986). However, this result does not indicate whether ramps or buried sections allow or improve the passage of caribou across above-ground pipelines compared to other designed crossing types. There appear to be no published results that explicitly test this hypothesis.

Benefits of Raised Above-Ground Pipeline Sections

Raising pipelines high above the ground may prevent above-ground pipelines from acting as a barrier to caribou movement. The recommended height to prevent above-ground pipelines from blocking ungulate species movement in northeast Alberta (including moose, the tallest ungulate in the region) is 1.8 m, based on reviews of scientific publications (see Golder 2004, 2010). However, the majority of research on this issue was conducted on barren-ground caribou. As noted above, this research shows that barren-ground caribou cross underneath pipelines ≥1.5 m with variable success (Smith and Cameron 1985; Curatolo and Murphy 1986; Carruthers and Jakimchuk 1987; Wolfe *et al.* 2000). While the highest elevated sections appeared to be used most frequently for crossings, the actual benefit of raised pipeline sections could not be quantified relative to other confounding influences on crossing success.

Recent research from the Peace River region of Alberta (Dunne and Quinn 2008) suggests that raising above-ground pipelines to ≥1.8 m may be conservative for allowing caribou movement underneath them, as a pipeline height ≥1.4 m was found to be necessary to avoid blocking moose. It is plausible that optimal above-ground pipeline height could be lower for caribou, given their smaller stature (adult approximately 100-120 cm at shoulder; Parker 1981; Thomas and Gray 2002) compared to moose. This distance does not account for antler height or snow depth. No research has tested the minimum above-ground height necessary to allow unobstructed caribou movement under pipelines in northeast Alberta.

There has been no systematic documentation of the location and length of above-ground pipelines in northeast Alberta (note that above-ground and buried pipelines are not differentiated in publicly available datasets). Golder has mapped the location of pipelines that are monitored for wildlife crossings as part of regulatory approval conditions and estimates there are approximately 400 km total of above-ground pipelines in northeast Alberta (Corey De La Mare, Golder Associates Ltd., pers. comm.). Given these current conditions, above-ground pipelines likely have a minimal influence on caribou movement at the range scale. However, based on projections for development in the region (Athabasca Landscape Team 2009), the amount of pipelines (including above-ground) will increase substantially over the next 50 years (simulations using Alberta Energy data suggest that total pipeline length will increase by 400% over this period).

Conclusion

Using the linkage evaluation criteria provided in Appendix 1, this linkage is concluded to be valid, but available evidence indicates that it is unlikely to be a significant contributor to current or future population-level effects. Specific conclusions for each criteria are:

1. Validity: valid.

2. Impact Rating: negligible to low magnitude (could affect 0-1<% of Lower Athabasca region ranges); of local geographic extent (up to 500 m from right-of-way); long-term duration (>10 years or duration of project); continuous frequency (structure present for duration of production phase); and reversible effect.

3. Importance: relatively unimportant compared to effects of roads and predation.

4. Uncertainty: moderate to high.

5. Research/Monitoring Cost: high cost to confirm significance.

2.2.2 Linkage 2: Roads affect caribou movement and distribution

Overview

Roads may create a barrier to movement through their physical presence or associated human and vehicle activity. Reduced use of habitat near roads by woodland and barren-ground caribou has been consistently observed (Dau and Cameron 1986; Dyer *et al.* 2001; Oberg 2001; Weclaw and Hudson 2004; Reimers and Colman 2006; Schindler *et al.* 2006; Antoniuk et *al*. 2007; Vors *et al.* 2007; Courbin *et al.* 2009; also see Cronin *et al.* 1998 for evidence of no effect). Thus, caribou may generally avoid habitat that is proximal to roads before ever reaching the road itself. The effect of anthropogenic footprint on caribou movement distribution may be the result of several factors including habitat availability, human activity, noise, odours, and predation risk. Disentangling the influence of roads on caribou movement and distribution may therefore be exceedingly challenging; relevant research is summarized below.

Road Effects on Movement

Very high rates of traffic (≥60 vehicles/hour) on roads likely create an absolute barrier to barren-ground caribou movement (Murphy and Curatolo 1987; Wolfe *et al.* 2000). Dyer *et al.* (2002) found that roads with moderate levels of traffic (33 ± 3 vehicles/hour) can create a semi-permeable barrier to boreal caribou movement during the winter, as caribou crossed roads almost 6 times less frequently than expected.

There is evidence that barren-ground caribou are less likely to pass underneath an above-ground pipeline if it is paralleled by a road with traffic (i.e., ≥15-30 vehicles/hour) (Curatolo and Murphy 1986). The combination of a visual barrier from the pipeline and movement from the traffic may together restrict caribou movement to a greater degree than these features alone. Roads typically parallel above-ground pipelines in northeast Alberta in-situ oil sands developments, constituting a 50 m wide right-of-way (Golder 2004). Disentangling the effects of roads from above-ground pipelines on caribou movement may be impossible unless appropriate experiments are implemented. Any such experiments are at risk of being highly confounded due to the complex nature of factors that influence ungulate movement (Forrester *et al.* 2007; Morales *et al.* 2010), and/or any influence that could be measured would likely be overwhelmed by other influences on caribou movement.

The width of a right-of-way may also influence whether caribou will cross an above-ground pipeline and/or road. Vistnes *et al.* (2004) found that two parallel power lines and a road closed to traffic (total width unknown) created a barrier to reindeer movement in Norway, whereas a single closed road did not.

Road Effects on Distribution

Boreal caribou movements within designated ranges in northeastern Alberta appear to be undirected and highly variable (Fuller and Keith 1981; Stuart-Smith *et al.* 1997), and there has been no movement of collared female caribou between ranges (D. Hervieux, Alberta Sustainable Resource Development, pers. comm.).

In Manitoba, woodland caribou were found to avoid areas up to 1 km from a logging road (Schindler *et al.* 2006). Similarly, woodland caribou in Alberta have been found to avoid roads to a maximum distance of 500 m (Oberg 2001) and 250 m (Dyer *et al.* 2001). Sorenson *et al.* (2008) found a significant negative relationship between the area of a caribou's range within 250 m of industrial features and woodland caribou local population growth rates in northeast Alberta.

In Norway, reindeer reduced their use of areas within 1-5 km of developments by 45-95% (Vistnes and Nellemann 2007). In Alaska, barren-ground caribou density was found to be inversely related to road density, declining by 63% at >0.0–0.3 km road/km^2 and by 86% at >0.6–0.9 km road/km^2 (Nellemann and Cameron 1998; Cameron *et al.* 2005). In the same area, mean caribou density (no./km^2) decreased from 1.41 to 0.31 within 1 km of a newly developed oil field access road, and increased from 1.41 to 4.53 at 5- 6 km from the road (Cameron *et al.* 1992).

Human activity on roads has been hypothesized as an important mechanism for the displacement of all caribou ecotypes (Dau and Cameron 1986; Dyer *et al.* 2001; Reimers and Colman 2006; Vors *et al.* 2007). Noise or disturbance may be important, as woodland caribou exposed to noise increased their movement rate by ~30% compared to unexposed caribou (Bradshaw *et al.* 1997).

Bergerud *et al.* (1984) warned that evidence of displacement of woodland and barren-ground caribou from roads relies too heavily on negative correlation between roads and caribou distribution, which does not identify the mechanism for the association. They suggested that a caribou decline in proximity to roads, and a decline in the number of caribou road crossings in a region, is not necessarily due to the roads displacing caribou and/or blocking caribou movement, but rather a function of declining caribou numbers and subsequent range contraction caused by other factors, particularly predation and human hunting. This emphasizes the difficulties with disentangling the influence of linear features on caribou movement from other influences on caribou distribution (e.g., human activity) and density (e.g., predation). For example, it is widely hypothesized that the negative association between the distribution of caribou and roads in northeastern Alberta is due to caribou avoiding roads that provide movement corridors to predators (James and Stuart-Smith 2000; McLoughlin *et al.* 2003; Latham *et al.* 2011). Ultimately predator encounters may have a greater influence on caribou distribution and density around linear features than on caribou's ability to cross a road and/or above-ground pipeline, or on the energetic costs of this movement.

Some authors (e.g., Bergerud *et al.* 1984; Reimers and Colman 2006) have hypothesized that, relative to other large mammals, caribou are easily capable of habituating to human disturbances, including above-ground pipelines and human activity on roads. This is indicated by the fact they have previously been domesticated by humans. Research from Alaska suggests that barren-ground caribou may habituate to human activity in an oilfield, moving closer to infrastructure after snow melt (Haskell *et al.* 2006). Above-ground pipelines and/or roads may become less of a barrier to caribou movement over time, if caribou habituate to the presence of these structures (and they are physically capable of crossing them). Antoniuk *et al.* (2007), and Tracz *et al.* (2010) found that boreal caribou did not abandon ranges with intensive land use, which could be interpreted either as habituation to human disturbances, or fidelity to traditional home ranges without habituation. Regardless of whether or not habituation occurs, continued use of highly disturbed ranges (attractive sinks) does not appear to be beneficial for woodland caribou as their population growth rate has been shown to be inversely related to total range disturbance (Sorensen *et al.* 2008; Environment Canada 2011).

Conclusion

Using the linkage evaluation criteria provided in Appendix 1, this linkage is concluded to be valid, but too difficult to detect relative to other pathways. Specific conclusions for each criteria are:

1. Validity: valid.
2. Impact Rating: moderate to high magnitude (could affect >5% of Lower Athabasca region ranges); of local geographic extent (up to 500 m from right-of-way); long-term duration (>10 years or duration of project); continuous frequency (roads present at least for duration of); effect reversible or permanent (depending on whether road is deactivated and reclaimed).
3. Importance: somewhat important compared to effects of predation.
4. Uncertainty: moderate to high.
5. Research/Monitoring Cost: high cost to confirm significance.

2.2.3 Linkage 3: Changes to movement patterns alter individual energy reserves which affects population dynamics (survival and reproduction)

Overview

Mountain woodland caribou have been found to select inter-patch movement pathways on winter ranges with the lowest energetic cost (Johnson *et al.* 2002). Thus, above-ground pipelines and/or roads that block least-cost pathways between habitat patches may increase energy expenditure by caribou. Pipelines that block caribou movements to a habitat patch or require caribou to move further distances to reach habitat patches may reduce an individual's energy reserves by increasing energy expenditure, and/or by decreasing energy intake if caribou spend time moving that they would otherwise spend foraging. However, caribou may be capable of compensating for this energy loss once arriving at the patch by increasing forage intake (Bradshaw *et al.* 1998). Energy reserve depletion can lead to death and reduced body mass. Loss of 20% of body mass may have negative implications for barren-ground caribou calf production (Cameron and Ver Hoef 1994). Reduced calf and adult survival directly affects local population growth rate.

Influence of Movement on Energetics, Survival, and Reproduction

No research has examined whether the blockage of habitat patches, or the extra movement distance required by caribou to travel around above-ground pipeline and road barriers to reach habitat patches has significant effects on caribou energetics, fecundity, or mortality.

Bradshaw *et al.* (1998) conducted analyses of the energetic costs of caribou encountering disturbances from seismic exploration in northeast Alberta and concluded that 41–137 encounters with disturbance events during a winter were necessary to lose >20% mass and have potential to affect calf survival (Cameron and Ver Hoef 1994). Given current above-ground pipeline frequency, it is likely that only caribou whose home ranges coincide with intensive development areas could be exposed to this frequency of disturbance events.

In theory, if energetic costs of calf movements negatively influence their survival, this could reduce caribou population growth rates (see linkage 4), although no studies were located that test this linkage. Oxygen consumption by barren-ground caribou calves is higher than for adults when moving at speeds >3-5 km/hour (Luick and White 1980) but it is not known whether effects of linear features would increase calf oxygen consumption.

Adult females may be especially sensitive to human activity during calving, and barren-ground caribou cows with calves appear more sensitive to anthropogenic features than cows without calves (Haskell *et al.* 2006). Barriers to adult female and/or calf movement could result in increased energy expenditure that negatively influences adult female reproduction and/or calf survival.

Access to high-forage productivity ranges contributes to heavier adult females, which contributes to higher fecundity (Parker 1981; Reimers 1983; White 1983; Cameron *et al.* 1993, but see Skogland 1985); increased calf birth weight (Parker 1981; White 1983; Rognmo *et al.* 1983; Skogland 1984; Elorantra and Nieminen 1986; Adamczewski *et al.* 1987; Cameron *et al.* 2005); increased lactation (White 1983; Adamczewski *et al.* 1987) and fawn and yearling growth (White 1983; Rognmo *et al.* 1983; Skogland 1984); and higher survival and recruitment (Skoglund 1985; Cameron *et al.* 2005). Barriers that reduce connectivity among high-forage productivity habitats may reduce population carrying capacity (Wang *et al.* 2009). However, it is believed that most caribou local populations exposed to predators (including northeast Alberta) are not forage-limited, as female pregnancy rates are typically high (McLoughlin *et al.* 2003; Wittmer *et al.* 2005a) and age of primiparity (initial reproduction) is relatively young (Rettie and Messier 1998; Festa-Bianchet *et al.* 2011).

Caribou in northeast Alberta do not appear to be forage-limited, as fertility rates are high (McLoughlin *et al.* 2003). Nevertheless above-ground pipelines and roads may limit an animal's ability to move between forage patches within their home range and thus reduce their ability to acquire energy, decreasing individual survival and reproduction.

It is possible that the influence of barriers to movement on caribou fitness and survival could be evaluated quantitatively with a simple model using existing datasets or assumptions on the effects of above-ground pipelines and roads on movement, caribou movement energetics and caribou survival (e.g., Bradshaw *et al.* 1998).

Conclusion

Using the linkage evaluation criteria provided in Appendix 1, this linkage is concluded to be valid, but too difficult to detect relative to other pathways. Specific conclusions for each criteria are:

1. Validity: valid.
2. Impact Rating: moderate to high magnitude (could affect >5% of Lower Athabasca region ranges); of local geographic extent (up to 500 m from right-of-way); long-term duration (>10 years or duration of project); continuous frequency (roads present at least for duration of); effect reversible or permanent (depending on whether road is deactivated and reclaimed).
3. Importance: somewhat important compared to effects of predation.
4. Uncertainty: moderate to high.
5. Research/Monitoring Cost: high cost to confirm significance.

2.2.4 Linkage 4: Changes to movement patterns and distribution alter predation rates

The ability for caribou to move freely within large intact ranges, particularly during calving, may be critical to maintaining spatial separation from predators. Above-ground pipelines and roads that restrict caribou movements could prevent caribou from effectively spatially separating themselves from predators.

Predation appears to be the dominant limiting factor for most caribou populations (Bergerud 1974; Bergerud *et al.* 1984; Bergerud and Elliott 1986; Bergerud and Ballard 1988; Edmonds 1988; Bergerud 1996; Bergerud and Elliott 1998; Schaefer *et al.* 1999; Wittmer et al. 2005b; McCutchen 2007), especially predation on calves and immature females (Parker 1981; Bergerud and Ballard 1988; Adams *et al.* 1995; Rettie and Messier 1998; Schaefer *et al.* 1999; McLoughlin *et al.* 2003). Declining caribou local populations in northeast Alberta specifically appear to be linked to low calf recruitment rate, likely due to calf predation, which accounted for 52% of 122 caribou deaths from 1993-2002 (McLoughlin *et al.* 2003).

Research has also identified strong correlations between anthropogenic features and caribou decline at the caribou range scale (Schaefer 2003; Wittmer *et al.* 2005a; Vistnes and Nellemann 2007; Vors *et al.* 2007; Environment Canada 2008, 2011; Bowman *et al.* 2010), including in northeast Alberta (Sorensen *et al.* 2008; Schneider *et al.* 2010). The leading explanation for this negative relationship is wolf-mediated 'apparent competition' (*sensu* Holt 1977, 1984; Holt and Kotler 1987). Apparent competition occurs when predator populations increase due to abundance of one or more primary prey species (*e.g.* moose and deer), thereby increasing incidental predation on the less common secondary prey species (*e.g.* caribou). Because predator abundance is driven by the primary prey species, proportional mortality on the secondary prey species increases as their numbers decline. This phenomenon is referred to as apparent competition because population responses resemble those from competition between the prey species (Holt 1977).

Apparent competition has been implicated for woodland caribou in British Columbia (Wittmer *et al.* 2005b) and is thought to occur in Alberta via two proposed mechanisms. First, conversion of old forests into early seral stage forests (e.g., forestry, agriculture, open right-of-ways) increases habitat quality for primary prey such as moose and deer ((reviewed in Fisher *et al.* 2005; Serrouya *et al.* 2011), providing more prey to wolves and possibly resulting in increased wolf densities and lower caribou survival rates (James *et al.* 2004; Sorensen *et al.* 2008). Secondly, anthropogenic linear features such as roads, pipelines, and seismic exploration lines provide wolves with efficient travel routes into caribou range (James & Stuart-Smith 2000; Whittington et al. 2011).

Despite the links between linear features and population decline, few studies have examined the mechanisms of how linear features, predator density, and predator-prey spatial interactions affect predation risk. Evidence for apparent competition in declining caribou populations includes:

1. High pregnancy rates and low age of primiparity (initial reproduction), indicating caribou are not food limited (Bergerud and Elliott 1986; Rettie and

Messier 1998; Schaefer *et al.* 1999; McLoughlin *et al.* 2003; Wittmer et al. 2005a; Festa-Bianchet *et al.* 2011).

2. High adult predation (Bergerud and Elliott 1986; Seip 1992; Wittmer *et al.* 2005a, Wittmer *et al.* 2005b) and/or low calf recruitment (Bergerud and Elliott 1986; Seip 1992; Rettie and Messier 1998; McLoughlin *et al.* 2003; Wittmer e*t al.* 2005a,b).
3. High numbers of alternative prey species (i.e., moose and deer) (Bergerud and Elliot 1986; Seip 1992; Latham *et al.* 2011).
4. Positive association between predators and anthropogenic disturbances (Courbin *et al.* 2009; Bowman et al. 2010; Whittington *et al.* 2011).
5. Increasing density of wolves and spatial overlap between wolf and caribou (Latham *et al.* 2011; Whittington *et al.* 2011).
6. Higher proportion of early seral stage forest habitat (Wittmer *et al.* 2007).
7. Increased presence of caribou in wolf diet (Latham *et al.* 2011).
8. Roads and pipeline rights-of-way allow predators such as wolves greater access to caribou and/or increase predator encounter rates (functional response) (James and Stuart-Smith 2000; McCutchen 2007; Latham 2009; Whittington *et al.* 2011).

Establishing the causal link between these factors through experimentation may be exceedingly difficult, if not impossible, due to the rarity of boreal caribou, lack of suitable treatment sites (e.g., control areas without extensive industrial footprints already in place), and the high expense of conducting research on caribou (McLoughlin *et al.* 2003). Nevertheless, existing evidence consistently supports the wolf-mediated apparent competition hypothesis across boreal woodland caribou range in Canada and northeast Alberta.

Conclusion

Using the linkage evaluation criteria provided in Appendix 1, this linkage is concluded to be valid and additional research or monitoring is not required. Specific conclusions for each criteria are:

1. Validity: valid.
2. Impact Rating: high magnitude (unnaturally high predation rates have been documented in Lower Athabasca region local population ranges); of regional geographic extent (at local population range scale); long-term duration (extends for duration of existing and future footprints); continuous frequency (land use footprints present until revegetation); effect reversible or permanent (depending on whether feature is deactivated and reclaimed).
3. Importance: most important linkage.

4. Uncertainty: low.

5. Research/Monitoring Cost: low cost to confirm significance.

2.2.5 Linkage 5: Changes in distribution and movement alter meta-population interchange frequency and rates

Woodland caribou are thought to occur as metapopulations (*sensu* Hanski 1991), local populations that are spatially or behaviourally disjunct and rarely interbreed or exchange individuals through immigration over short time periods (Rettie and Messier 1998; Schaefer *et al.* 2001; McLoughlin *et al.* 2004; Schaefer 2006). It is believed that this metapopulation structure historically allowed for recolonization of local populations that had declined or been extirpated by natural disturbance and processes, thus facilitating regional persistence. Creation of complete or partial movement barriers that prevents movement between local populations could affect immigration rates and thus long-term population growth rate, reducing the probability of recolonization following extirpation.

Fisher *et al.*'s (2009) review of Northwest Territories barren-ground caribou management concluded that herd connectivity allowing for metapopulation dynamics was a key management requirement for herd recovery. The Josyln North Mine Joint Review Panel (2011) concluded that wildlife corridors should be provided to maintain long-term habitat connectivity for wildlife in the Lower Athabasca region at local and regional scales.

No adult female movement between ranges has been observed during telemetry studies conducted in northeast Alberta over the last fifteen years (D. Hervieux, pers. comm.) and high fidelity to suitable habitat has been demonstrated (Stuart-Smith *et al.* 1997; Tracz *et al.* 2010). Telemetry of adult males has not been conducted, so between-range movements may still be occurring. McLoughlin *et al.* (2005) found that caribou in northeast Alberta were not genetically isolated and that range fragmentation has not yet affected the genetic makeup of the populations or larger metapopulation. *Conclusion*

In the long-term, putative caribou local populations in northeast Alberta that are extirpated may not be recolonized through dispersal if barriers block movements between caribou ranges. Using the linkage evaluation criteria provided in Appendix 1, this linkage is concluded to be valid, but too difficult to detect relative to other pathways. Specific conclusions for each criteria are:

1. Validity: valid.

2. Impact Rating: moderate to high magnitude (could affect all Lower Athabasca region ranges); of regional geographic extent (between local population ranges); long-term duration (>10 years or duration of human footprints); continuous frequency (land use footprints present until revegetation); effect reversible or permanent (depending on whether feature is deactivated and reclaimed).

3. Importance: somewhat important compared to effects of predation.

4. Uncertainty: moderate to high.
5. Research/Monitoring Cost: high cost to confirm significance.

2.2.6 Linkage 6: Changes in survival, reproduction, and local population size affect population growth rate

Overview

All caribou populations are dynamic and respond to a wide variety of external factors, such as climate, anthropogenic landscape change and predation (Vors and Boyce 2009). Woodland caribou local populations naturally fluctuate by up to an order of magnitude over several decades (Thomas and Gray 2002). Two relevant factors are discussed below.

Recruitment and Mortality

Local population growth reflects the annual balance between recruitment of calves less adult mortality from natural causes, predation, harvest, and other forms of man-made mortality (e.g., road kills). Low recruitment resulting from high calf mortality appears to be a substantial contributor to recent caribou population declines in Alberta (Stuart-Smith *et al.* 1997; McLoughlin *et al.* 2003), and North America more generally (Bergerud and Ballard 1988; Seip 1992; Bergerud and Elliott 1986; Rettie and Messier 1998, but see Walsh *et al.* 1995). Thus, factors that directly or indirectly influence calf survival (i.e., other linkages depicted in Figure 4) appear to have a large effect on local population growth rate.

Allee Effect

At low population numbers, woodland caribou may be subject to the Allee effect, whereby growth rate decreases as populations get smaller (Wittmer et al. 2005b; McLellan et al. 2010). This is caused by factors such as inbreeding, random events that cause mortality, and loss of interactions with others in the local population (e.g., breeding, immigration). Thus, the rate of decline in population growth rate could increase as local populations in northeast Alberta become smaller.

Conclusion

Distinguishing the relative importance of climatic, predator, and anthropogenic influences on woodland caribou populations has proven to be very challenging because of the number of confounding factors. As an example, in spite of over twenty years of research and monitoring, there is no scientific consensus about the influence of oil-field development on barren-ground caribou population dynamics. Some researchers have argued that hydrocarbon development has reduced herd productivity (Cameron 1992, 1994, 1995; Nellemann and Cameron 1996). Others note that the Central Arctic barren-ground caribou population has grown steadily since the oil fields were developed, which suggests that few or no population-scale effects have been realized (Bergerud *et al.* 1984; Ballard and Cronin 1995; Cronin et al. 1997, 1998). Gunn *et al.* (2001) suggested that barren-ground caribou populations are resilient to anthropogenic disturbances during population growth phases (the Central Arctic herd was in a growth phase), but may be less so during population decline phases.

The literature summarized above suggests that indirect effects on predation risk rather than caribou movements have been the major contributor to recent boreal caribou declines in the Lower Athabasca region.

3. MAY TECHNICAL WORKSHOP CONCLUSIONS

A workshop of invited government, industry, academic, and consulting sector representatives was held at University of Alberta on May 12, 2011. This workshop was held to build mutual understanding among government, industry, academic, and ABMI technical specialists about:

1. the rationale for mitigating above-ground pipelines (i.e., raising above-ground pipelines and/or creating above-ground pipeline crossing structures);
2. associated design and cost implications for raising above-ground pipelines and/or creating above-ground pipeline crossing structures;
3. existing monitoring programs to assess the influence of above-ground pipelines on boreal caribou movement and population dynamics; and
4. the ecological linkages between above-ground pipelines and associated linear features and boreal caribou movement and population dynamics based on the impact hypothesis diagram described in Section 2.

During workshop discussions, the objective of this project was further clarified to be the delivery of an independent scientific analysis that is: 1) different from what other groups have done or are doing; and 2) helps identify planning, design, and mitigation measures for future development that would definitely benefit caribou in the Lower Athabasca region.

Attendees were:

Paula Bentham, Golder Associates Ltd. (Golder)
Dr. Stan Boutin, U of A/ Alberta Biodiversity Monitoring Institute (ABMI)
Dr. Cole Burton, ABMI
Dr. Tyler Colberg, Imperial Oil Ltd./EMCLA
Susanne Cote, ABMI/EMCLA
Corey De La Mare, Golder/ U of A
Dave Hervieux, Alberta Sustainable Resource Development (ASRD)
Paul MacMahon, ASRD/EMCLA
Tyler Muhly, ABMI/AITF
Amit Saxena, Devon Canada Corp.
Terry Antoniuk, Salmo Consulting Inc.

3.1 WORKSHOP DISCUSSIONS

3.1.1 Mitigation Rationale

Dave Hervieux reviewed the rationale for mitigating above-ground pipelines. He noted that it is self-evident that caribou will not cross some configurations of above-ground pipelines and in-situ infrastructure. Restricted movement is inconsistent with boreal caribou's predator avoidance strategy of remaining dispersed within large range areas, and increasing anthropogenic footprint (including linear corridors) has been demonstrated to be linked to population decline (Environment Canada 2008; Sorensen *et al.* 2008; Schneider *et al.* 2010). While there are few research findings on how restrictions to movement affect caribou demographics, it is hard to argue that altered movement would be neutral or positive.

Although the total length of above-ground pipelines is currently low inside designated caribou ranges, ASRD's long-term goal is to maintain the distribution of caribou in Alberta across current caribou ranges (ASRD 2005). Because in-situ development is forecast to increase substantially over the next few decades (Athabasca Landscape Team 2009), it is thought that mitigating individual rights-of-way would contribute to this goal, regardless of whether or not mitigation has a measurable effect on population growth rate at present.

During follow-up discussion, it was noted that there is likely limited benefit to mitigating above-ground pipelines where roads and other potential barriers co-occur. Above-ground pipeline mitigation would have greatest benefit where limited footprint is present. The concept of providing range-scale movement corridors with limited footprint was then introduced and discussed.

3.1.2 Mitigation Design

Tyler Colberg described the design of above-ground pipeline crossing structures and raised sections (see Section 2.1). Use of elevated pipeline sections is more common than crossing structures because elevated pipelines are preferred by ASRD and it is technically and economically easier to construct elevated sections where multiple crossings are required along a pipeline segment. All-weather access roads generally parallel above-ground pipelines, not because it is necessary to have all weather access to the pipes, but because roads and above-ground pipelines are generally linked to the same well pads and facilities, and common rights-of-way minimize total project footprint and linear corridor density.

Tyler noted that building these mitigation measures costs operators tens of millions of dollars, so they want to ensure that these expenditures contribute to caribou conservation.

At present there is no publicly available database that documents the location of above-ground pipelines and crossing structures - this information is proprietary to individual operators, although reporting provisions are being included in some project approvals. Discussions with all operators would be required to develop a consolidated GIS database.

3.1.3 Monitoring Programs

Corey De La Mare provided an overview of the tracking and camera monitoring programs that Golder has undertaken to document crossing success at in-situ projects in the Lower Athabasca region. He estimated that about 400 km of above-ground pipelines currently occur in the region.

Above-ground pipeline wildlife monitoring being conducted by industry has confirmed that caribou will cross mitigated pipeline/road corridors, but the avoidance of mitigated pipeline / road corridors is not known. Also, this sort of monitoring alone cannot be used to draw conclusions on population- or range scale effects because of low caribou density (most pipeline is not within caribou range), low sample size, and the confounding effects of factors such as associated linear and land use features, habitat quality, type and frequency of associated human activity, and predator density and movement patterns.

Following discussion, the group concluded that effort currently expended to monitor crossing success of individual animals would be better focused on range-scale movement and distribution as this is the primary management goal.

3.1.4 Effects of Pipelines and Associated Rights-of-Way

Tyler Muhly provided an overview of the IHD described in Section 2. Terry Antoniuk described proposed criteria that would be used to evaluate the significance of each linkage (Appendix 1).

Following extensive discussion, participants reached consensus based on current evidence from the literature and study area, as well as professional judgment, that caribou are unlikely to cross an unmitigated above-ground pipeline but can cross a mitigated above-ground pipeline. They also agreed that the overall effect of above-ground pipelines and associated roads on caribou, at current levels of development (roughly 400 km of above ground pipelines in total), is small relative to the effects of predation. This conclusion was developed by using the linkage criteria to evaluate the relationship between caribou movement and caribou population growth relative to predation.

Participants then concluded that there would be little value in completing an extensive IHD-based literature review as originally proposed for this project, and that a revision to the project work plan was warranted.

3.1.5 Modified Work Scope

Participants spent the rest of the workshop developing a modified work scope for this project. They agreed that further work on the literature review should be stopped and that initial findings and workshop results should be provided in a brief report that summarizes the current state of knowledge (this report).

Workshop participants also agreed that further work should focus on caribou distribution at the range scale (i.e., change focus from animal movement to range fragmentation). The following logic was applied:

- it can be assumed that individual in-situ projects represent complete barriers to caribou movement because of the intensity of development and human activity during construction and operations and because it is unreasonable to expect to tease out the influence of individual infrastructure (footprint) types because of confounding factors, small sample size and cost. Evaluating and monitoring at the scale of entire developments (i.e., intensive development areas) is therefore most appropriate;

- while the direct effect of above-ground pipelines and associated linear features may be comparatively small, they contribute to cumulative effects on caribou populations, so management of all activities at the range scale is still required;
- a reasonable alternative approach might be to stop mitigation in intensive development areas and instead, set aside no development areas or undertake more intensive mitigation in corridors that will maintain range-scale movement opportunities for caribou;
- additional analyses on caribou movement patterns and information on future development scenarios will be required to evaluate the potential feasibility and benefits of this alternative approach; and
- ideally, additional analyses should help inform the GoA's 'Regional Land Disturbance Plan' for the Lower Athabasca planning region (GOA 2011).

There was general agreement on the following components of a revised 2011 project work scope:

1. Obtain and analyze available GPS monitoring data to: a) calculate caribou movement metrics (daily, seasonal, annual, multi-year, and between range); b) document the influence of habitat and anthropogenic footprints on movement; and c) identify caribou movement corridors.
2. Develop spatially explicit in-situ development trajectories by digitizing existing project footprints and orienting the resulting footprint relative to mapped bitumen reserves to represent a future development scenario. This would build on work previously completed by the Athabasca Landscape Team by adding spatial analyses. Work conducted by the Cumulative Effects Management Association was cited as an example, with the proviso that ongoing reclamation of existing features needs to be incorporated in this scenario. [1]
3. Use the products of steps 1 and 2 to identify the types of mitigation that would be needed to maintain caribou distribution, considering all infrastructure (footprint) types. Options to be considered include: companies doing more mitigation on specific areas of their leases in return for less mitigation elsewhere; zonation and land management thresholds; coordinated reclamation; and designated corridors or areas within each range.

[1] Following the workshop, industry representatives who did not attend the workshop expressed significant concern that this task could lead to impractical or inappropriate conclusions depending on the spatial layout assumptions adopted. As a result, this task was dropped and the revised work plan focused on tasks 1 and 3.

4. CONCLUSIONS AND RECOMMENDATIONS

The first objective of the caribou range fragmentation project commissioned by the Ecological Monitoring Committee for the Lower Athabasca region was to review and summarize the current state-of-knowledge regarding the influence of above-ground pipelines and associated linear features on caribou movement in the Lower Athabasca Planning Region. This document summarizes the current state-of-knowledge based on a preliminary literature review and technical workshop held on May 12, 2011.

Workshop participants reached consensus based on current evidence from the literature and study area (Section 2), as well as their experience and professional judgment (Section 3), that the overall effect of above-ground pipelines and associated roads on caribou is small relative to predation at current levels of development (roughly 400 km of above ground pipelines in total).

They also concluded that it is unreasonable to expect to tease out the influence of individual footprint types (i.e., above-ground pipelines, roads, facilities) because of: 1) confounding factors; 2) small sample size from existing monitoring programs; and 3) cost of a directed research and monitoring program that would require extensive long-term monitoring of individual caribou (e.g., using Global Position System telemetry devices – see Walsh *et al.* 1995). Further work to finalize a detailed literature review (as stipulated in the original project scope of work) was therefore determined to be unnecessary.

A defined goal of caribou management in the Lower Athabasca region is to maintain caribou distribution, which means that future range fragmentation should be avoided. However, as in-situ bitumen development proceeds, widespread barriers to caribou movement will likely arise. To reduce ongoing range fragmentation, landscape-scale mitigation strategies should consider entire in-situ project areas, and focus on ways that all features within these intensive development areas can be planned, designed, operated, and restored to maintain range-scale caribou movements and distribution. Additional information on caribou movement metrics is required to inform the design of these mitigation strategies (e.g., Are there existing movement corridors or hotspots that should be protected? Are there seasonal differences in movement patterns? How much space is needed to maintain movement?).

EMCLA project representatives and workshop participants therefore agreed that remaining project effort during 2011 should focus on original objective 2, namely compiling existing datasets that could be used to analyze current caribou movement patterns in the Lower Athabasca Planning Region in relation to linear features, as well as other man-made and natural factors. Dave Hervieux agreed to provide caribou telemetry data gathered by ASRD and Tyler Muhly committed to develop a proposed methodology for analyzing these movement data in conjunction with other members of the project team.

5. REFERENCES

Adamczewski, J.Z., Gates, C.C., Hudson, R.J. & Price, M.A. (1987) Seasonal changes in body composition of mature female caribou and calves (*Rangifer tarandus groenlandicus*) on an arctic island with limited winter resources. *Canadian Journal of Zoology*, **65**, 1149-1157.

Adams, L.G., Singer, F.J. & Dale, B.W. (1995) Caribou calf mortality in Denali National Park, Alaska. *The Journal of Wildlife Management*, **59**, 584-594.

Alberta Sustainable Resource Development & Association Conservation Association (2010) *Status of the Woodland Caribou in Alberta: Alberta Wildlife Status Report No. 30 (Update 2010)*. Edmonton, AB.

Antoniuk, T., T. Raabis, B. Culling, D., and A. Creagh. 2007. Snake - Sahtaneh Boreal Caribou Study: Cumulative Effect Component. Prepared for Science and Community Environmental Knowledge Fund, Victoria, BC by Salmo Consulting Inc., Boreal Enterprises, Diversified Environmental Services, and Tera Environmental Consultants.

ASRD (Alberta Sustainable Resource Development). 2005. Alberta woodland caribou recovery plan, 2004/05 - 2013/14. Prepared by Alberta Woodland Caribou Recovery Team. Alberta Species at Risk Recovery Plan No. 4.

Athabasca Landscape Team (2009). *Athabasca Caribou Landscape Management Options Report: Management Options*.

Bergerud, A.T. (1974) Decline of caribou in North America following settlement. *The Journal of Wildlife Management*, **38**, 757-770.

Bergerud, A.T. (1996) Evolving perspectives on caribou population dynamics, have we got it right yet? *Rangifer*, **Special Issue No. 9**, 95-116.

Bergerud, A.T. & Ballard, W.B. (1988) Wolf predation on caribou: the Nelchina herd case history, a different interpretation. *The Journal of Wildlife Management*, **52**, 344-357.

Bergerud, A.T. & Elliot, J.P. (1986) Dynamics of caribou and wolves in northern British Columbia. *Canadian Journal of Zoology*, **64**, 1515-1529.

Bergerud, A.T. & Elliott, J.P. (1998) Wolf predation in a multiple-ungulate system in northern British Columbia. *Canadian Journal of Zoology*, **76**, 1551-1569.

Bergerud, A.T., Jakimchuk, R.D. & Carruthers, D.R. (1984) The buffalo of the north: Caribou (*Rangifer tarandus*) and human developments. *Arctic*, **37**, 7-22.

Bowman, J., Ray, J.C., Magoun, A.J., Johnson, D.S. & Dawson, F.N. (2010) Roads, logging, and the large-mammal community of an eastern Canadian boreal forest. *Canadian Journal of Zoology*, **88**, 454-467.

Bradshaw, C.J.A., Hebert, D.M., Rippin, A.B. & Boutin, S. (1995) Winter peatland habitat selection by woodland caribou in northeastern Alberta. *Canadian Journal of Zoology*, **73**, 1567-1574.

Bradshaw, C.J.A., Boutin, S. & Hebert, D.M. (1997) Effects of petroleum exploration on woodland in northeastern caribou. *The Journal of Wildlife Management*, **61**, 1127-1133.

Bradshaw, C.J.A., Boutin, S. & Hebert, D.M. (1998) Energetic implications of disturbance caused by petroleum exploration to woodland caribou. *Canadian Journal of Zoology*, **76**, 1319-1324.

Cameron, R.D., Smith, W.T., Fancy, S.G., Gerhart, K.L. & White, R.G. (1993) Calving success of female caribou in relation to body weight. *Canadian Journal of Zoology*, **71**, 480-486.

Cameron, R.D., Reed, D.J., Dau, J.R. & Smith, W.T. (1992) Redistribution of calving caribou in response to oil field development on the arctic slope of Alaska. *Arctic*, **45**, 338-342.

Cameron, R.D., Smith, W.T., White, R.G. & Griffith, B. (2005) Central arctic caribou and petroleum development: Distributional, nutritional, and reproductive implications. *Arctic*, **58**, 1-9.

Cameron, R.D. & Ver Hoef, J.M. (1994) Predicting parturition rate of caribou from autumn body mass. *The Journal of Wildlife Management*, **58**, 674-679.

Carruthers, A.D.R. & Jakimchuk, R.D. (1987) Migratory movements of the Nelchina caribou herd in relation to the trans-Alaska pipeline. *Wildlife Society Bulletin*, **15**, 414-420.

Courbin, N., Fortin, D., Dussault, C. & Courtois, R. (2009) Landscape management for woodland caribou: the protection of forest blocks influences wolf-caribou co-occurrence. *Landscape Ecology*, **24**, 1375-1388.

Cronin, M.A., Amstrup, S.C., Durner, G.M., Noel, L.E., McDonald, T.L. & Ballard, W.B. (1998) Caribou distribution during the post-calving period in relation to infrastructure in the Prudhoe Bay oil field , Alaska. *Arctic*, **51**, 85 - 93.

Curatolo, J.A. & Murphy, S.M. (1986) The effects of pipelines, roads, and traffic on the movements of caribou, *Rangifer tarandus*. *Canadian Field-Naturalist*, **100**, 218-224.

Dau, J.R. & Cameron, R.D. (1986) Effects of a road system on caribou distribution during calving. *Rangifer*, **Special Issue 1**, 95 - 101.

Dunne, B. & Quinn, M. (2009) Effectiveness of above-ground pipeline mitigation for moose (*Alces alces*) and other large mammals. *Biological Conservation*, **142**, 332-343.

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

Dyer, S.J., O'Neill, J.P., Wasel, S.M. & Boutin, S. (2002) Quantifying barrier effects of roads and seismic lines on movements of female woodland caribou in northeastern Alberta. *Canadian Journal of Zoology*, **80**, 839-845.

Edmonds, E.J. (1988) Population status, distribution, and movements of woodland caribou in west central Alberta. *Canadian Journal of Zoology*, **66**, 817-826.

Eloranta, E. & Nieminen, M. (1983) Calving of the experimental reindeer herd in Kaamanen during 1970 - 85. *Rangifer*, **1**, 115-121.

Environment Canada. 2008. Scientific Review for the Identification of Critical Habitat for Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population, in Canada, August 2008. Ottawa, Ontario.

Environment Canada. 2011. Scientific Assessment to Inform the Identification of Critical Habitat for Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population, in Canada, 2011 Update. Ottawa, Ontario.

Fancy, S.G. (1983) Movements and activity budgets of caribou near oil drilling sites in the Sagavanirktok River floodplain, Alaska. *Arctic*, **38**, 193-197.

Festa-Bianchet, M., Ray, J.C., Boutin, S. and Gunn, A. (2011) Conservation of caribou (*Rangifer tarandus*) in Canada: an uncertain future. *Canadian Journal of Zoology*, **89**, 419-434.

Fisher, J.T., L.D. Roy, and M. Hiltz. 2009. Barren-ground caribou Management in the Northwest Territories: An Independent Peer Review. Alberta Research Council, Edmonton, Alberta. 53 pp. http://www.enr.gov.nt.ca/_live/documents/content/ARC_NWT_Caribou_Review_January_2009.pdf.

Fisher, J.T., and L. Wilkinson. 2005. The response of mammals to forest fire and timber harvesting in the North American boreal forest. Mammal Review 35(1): 51-81.

Forester, J.D., Ives, A.R., Turner, M.G., Anderson, D.P., Fortin, D., Beyer, H.L., Smith, D.W. & Boyce, M.S. (2007) State–space models link elk movement patterns to landscape characteristics in Yellowstone National Park. *Ecological Monographs*, **77**, 285-299.

Fuller, T.K., and Keith, L.B. (1981) Woodland caribou population dynamics in northeastern Alberta. *The Journal of Wildlife Management*, **45**, 197-213.

GOA (Government of Alberta). 2011. Draft Lower Athabasca Integrated Regional Plan 2011-2021. Strategic Plan, Implementation Plan. March 29, 2011.

Golder (Golder Associates Ltd.). (2004) *Review of wildlife crossing structures for above-ground pipelines*. Prepared for South SAGD Operators. Report Number: 04-1335-018.

Golder (Golder Associates Ltd.). (2010) *Caribou – "State Of The Science" 2010 Update (Biology, Impact Pathways And Next Steps; Alberta And British Columbia)*. Prepared for Canadian Association of Petroleum Producers Caribou Working Group. Report Number: 10-1372-0001.

Gunn, A., B. Griffith, G. Kofinas, and D. Russell. 2001. Cumulative impacts and the Bathurst caribou herd: proposed tools for assessing the effects. Unpublished Report. Government of the Northwest Territories, Department of Resources, Wildlife and Economic Development, Yellowknife, Northwest Territories, Canada.

Hanski, I. 1991. Metapopulation dynamics: brief history and conceptual domain. Biological Journal of the Linnean Society 42: 3-16.

Haskell, S.P., Nielson, R.M., Ballard, W.B., Cronin, M.A. & McDonald, T.L. (2006) Dynamic responses of calving caribou to oilfields in northern Alaska. *Arctic*, **59**, 179-190.

Holt, R.D. 1984. Spatial heterogeneity, indirect interactions, and the coexistence of prey species. The American Naturalist 124(3): 377-406.

Holt, R.D. 1977. Predation, apparent competition, and the structure of prey communities. Theoretical Population Biology 12: 197-229.

Holt, R.D., and B.P. Kotler. 1987. Short-term apparent competition. The American Naturalist 130(3): 412-430.

James, A.R.C. & Stuart-Smith, A.K. (2000) Distribution of caribou and wolves in relation to linear corridors. *The Journal of Wildlife Management*, **64**, 154-159.

Johnson, C.J., Parker, K.L., Heard, D.C. & Gillingham, M.P. (2002) A multiscale behavioral approach to understanding the movements of woodland caribou. *Ecological Applications*, **12**, 1840-1860.

Joslyn North Mine Joint Review Panel. 2011. Report of the Joint Review Panel for the Joslyn North Mine Project, TOTAL E&P Ltd., Alberta. ERCB Decision 2011-005, January 27, 2011. Available online at: http://www.ercb.ca/docs/documents/decisions/2011/2011-ABERCB-005.pdf

Latham, A.D.M. 2009. Wolf ecology and caribou-primary prey-wolf spatial relationships in low productivity peatland complexes in northeastern Alberta. Dissertation, University of Alberta, Edmonton, Canada.

Latham, A.D.M., Latham, M.C., McCutchen, N.A. & Boutin, S. (2011) Invading white-tailed deer change wolf-caribou dynamics in northeastern Alberta. *The Journal of Wildlife Management*, **75**, 204-212.

LGL Limited, ESL Environmental Sciences Limited, ESSA Environmental and Social Systems Analysts Limited, and P.J. Usher Consulting Services Limited. 1986. Mackenzie Environmental Monitoring Project, 1985-1986 Final Report. Prepared for Indian and Northern Affairs Canada, Environment Canada, Fisheries and Oceans Canada, Government of the Northwest Territories, and Government of the Yukon.

Luick, B.R., & White, R.G. (1986) Oxygen consumption for locomotion by caribou calves. *The Journal of Wildlife Management*, **50**, 148-152.

McCutchen, N.A. (2007) Factors affecting caribou survival in northern Alberta: the role of wolves, moose, and linear features. Dissertation, University of Alberta, Edmonton, Canada.

McLellan, B. N., R. Serrouya, H. U. Wittmer, and S. Boutin. 2010. Predator-mediated Allee effects in multi-prey systems. Ecology **91:**286–292.

McLoughlin, P.D., Dzus, E., Wynes, B., & Boutin, S. (2003) Declines in populations of woodland caribou. *The Journal of Wildlife Management*, **67**, 755-761.

McLoughlin, P.D., D. Paetkau, M. Duda, and S. Boutin 2004. Genetic diversity of relatedness of boreal caribou populations in western Canada. Biological Conservation 118: 593-598.

Morales, J.M., Moorcroft, P.R., Matthiopoulos, J., Frair, J.L., Kie, J.G., Powell, R.A, Merrill, E.H. & Haydon, D.T. (2010) Building the bridge between animal movement and population dynamics. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **365**, 2289-2301.

Murphy, S.M. & Curatolo, J.A. (1987) Activity budgets and movement rates of caribou encountering pipelines, roads, and traffic in northern Alaska. *Canadian Journal of Zoology*, **65**, 2483-2490.

National Council for Air and Stream Improvement, Inc. (NCASI). (2007) S*tate of knowledge and analysis of current research on woodland caribou in Canada: technical bulletin no. 939*. Research Triangle Park, N.C.

Nellemann, C. & Cameron, R.D. (1998) Cumulative impacts of an evolving oil-field complex on the distribution of calving caribou. *Canadian Journal of Zoology*, **76**, 1425-1430.

Oberg, P.R. (2001) Responses of mountain caribou to linear features in a west-central Alberta landscape. Master Thesis, University of Alberta, Edmonton, AB.

Parker, G.R. (1981) Physical and reproductive characteristics of an expanding woodland caribou population (*Rangifer tarandus caribou*) in northern Labrador. *Canadian Journal of Zoology*, **59**, 1929-1940.

Reimers, E. (1983) Reproduction in wild reindeer in Norway. *Canadian Journal of Zoology*, **61**, 211-217.

Reimers, E. & Colman, J.E. (2006) Reindeer and caribou (*Rangifer tarandus*) response towards human activities. *Rangifer*, **26**, 55-71.

Rettie, W.J. & Messier, F. (1998) Dynamics of woodland caribou populations at the southern limit of their range in Saskatchewan. *Canadian Journal of Zoology*, **76**, 251-259.

Rognmo, A., Markussen, K.A., Jacobsen, E., Grav, H.J. & Blix, A.S. (1983) Effects of improved nutrition in pregnant reindeer on milk quality, calf birth weight, growth, and mortality. *Rangifer*, **3**, 10 - 18.

Seip, D.R. (1992) Factors limiting woodland caribou populations and their interrelationships with wolves and moose in southeastern British Columbia. *Canadian Journal of Zoology*, **70**, 1494-1503.

Schaefer, J.A. 2006. Towards maturation of the population concept. Oikos 112(1): 236-240.

Schaefer, J.A. (2003) Long-term range recession and the persistence of caribou in the taiga. *Conservation Biology*, **17**, 1435-1439.

Schaefer, J.A., A.M. Veitch, F.H. Harrington, W.K. Brown, J.B. Theberge, and S.N. Luttich. 2001. Fuzzy structure and spatial dynamics of a declining woodland caribou population. Oecologia 126: 507–514.

Schaefer, J.A., Veitch, A.M., Harrington, F.H., Brown, W.K., Theberge, B., & Luttich, S.N. (1999) Demography of decline of the Red Wine Mountains caribou herd. *The Journal of Wildlife Management*, **63**, 580-587.

Schindler, D.W., Walker, D., Davis, T. & Westwood, R. (2006) Determining effects of an all weather logging road on winter woodland caribou habitat use in south-eastern Manitoba. *Rangifer*, **Special Issue 17**, 209-217.

Serrouya, R., B.N. McLellan, S. Boutin, D.R. Seip, and S.E. Nielsen. 2011. Developing a population target for an overabundant ungulate for ecosystem restoration. Journal of Applied Ecology 48: 935-942.

Skogland, T. (1984) The effects of food and maternal conditions on fetal growth and size in wild reindeer. *Rangifer*, **4**, 39-46.

Skogland, T. (1985) The effects of density-dependent resource limitations on the demography of wild reindeer. *Journal of Animal Ecology*, **54**, 359-374.

Smith, W.T. & Cameron, R.D. (1985) Reactions of large groups of caribou to a pipeline corridor on the arctic coastal plain of Alaska. *Arctic*, **38**, 53-57.

Sorensen, T., McLoughlin, P.D., Hervieux, D., Dzus, E., Nolan, J., Wynes, B. & Boutin, S. (2008) Determining sustainable levels of cumulative effects for boreal caribou. *Journal of Wildlife Management*, **72**, 900-905.

Stuart-Smith, A.A.K., Bradshaw, C.J.A., Boutin, S., Hebert, D.M. & Rippen, A.B. (1997) Woodland caribou relative to landscape patterns in northeastern Alberta. *The Journal of Wildlife Management*, **61**, 622-633.

Thomas, D.C. & Gray, D.R. (2002) COSEWIC assessment and update status report on the Woodland Caribou *Rangifer tarandus* caribou in Canada. Ottawa, ON, Committee on the Status of Endangered Wildlife in Canada.

Tracz, B., J.L. LaMontagne, E.M. Bayne, and S. Boutin. 2010. Annual and monthly range fidelity of female boreal woodland caribou in response to petroleum development. Rangifer 30: 31-44.

Vistnes, I., Nellemann, C., Jordhøy, P. & Strand, O. (2004) Effects of infrastructure on migration and range use of wild reindeer. *Journal of Wildlife Management*, **68**, 101-108.

Vistnes, I. & Nellemann, C. (2007) Impacts of human activity on reindeer and caribou: The matter of spatial and temporal scales. *Rangifer*, **12**, 47-56.

Vors, L.S. & Boyce, M.S. (2009) Global declines of caribou and reindeer. *Global Change Biology*, **15**, 2626-2633.

Vors, L.S., Schaefer, J.A, Pond, B.A, Rodgers, A.R. & Patterson, B.R. (2007) Woodland caribou extirpation and anthropogenic landscape disturbance in Ontario. *Journal of Wildlife Management*, **71**, 1249-1256.

Walsh, N.E., Griffith, B. & McCabe, T.R. (1995) Evaluating growth of the porcupine caribou herd using a stochastic model. *The Journal of Wildlife Management*, **59**, 262-272.

Wang, G., Hobbs, N.T., Twombly, S., Boone, R.B., Illius, A.W., Gordon, I.J. & Gross, J.E. (2008) Density dependence in northern ungulates: interactions with predation and resources. *Population Ecology*, **51**, 123-132.

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

White, R.G. (1983) Foraging patterns and their multiplier effects on productivity of northern ungulates. *Oikos*, **40**, 377-384.

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

Wittmer, H.U., McLellan, B.N., Seip, D.R., Young, J.A., Kinley, T.A., Watts, G.S. & Hamilton, D. (2005a) Population dynamics of the endangered mountain ecotype of woodland caribou (*Rangifer tarandus caribou*) in British Columbia , Canada. *Canadian Journal of Zoology*, **83**, 407-418.

Wittmer, H.U., Sinclair, A.R.E., &McLellan, B.N. (2005b) The role of predation in the decline and extirpation of woodland caribou. *Ecology*, **144**, 257-267.

Wittmer, H.U., McLellan, B.N., Serrouya, R. & Apps, C.D. (2007) Changes in landscape composition influence the decline of a threatened woodland caribou population. *The Journal of animal ecology*, **76**, 568-579.

Wolfe, S.A., Griffith, B. & Wolfe, C.A.G. (2000) Response of reindeer and caribou to human activities. *Polar Research*, **19**, 63-73.

APPENDIX 1

LINKAGE EVALUATION CRITERIA

Linkage Significance Evaluation Criteria

1. What is the anticipated magnitude, extent, duration, frequency, and reversibility of this linkage (as monitored, estimated, or modelled)?
    - magnitude: how large is the effect relative to range of natural variability (estimated quantitatively where possible, or: not detectable; within RNV; outside RNV);
    - extent: over what area will the effect occur (metres; kilometres; tens of kilometres; hundreds of kilometres)
    - duration: how long will the effect persist for (days, weeks, years)
    - frequency: how often will the effect occur (accidental; isolated; periodic; continuous)
    - reversibility: is the effect reversible or permanent?

2. How important is this linkage relative to other population-level effects?

3. What is the level of uncertainty?
    a. Low - supporting data from study area or equivalent biophysical setting or consistent conclusions from multiple lines of evidence
    b. Moderate - supporting data from different biophysical setting or inconsistent evidence from multiple lines of evidence (theoretical/modelling evaluation; expert opinion)
    c. High - equivocal data on linkage, equivocal evidence from one line of evidence (theoretical/modelling evaluation; expert opinion)

4. What would cost/level of effort be to confirm the significance of this linkage in the study area?
    a. High - >10 years and >ten million dollars
    b. Moderate - 3-10 years and 2-10 million dollars
    c. Low - 1-3 years and <2 million dollars

Conclusion

1. Hypothesis is extremely unlikely and does not justify further action.

2. Hypothesis is valid, but available evidence indicates that it is unlikely to be a significant contributor to current or future population-level effects.

3. Hypothesis is valid and should be tested with a detailed research plan.

4. Hypothesis is valid, but would be too difficult to detect.

5. Hypothesis is valid and additional research or monitoring is not required.

6. More information is required before designing any further research or monitoring.