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Use of Space by Caribou in Northern Canada

by

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Abstract

Understanding how populations are structured and how they use natural and anthropogenic spaces is essential for effective wildlife management. A total of 510 barren-ground (*Rangifer tarandus groenlandicus*), 176 boreal (*R. t. caribou*), 11 mountain woodland (*R. t. caribou*), and 39 island (*R. t. groenlandicus x pearyi*) caribou were tracked with satellite collars in 1993-2009 in the Northwest Territories, Nunavut, and northern Alberta. Using satellite location data and hierarchical and fuzzy cluster analyses, I verified that Cape Bathurst, Bluenose-West, Bluenose-East, Bathurst, Beverly, Qamanirjuaq, and Lorillard barren-ground subpopulations were robust; the Queen Maude Gulf and Wager Bay barren-ground subpopulations were distinct. Dolphin and Union island caribou formed one population; boreal caribou formed two distinct subpopulations. Females in robust subpopulations were structured by strong annual spatial affiliation; those in distinct subpopulations were spatially independent and structured by migratory connectivity, movement barriers, and/or habitat discontinuity. An east-west cline in annual-range sizes and path lengths supported the subpopulation structure identified for migratory barren-ground caribou. I analyzed satellite location data to determine parturition dates and activity periods for all caribou ecotypes. For parturition dates I found a north-south cline for boreal caribou, west-east cline for migratory barren-ground caribou, and ecotype and subspecies clines for boreal and barren-ground caribou. Based on annual changes in movement rates I identified eight activity periods for boreal and tundra-wintering, 10 for mountain woodland, and 12 for migratory barren-ground

caribou. Based distribution and movements, boreal caribou avoided seismic lines during periods when females and calves were most vulnerable to predators or hunters. They crossed fewer seismic lines and travelled faster when they crossed them than expected. Caribou avoided areas ≤400 m from seismic lines where they could space away from them suggesting that they perceive these as risky areas. I defined secure habitats as areas that were >400 m from anthropogenic linear features. Population growth rates were higher in areas where they had access to secure unburned habitat and where most of that was in patches >500 km^2. Critical habitat for boreal caribou is a habitat state that provides “security” from predation risk and facilitates the effectiveness of their anti-predator strategies.

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A study of this magnitude was only possible because a number of people and organizations supported caribou satellite tracking studies in northern Canada. The aboriginal and government organizations that supported various satellite tracking studies are detailed in each chapter. I thank Susan Fleck and Ray Case for supporting my work and Nicholas Larter, Danny Allaire, Deborah Johnson, Allicia Kelly, Bruno Croft, Mitch Campbell, Mathieu Dumond, Alasdair Veitch, and Marsha Branigan for providing access to various satellite tracking data. Nicholas Larter, Danny Allaire, Deborah Johnson, and Allicia Kelly provided comments on earlier versions of chapters two to five; Bruno Croft, Mitch Campbell, and Mathieu Dumond provided comments on earlier versions of chapters two and three. I thank Jari Heikkilä and Denise Auriat for helping me with much of the boreal caribou field work in the Gwich'in Settlement Area; Jari Heikkilä also commented on chapters four and five. Special thanks to Ian Ellsworth and Robert Fletcher for helping capture and collar many of the caribou that provided data for the western Northwest Territories; Wendy Wright, Bonnie Fournier, Adrian D'Hont, and Phil Spencer for processing and "cleaning" many of the satellite tracking data included in my analyses; and Wendy Wright and Charlene Nielsen for providing advice and training on the use of various geographic information system (GIS) applications. I also thank Mark Edwards, Evan Richardson, and Vicki Sahanatien for many hours of discussions on data analyses; Marie Auger-Methe for showing me how to run applications using the GIS program Geospatial Modeling Environment; and Michelle Green for making sure that I was always enrolled in the right courses and on time and made following administrative protocols easier.

During the preparation of this thesis I became proficient in a number of statistical, spreadsheet, word processing, and GIS applications. This thesis is a testament that you can teach "old dogs" new tricks.

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Chapter 1 - Introduction

Species that occupy vast geographic areas in the form of single populations and multiple subpopulations of behaviourally different subspecies and ecotypes pose significant challenges for wildlife management. Groups of individuals within populations or subpopulations may exhibit movement patterns that range from sedentary, migratory, to permanently nomadic (Olson et al. 2010, Robinson et al. 2010). Effective management and conservation of these species requires an understanding of how they are structured (i.e., single populations and/or multiple subpopulations) and organized (i.e., strong annual spatial affiliation among individuals or individuals spatially independent), their location on the landscape (i.e., annual and seasonal ranges), and how they respond to natural and anthropogenic disturbances (attracted to, interact with in proportion to availability, or avoid). These are particularly important for ecotypes that annually migrate through large-scale assemblages of habitats to access broadly distributed high quality forage resources in seasonally changing environments (Fryxell et al. 1988, Vavra and Riggs 2010); where habitats maybe modified, fragmented, or lost as a result of natural and anthropogenic disturbances (Sawyer et al. 2009, Olson et al. 2010). No species exemplifies the challenges caused by larger scale management more than caribou

Caribou (*Rangifer tarandus* L.) occur in the form of single populations and multiple subpopulations of behaviourally different subspecies and ecotypes across their range. In the Northwest Territories (NT) and Nunavut (NU), Canada the total caribou population includes four subspecies (*Rangifer t. groenlandicus, R. t. caribou, R. t. groenlandicus x pearyi, and R. t. pearyi*), six ecotypes (migratory and tundra-wintering barren-ground, boreal, mountain woodland, Dolphin and Union island, and Peary), and a number of subpopulations that interact to varying degrees. All of these biological concepts (subspecies, ecotypes, and subpopulations) are used in management of caribou although the utility of these concepts for effective management has been questioned. I evaluated some of these concepts by focusing my thesis on the use of space by migratory and tundra-wintering barren-ground, Dolphin and Union island, boreal, and mountain woodland caribou. More specifically my objectives are to explore four aspects of caribou space use including: i) the structure and organization of migratory and tundra-wintering barren-ground, boreal, and Dolphin and Union island caribou; ii) the timing and synchrony of activities among migratory and tundra-wintering barren-ground, boreal, and mountain woodland caribou; iii) the response of boreal caribou to seismic lines; and iv) habitat conditions that are critical for conservation and recovery of boreal caribou.

Current definitions of caribou ecotypes

Migratory barren-ground caribou are usually found in large groups that space-away from predators to reduce predation risk during calving and they use different calving grounds across the tundra in the NT and NU (Banfield 1954, Thomas 1969, Parker 1972, Heard et al. 1987, Nagy et al. 2005). Females collectively migrate annually from winter ranges that are generally near or below treeline to calving grounds on the tundra (Heard et al. 1987), thus spacing away from the area around treeline where there are more predators and alternate prey (Bergerud et al. 2008). Females, numbering in the thousands to 10s of thousands, congregate on tundra calving grounds during late May and early June. Most calves are born over a two week period in early June (Bergerud 1975) and predator swamping is likely the operational anti-predator tactic being used. However, nutritional requirements may also dictate calving sites selection (Young and McCabe 1998). Seeking relief from insects in early to mid July, an entire subpopulation may be found in a few large, mixed sex groups of thousands to 10s of thousands of caribou (Valkenburg et al. 1985, Russell et al. 1996). Seasonal activities (Maier and White 1998) and range use are synchronized among females within and among subpopulations. As a result the movements and activities of female migratory barren-ground caribou are coordinated throughout the year and they exhibit strong migratory connectivity. Tundra-wintering barren-ground caribou live on the tundra year round (Calef and Heard 1981) but little is known about their ecology. Female barren-ground caribou have been assigned to subpopulations based on their use of calving grounds (Skoog 1968, Thomas 1969, Miller 1982); however, the areas used during calving by a subpopulation may change over time (Sutherland and Gunn 1996, Hinkes et al. 2005) .

Dolphin and Union island caribou are migratory and remain above treeline throughout the year (Poole et al. 2010). They migrate over the sea ice between calving, summer, rutting, and autumn ranges on Victoria Island, and winter ranges on the mainland. Unlike barren-ground caribou they disperse to calve and most calves are born in early-mid June. In autumn they aggregate along the south coast of Victoria Island where crossing to the mainland is synchronized by freeze-up. Their winter range overlaps the northern extent of the post-calving and summer ranges of barren-ground caribou, however this overlap is spatial and not temporal.

Boreal caribou are sedentary (Bergerud et al. 2008) and remain largely within the boreal forest throughout the year. Females space away from other females and predators during calving (Schaefer et al. 2001, Bergerud et al. 2008); they select areas with low densities of other females or ungulates rather than sites within specific habitats (James 1999, Dzus 2001). Most calves are born during early to late May. Group size is highest in winter and lowest in summer (Stuart-Smith et al. 1997, Metsaranta and Mallory 2007). During pre-calving, calving, and summer the typical group size is 1-2 (cow, or cow-calf pairs, or bulls), while in late summer they begin forming mixed sex groups of 3 or more caribou and remain in small dispersed groups until the spring pre-calving dispersal begins (Stuart-Smith et al. 1997, Rettie and Messier 1998, Metsaranta and Mallory 2007). Activities of boreal females are coordinated in time but not in space and are thus more independent of con-specifics than female barren-ground caribou. Boreal caribou occur throughout the Mackenzie River Valley and adjacent boreal forests in the NT, Alberta (AB), and northern Yukon (YT). No subpopulations have been recognized to date in the NT.

Brief history of caribou collaring in northern Canada

Many of the subpopulation definitions used in caribou management in northern Canada are based on research and decisions made decades ago (Skoog 1968, Thomas 1969, Miller 1982). However, relatively little analysis has been done to determine the validity of many of the ecotypes and subpopulations that are currently used in management. A large part of my thesis was to coordinate the data needed to reevaluate some of these definitions and determine their robustness.

My the study area is defined by the movements of 510 migratory and tundra-wintering barren-ground, 176 boreal, 11 mountain, and 39 Dolphin and Union caribou that were tracked using satellite radio-collars in the NT, NU, YT, AB, Saskatchewan (SK), and Manitoba (MB) during 1993-2009 (Fig. 1-1). The area included the Taiga Cordillera, Taiga Plains, Taiga Shield, Southern Arctic, and Northern Arctic ecozones (Terrestrial Ecozones, The Atlas of Canada; http:/atlas.nrcan.gc.ca). The area spanned approximately 2400 km east-west, with the north-south span ranging from 500 km in the west to 1400 km in the east.

Satellite tracking studies have been ongoing since 1993 in the NT and NU, Canada to document the movements of female barren-ground caribou. In eastern NU, satellite collars were first deployed in 1993 and by 2009 movement data for 155 females had been obtained. Satellite collars were typically deployed along spring migration routes or uniformly across late winter ranges (Mitch Campbell, pers. comm.). In the NT and western NU, 94 satellite collars were deployed on females in 1996-2004 to support various habitat use and subpopulation and range delineation studies. The number of active satellite collars varied over time and among females using each calving ground. After 2004, 156 females were collared in preparation for subpopulation surveys. Reconnaissance surveys were flown during late February and early March 2005, 2006, and 2008 to document the distribution of caribou on winter ranges. Satellite collars were then deployed as uniformly as possible, given weather and logistical constraints, throughout these winter ranges.

By 2006 satellite tracking studies designed to obtain detailed information on the movements and distribution of 5 of the 6 recognized migratory barren-ground caribou subpopulations were underway and data for a large number of females in the Cape Bathurst (n=23), Bluenose-West (n=31), Bluenose-East (n=34), Bathurst (n=56), and Qamanirjuaq (n=41) subpopulations had been obtained. In comparison, based on use of calving grounds it was believed that only 2 females in the Beverly subpopulation had been tracked and that the distribution and movements of this subpopulation was largely unknown. The first study that was specifically designed to document the distribution and movements of the Beverly subpopulation was initiated in 2006 and by 2008, 66 satellite collars had been deployed within their winter and post-calving ranges.

A few collars (n=5) were deployed east of Bathurst Inlet in 1996 to describe the movements of the tundra-wintering Queen Maude Gulf subpopulation (Gunn et al. 2000); however, additional collaring (n=10) did not begin until 2008. Studies designed to describe the distribution and movements of the tundra-wintering Lorillard and Wager Bay subpopulations began in 1999.

These studies gave sufficient data to assess subpopulation structure among females that used most of the calving grounds in the NT and NU in 2006-2009. Although the number of satellite collared females tracked in 1993-2005 varied annually, they provided movement data with which I could assess subpopulation structure among females using each calving ground and their area fidelity. Similarly, satellite tracking data were obtained for 39 female Dolphin and Union island caribou in 1999-2006, allowing me to assess subpopulation structure among island and adjacent barren-ground caribou.

The first satellite tracking studies for boreal caribou began in the NT in 2002 to obtain data required to assess the potential impacts of the proposed Mackenzie Valley Pipeline (Ray Case, pers. comm.). Boreal caribou were reconfirmed as Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2002) in that year. By 2004, studies were underway throughout their range in the NT and into northern AB and YT to obtain demographic, habitat, and range use data. Initially, reconnaissance surveys were conducted and satellite collars were deployed uniformly in 5 study areas including the Gwich'in and Sahtu settlement areas, the Dehcho and South Slave regions, and in the Cameron Hills, NT and AB. In subsequent years, movement data were analyzed before capture work and satellite collars were deployed to fill in gaps. The location data obtained for 176 female boreal caribou in 2002-2009 allowed me to assess subpopulation structure among females within and among these study areas.

A mountain woodland caribou satellite tracking study was conducted in the Mackenzie Mountains, NT in 2001-2005; however, the sample size of collared females (n=11) was too small to assess subpopulation structure. I included data for these caribou when comparing annual home range size and path length among ecotypes.

Why do we need to understand the subpopulation structure of caribou?

In order to obtain reliable population or subpopulation specific demographic information (i.e., populations estimates, birth rates, and mortality rates) and to estimate sustainable harvest rates, population or subpopulation boundaries must be known (Bethke et al. 1996). Skoog (1968) proposed a classification system for barren-ground caribou that was based the assumption that each subpopulation maintained fidelity to a specific calving ground. Miller (1982) extended this definition to include that caribou subpopulations remained together most of the year but each used an exclusive calving ground. These are known as “traditional” calving grounds and are considered as being “central to the social structure of each herd and thus are of paramount importance to caribou” (Jingfors et al. 1982). The prevailing paradigm has been that barren-ground caribou subpopulations maintain fidelity to specific “traditional” calving grounds, each calving ground is exclusively used by one subpopulation, subpopulations do not abandon use of these areas for calving, and one can identify and census subpopulations by locating females on these areas during the calving period.

However, by 1996 it was known that female Bathurst caribou had not maintained fidelity to one specific geographic area to calve (Sutherland and Gunn 1996). In order for female Bathurst caribou to conform with the prevailing paradigm Sutherland and Gunn (1996) redefined the term “traditional calving ground" to include all areas know to be used by a subpopulation during calving. By changing the definition Sutherland and Gunn (1996) created the impression that a shift in calving ground use by the Bathurst subpopulation had not occurred and thus promoted the view that barren-ground caribou subpopulations do not abandon their calving grounds. As a result of the belief that migratory barren-grounds do not change use of or abandon their calving grounds, female caribou collared on the Beverly subpopulation winter range that subsequently calved on the Queen Maude Gulf rather than the "traditional" Beverly calving ground were assumed to be a new subpopulation and named the "Ahiak" subpopulation (Gunn and D'Hont 2002) simply because they calved in the Queen Maude Gulf area. Lack of clarity in the origin of the "Ahiak" subpopulation and subsequent declines of the major migratory caribou subpopulations harvested in the western and central NT resulted in a challenge by big game outfitters of the validity of all of the recognized caribou subpopulations. Hinkes et al. (2005) documented three patterns of calving ground use which included abandonment of old and occupation of new ones for barren-ground caribou (*R. t. granti*) in Alaska. These variations in calving ground use indicate that Skoog's (1968) and Miller's (1982) classifications should have been treated as hypotheses rather than absolute rules until the patterns of calving ground use for all subpopulations of barren-ground caribou had been examined over time. These variations indicate that migratory barren-ground caribou subpopulations cannot be reliably identified solely based on calving ground use therefore alternative methods are required to define subpopulations for effective management.

The structure and organization of the Bathurst subpopulation during the period when it made the 250 km shift in calving ground use between 1986 and 1996 was maintained by strong annual spatial affiliation among its members rather than by an affinity to a specific geographic area for calving. Therefore it is reasonable to assume that all migratory barren-ground caribou are structured by similar behaviours. There are five other behaviourally different caribou ecotypes in the NT and NU including mountain woodland, boreal, tundra-wintering barren-ground, Dolphin and Union island, and Peary caribou. It is reasonable to assume that their behaviours also influence how individuals within their populations or subpopulations are structured. Thus a goal of my thesis is to evaluate how movements of individuals can be used to define subpopulations.

Why do we need to understand the seasonal activity patterns of caribou?

The prevailing paradigm is that calving grounds are the most important areas used by barren-ground caribou during the year and they should be protected (Committee 1993). However, during late summer and fall pre-breeding periods barren-ground caribou regain body condition before the breeding period (Russell et al. 1993). The condition of females during the breeding period affects the timing and synchrony of calving and calf survival the following spring (Russell et al. 1993, Gerhart 1995, Whitten 1995). In addition, winter is a critical period for barren-ground caribou and most large migratory subpopulations of *Rangifer* travel to woodland areas below the treeline where photoperiod and food quality and availability affect activity budgets (Russell et al. 1993). Knowledge of the areas used by caribou during these ecological periods is important for habitat management and conservation. Although calving areas are important, land managers need to recognize the importance of other seasonal ranges and ensure connectivity is maintained among these ranges.

Russell et al. (1993) defined 15 activity periods for Porcupine barren-ground caribou based on snow, plant, and insect phenology and changes in caribou movement rates. Based on these activity periods the seasonal ranges and sensitive habitats used by these caribou were mapped for management and conservation purposes (Committee 1993). Maier and White (1998) defined similar activity periods for migratory caribou in Alaska based on activities of captive and wild radio-collared animals. Although the location of most barren-ground caribou calving grounds in the NT and NU have been identified, little is known about the distribution of boreal, mountain woodland, and Dolphin and Union island caribou during calving. In addition, activity periods had not been defined based on analyses of subpopulation specific movement rates for any caribou ecotype in the NT and NU.

In Chapter three I examined movement rates of boreal, migratory and tundra-wintering barren-ground, and Dolphin and Union island caribou around calving to determine calving dates and locations. I used analysis of variance (ANOVA) of movement data for boreal, migratory and tundra-wintering barren-ground, and mountain caribou to identify biologically significant activity periods. These analyses provide the information required to map seasonal ranges, to examine the degree of spatial overlap among seasonal ranges used by individuals within and among caribou subpopulations, allow for the development of models to examine the patterns and intensity of range use (caribou-days of use), and allow for more inclusive consideration of caribou habitat in land use and management practices.

Why do we need to know how boreal caribou respond to seismic lines?

Boreal caribou are listed as threatened in Canada (COSEWIC 2002) and their populations have declined throughout much of their range in Canada (Canada 2009). In some areas these declines have been linked to the impacts of oil and gas exploration and development (Schneider et al. 2010) and in particular to the network of anthropogenic linear features used for resource access. Many wildlife species have been documented to avoid habitats with high densities of anthropogenic linear disturbances (McLellan and Shackleton 1988, James and Stuart-Smith 2000), resulting in functional habitat loss (Dyer et al. 2001, 2002, Weclaw and Hudson 2004, Linke et al. 2005), increased predations risk (James and Stuart-Smith 2000), and potentially reduced fitness (Frid and Dill 2002). Therefore, we need to understand how boreal caribou react to anthropogenic linear features such as seismic lines in order to manage industrial developments and impacts to maintain effective caribou habitat.

Seismic lines are the first and most extensive component of the oil and gas exploration network and are common features on NT landscapes. Over 100,000 km of seismic lines were cut in the Mackenzie River basin from 1960 to 1990 (National Energy Board Records). Construction of the proposed Mackenzie Valley Pipeline will likely result in an increase in oil and gas exploration activity and the density of seismic lines on the landscape. Although the impacts of linear disturbances on wildlife in northern environments have been poorly studied, it is clear that permafrost is easily degraded (Mackay 1970, Lambert 1972, Zoltai and Pettapiece 1973, Nicholas and Hinkel 1996) and vegetation is slow to recover (Billings 1987, Harper and Kershaw 1996). This suggests that 1) linear disturbance are more likely to alter wildlife habitat in the north; and 2) any alteration of wildlife habitat will last longer.

A number of researchers have assessed the response of boreal caribou to seismic lines however their results varied and some methods used did not appear to be appropriate. Dyer et al. (2001), using broad distance categories and time periods, found a seasonal response with maximum avoidance distances of 100 m during calving through early winter and 250 m in late winter in northeastern AB. In comparison, Antoniuk et al. (2007) found that boreal caribou did not avoid areas close to seismic lines in northeastern British Columbia (BC). However, Antoniuk et al. (2007) compared the distance between caribou use locations and seismic lines with those between random locations and seismic lines in randomly generated home ranges and, as a result, did not directly assess the response of caribou to these features. Antoniuk et al. (2007) also reported that caribou avoided areas more than 500 m from seismic lines, however, there were few areas more than 500 m from seismic lines within their study area.

Dyer et al. (2002) reported that caribou crossed seismic lines in proportion to their occurrence and as a result seismic lines were not considered to be barriers to caribou movement. However, Dyer et al. (2002) compared the rates at which caribou paths crossed real and simulated random seismic lines. A caribou's path provides a record of the caribou’s response to fixed features such as seismic lines within its home range. For caribou to cross seismic lines in proportion to their occurrence they must move randomly within their ranges. Therefore, I believe that the best way to determine whether caribou avoid crossing seismic lines or cross them in proportion to their occurrence is by comparing actual crossing rates with those for simulated random caribou paths.

Harron (2007) suggested that Dyer et al. (2001) overestimated the influence of seismic lines on woodland caribou habitat. As indicated by Dyer et al. (2001), there was an avoidance response, it varied by time period, and was greatest in the area near and diminished with distance from seismic lines (response gradient). Dyer et al. (2001) pooled data for all study animals and used broad distance categories and time periods to measured caribou responses to seismic lines within a narrow range of line densities (1.0 to 1.3 per km^2). As a result Dyer et al. (2001) may have underestimated the response. Because Dyer et al. (2001) measured the response of caribou to seismic lines over a narrow range of line densities, it is not known whether the response observed reflected selection or the inability to select optimal habitats (Caughley and Gunn 1996).

In Chapter four I examined the response of boreal caribou to seismic lines in six study areas with different ecological conditions and seismic line densities (0.12 to 3.32 km per km^2). This allowed me to determine whether observed responses reflected selection or the inability to select optimal habitats. I used 50-m distance intervals and 5-day time periods and used individual based models to examine the temporal and spatial response of caribou to seismic lines. I determined whether observed responses were consistent throughout the duration of the activity periods I identified for boreal caribou in Chapter 3. I assessed the barrier effects of seismic lines by comparing crossing rates of actual and simulated random caribou paths. I also measured the response of caribou to seismic lines by comparing travel rates during periods when they crossed and were not crossing seismic lines.

Why do we need to define critical habitat for boreal caribou?

Boreal caribou are listed as threatened in Canada (COSEWIC 2002) and as such “their critical habitats or habitats that are necessary for their long-term survival or recovery must be identified in the recovery strategies or action plans and be protected” (Statutes of Canada 2003). However this has been a difficult task because of their ecology. Six key things were known about boreal caribou when I began my analyses including: i) adult female and calf survival were the primary demographic factors that determined population growth rates (Hatter and Bergerud 1991), ii) females spaced away from conspecifics during calving to reduce predation risk (Stuart-Smith et al. 1997, McLoughlin et al. 2003), iii) females used areas up to 250 m near seismic lines less than expected or selected areas that were >250 m from these features to reduce predation risk (Dyer et al. 2001, 2002), iv) developments that fragmented habitat seem to reduce the effectiveness of the spacing-out strategy that boreal caribou used to avoid other ungulates and concomitant predation risk (Stuart-Smith et al. 1997); v) boreal caribou avoided areas disturbed by wildfires (Schaefer and Pruitt 1991), and vi) the spatial configuration of habitat at the range level was very important when assessing habitat quality for woodland caribou (O'Brien 2006). These factors played a significant role in how I defined critical habitat for boreal caribou.

In Chapter five I considered areas within caribou-seismic line avoidance zones as risky habitats and those that were beyond these zones as secure habitats for caribou. Because boreal caribou avoid areas disturbed by wildfires I classified secure habitats as unburned or burned. The amount and configuration of secure unburned habitats available in an area should indicate how successfully caribou can employ their anti-predator strategies and thus facilitate or enhance adult female and calf survival. I used multiple regression models to explore the relationship between population growth rates and the amount and configuration of secure unburned habitats available to and used by boreal caribou in six study areas with different ecological conditions and seismic line densities.

Synopsis

My thesis summarizes the results of the first multi-subspecies, multi-ecotype, and multi-subpopulation analysis of satellite location data conducted in the NT and NU, Canada. In Chapter 6 I identify the most significant results presented in Chapters 2 to 5 and discuss the implications of these results to the conservation and management of all caribou ecotypes in northern Canada.

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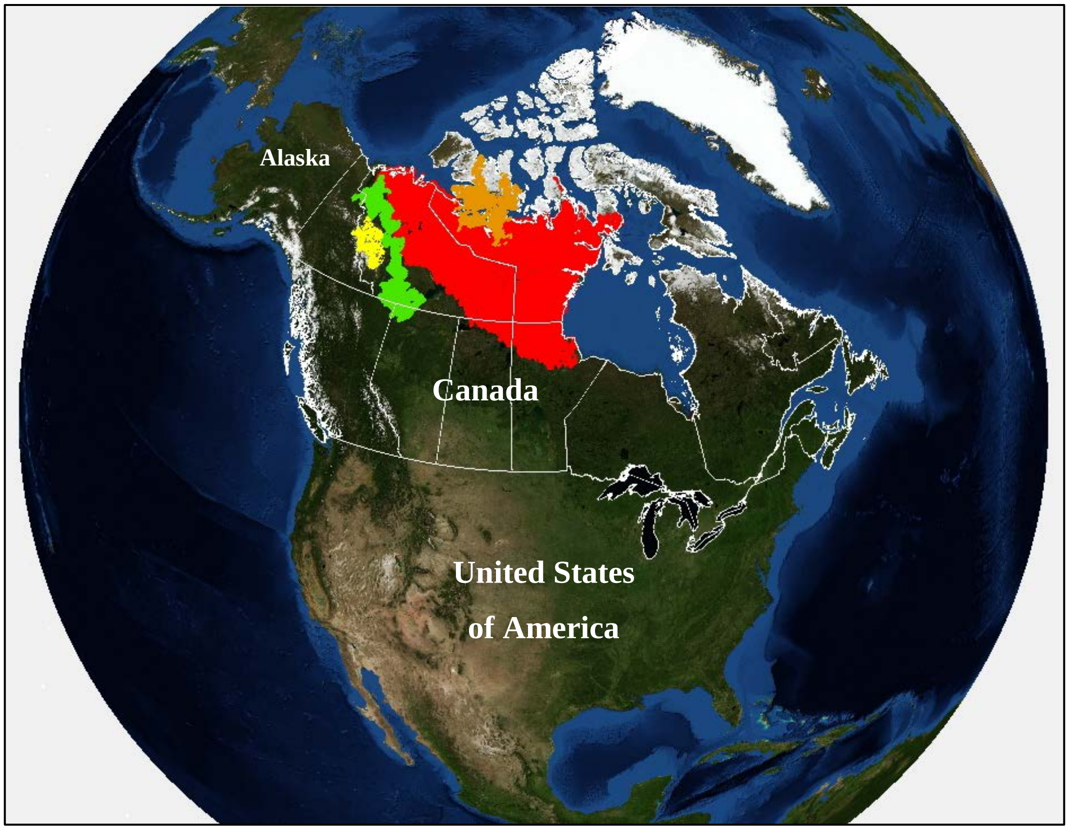

Fig. 1-1. Location of study area in Canada as defined by the distribution of satellite collared mountain woodland (yellow), boreal (light green), migratory and tundra-wintering barren-ground (red), and Dolphin and Union island caribou (orange).

Chapter 2 - Subpopulation Structure of Caribou in Arctic and Sub-Arctic Canada[1]

Introduction

Management, conservation, and biodiversity of species, subspecies, or ecotypes can only be addressed effectively if we understand how populations are structured in space. Andrewartha and Birch (1984) concluded that ‘natural populations’ consist of many interbreeding ‘local populations’ and that dispersal among local populations is almost certain. Little or no dispersal is expected among natural populations because they are isolated by barriers to movement. Wells and Richmond (1995) recommended that when groups of individuals are “spatially, genetically, or demographically” separated from each other the term population should be used and when they are not, one should use the terms “group, subpopulation, or local population”. Berryman (2002), attempting to clarify the terminology, defined a population as “a group of individuals of the same species that live together in an area of sufficient size to permit normal dispersal and/or migration behaviour and in which numerical changes are largely determined by birth and death rates”. Schaefer (2006), however, argued that Berryman's (2002) definition included vague and ambiguous terms like “together”, “sufficient”, “normal”, and “largely” that are open to interpretation. Further, Harwood (2009) argued that “we cannot assign an individual to the population unless we have defined the population and we cannot define the population until we have assigned all of the individuals”. Without an

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unambiguous definition, “we can only sample an area, and our sample cannot be assumed to be representative of more than this” (Harwood 2009).

A number of techniques have been used to identify subpopulations of animals for research and management including comparing the spatial distribution of individuals with that of a random distribution (Amarasekare 1994), hierarchical and/or fuzzy classification of movement data (Bethke et al. 1996, Schaefer et al. 2001, Klaver et al. 2008), movement and mtDNA data (Calambokidis et al. 2001), DNA data (Barr et al. 2008), and carbon and nitrogen stable isotopes (Witteveen et al. 2009). However, Harwood (2009) argued that populations are composed of a number of individuals whose membership to a population is determined by a “relevant degree of interaction” or connectivity to the rest of the population. Thus he argues that populations are defined by the “relationship between individuals” and not by “an externally imposed classification”.

Social relationships determine the degree of interaction or connectivity expected among individuals within a species, subspecies, or ecotype. As a result, behaviours such as spatial tenure (e.g., territories or overlapping home ranges), degree of sociality (e.g., solitary or gregarious), and movement ecology (e.g., migratory or non-migratory) determine, in part, how populations are structured. It is reasonable to hypothesize that populations of solitary or gregarious and migratory or non-migratory species may be structured differently. It is also reasonable to assume that populations are structured by area fidelity, habitat discontinuity, resource distribution in continuous habitats, and barriers to movement.

The objective of my study is to quantify the subpopulation structure of four behaviourally different caribou ecotypes including migratory and tundra-wintering barren-ground (*Rangifer tarandus groenlandicus*), Dolphin and Union island (*R. t. groenlandicus x pearyi*), and boreal (*R. t. caribou*) caribou in northern Canada using satellite telemetry data. Although I had insufficient location data to assess the subpopulation structure of the mountain woodland ecotype (*R. t. caribou*), I included information about their use of annual ranges for comparison. Migratory barren-ground caribou are usually found in large groups and females collectively migrate annually between winter ranges near or below tree line and calving grounds on the tundra (Banfield 1954). Tundra-wintering barren-ground caribou remain above tree line year round (Calef and Heard 1981) but little is known about their ecology. Seasonal movements and activities are synchronized among female barren-ground caribou (Maier and White 1998). Dolphin and Union island caribou also remain above tree line throughout the year. They collectively migrate over the sea ice between calving to autumn ranges on Victoria Island where they are geographically isolated from barren-ground caribou, and their winter ranges on mainland Nunavut (NU). Boreal caribou are sedentary and remain largely within the boreal forest throughout the year. Females are solitary (i.e., cows, cow-calf pairs) during pre-calving to late summer and form mixed sex groups of 3-8 or more caribou the rest of the year (Stuart-Smith et al. 1997, Metsaranta and Mallory 2007). Activities of female boreal caribou are coordinated in time but not in space and are thus more independent of conspecifics than female barren-ground caribou. Mountain woodland caribou occur in small groups most of the year and migrate annually to calving grounds in the mountains. Barren-ground caribou females have been assigned to subpopulations based on the belief that they aggregate on and maintain fidelity to specific calving grounds (Skoog 1968, Miller 1982). In contrast, boreal and Dolphin and Union island caribou disperse to calve (Bergerud et al. 2008).

I hypothesized that subpopulations of caribou within these ecotypes are largely structured by the degree of spatial affiliation that exists among individuals, migratory connectivity, habitat discontinuity, and/or barriers to movement. I hypothesized that these structures and behaviours could be quantified using hierarchical and fuzzy clustering. Because there are nine barren-ground caribou calving grounds in the Northwest Territories (NT) and NU (Fig. 2-1), I hypothesized that there should be nine subpopulations that are organized around the annual movements of females that used them. Because association during calving represents only a brief period in an annual cycle, I extended the definition of subpopulation to a more inclusive perspective that includes individuals that are spatially affiliated throughout most or all of the year. Female Dolphin and Union island caribou are most strongly affiliated during spring and fall migrations so I hypothesized that there should be one subpopulation that is organized as individuals and is structured by migratory connectivity and barriers to movement. Because boreal caribou are dispersed over the landscape and are weakly affiliated (i.e., are largely spatially independent) during much of the year, I hypothesized that there should be one subpopulation organized as individuals and, if subpopulations exist, they are primarily structured by habitat discontinuity. Because the behaviours of ecotypes and the distribution of resources within their subpopulation ranges vary, I hypothesized that this variation should be manifested in two ecologically important factors: annual home range size and path length.

Methods

Caribou were captured and handled according to standard operating procedures of the Northwest Territories Wildlife Care Committee or Nunavut Wildlife Live-capture Protocols (Campbell 2002) following methods in compliance with the Canadian Council on Animal Care. Animals were equipped with either ARGOS Doppler shift (DS) or Global Positioning System (GPS) satellite collars (Telonics, Mesa, Arizona, USA and Service Argos, Landover, Maryland, USA). DS and GPS collars provided locations on 1- to 10-day and 0.33- to 1-day intervals, respectively, although most DS collars provided locations on 1- to 5-day intervals. Locations were recorded as longitude and latitude coordinates and projected to the NAD 1983 projection datum of the North America Lambert Conformal Conic coordinate system. I converted longitude and latitude data to x, y coordinates using Hawth’s Tools (Beyer 2007). All geographic information system (GIS) analyses used ArcMap 9.3 (Environmental Systems Research Institute, Inc., Redlands, California, USA).

I used sums-of-squares agglomerative hierarchical linkage (Ward's; Bethke et al. 1996) and fuzzy *c*-means clustering methods (Schaefer et al. 2001) to identify and validate caribou subpopulations (Kos and Psenicka 2000). I conducted hierarchical clustering using PC-ORD 5 (MjM Software Design, Glenden Beach, Oregon, USA) and STATA 9 (STATCORP, College Station, Texas, USA), with the number of distinct subpopulations indicated by a sharp rise in the values of the post-hierarchical clustering Duda-Hart pseudo t-test (Rabe-Hesketh and Everett 2007). I conducted fuzzy *c*-means clustering using the program FUZME 2.0 (Minasny and McBratney 2002) with the diagonal distance transformation option to standardize measurements to equal variance and prevent y-coordinates from dominating x-coordinates (McBratney and Moore 1985, Klaver et al. 2008). I specified fuzzy exponents (*m*) in increments of 0.1 from 1.5 to 3.0 (Odeh et al. 1992b) and 2-15 potential subpopulations for barren-ground caribou and 2-99 potential subpopulations for boreal and Dolphin and Union island caribou. A maximum of 99 potential subpopulations can be specified in FUZME 2.0. The fuzzy performance index (FPI) and normalized classification entropy (NCE) validity functions were used to identify the optimal number of subpopulations (Odeh et al. 1992a) .

Fuzzy clustering is sensitive to data configuration (Ohashi 1984). My data spanned about 2400 km east-west, with the north-south span increasing from about 500 km in the west to 1600 km in the east. Fuzzy cluster analyses of all caribou data combined were affected by the predominantly east-west orientation of the data. For example, with each incremental increase in *m* from 2.0 to 3.0 more Dolphin and Union island caribou were assigned to adjacent barren-ground caribou subpopulations. I resolved configuration issues by analyzing data for i) migratory barren-ground caribou using calving grounds A, B, C, D, E-1, and F (west-central), ii) migratory barren-ground caribou using calving grounds C, D, E-

1, and F and Dolphin and Union island caribou (central), iii) migratory and tundra-wintering barren-ground caribou using calving grounds E including area E-1, F, G, H, and I (east-central; Fig. 2-1), and iv) boreal caribou separately (Fig. 2-2). Females using calving grounds E-1 and F provided continuity between the classifications of western and eastern migratory barren-ground caribou.

For cluster analyses, I sub-sampled the data to a 5-day interval because inter-location intervals varied among studies. I included individuals with ≥4 locations per month and full years of data in analyses to reduce sampling bias. I used matrices of median monthly interval x, y coordinates for west-central, central, and boreal caribou (24 variables) and 14-day interval x, y coordinates for east-central caribou (52 variables; Bethke et al. 1996). I used the median location to account for data asymmetries (Sokal and Rohlf 1998). I used higher resolution x, y coordinate data for the east-central area to increase the probability of separating migratory and tundra-wintering caribou subpopulations.

I used a two step approach to i) identify subpopulations that were distinct and well organized (here after distinct; Triantafilis et al. 2001); step one) and ii) determine how individuals within each subpopulation were organized (step two). Subpopulations that were formed by strong annual spatial affiliation among individuals were considered to be "robust" (hereafter robust subpopulations). Subpopulations that were comprised of individuals that were largely spatially independent of each other and were structured by habitat discontinuity, barriers to movement, or migratory connectivity were considered to be "organized as individuals" (hereafter subpopulations organized as individuals).

Subpopulations were distinct (step one) when the Duda-Hart pseudo t-test and the validity functions indicated the same number of subpopulations (Schaefer et al. 2001), ≥90% of individuals were assigned to the same subpopulations by hierarchical and fuzzy (*m*=2.0) clustering, and ≥90% of the individuals were consistently assigned to the same subpopulation by fuzzy clustering for most values of *m*. I determined assignment consistency by comparing each individuals subpopulation assignment at *m*=2.0 (moderate level of fuzziness) with those at *m*=1.5-1.9 (less fuzzy) and m=2.1-3.0 (more fuzzy).

To determine how individuals within subpopulations were organized (step two), I conducted fuzzy clustering on the data for individuals that were assigned to each distinct subpopulation for *m*=2.0 in step one. I used only fuzzy clustering because hierarchical clustering will generate group structures even when none exist (Pillar 1999). Subpopulations were robust when the fuzzy clustering validity functions were $\geq$0.90 for most *m*$\geq$2.0 indicating that there were no significant substructures in the data. When distinct subpopulations were not robust, the validity functions either indicated that i) there were significant substructures in the data or ii) they were organized as individuals. If significant substructures were indicated and sample sizes were adequate, I repeated step two until analyses indicated subpopulations were robust or were organized as individuals. Subpopulations were organized as individuals when the validity functions approached 0 when the specified number of potential subpopulations equaled *n*.

Utilization Distributions

I used the GIS program Home Range Tool (HRT; Rodgers et al. 2007) to generate fixed kernel utilization distributions (50, 60, 70, 80, 90, and 95% UD) for each barren-ground, island, and boreal caribou. I used the reference bandwidth, a raster cell size of 1000 m, and minimized the extent of each UD. I calculated mean 90% UD for barren-ground caribou that were assigned to each subpopulation by hierarchical and fuzzy clustering (excluding females that used multiple calving grounds) and island caribou. I considered the mean 90% UD as the core range of barren-ground and island caribou subpopulations but where appropriate, I clipped them to the coastline to exclude marine areas that were not used. I mapped boreal caribou subpopulation core ranges by merging all individual 90% UD. Each caribou contributed equally to the delineation of subpopulation core ranges.

Home range size and migratory path length

I generated annual (calculated from the date of capture) minimum convex polygons (MCPs) and paths (straight-line distances between sequential locations) for each caribou using Hawth's Tools (Beyer 2007). To ensure an unbiased sample, I included data for GPS and DS collared individuals with ≥329 locations each year (90% of possible locations for 1-day inter-location interval collars) and ≥66 locations each year (90% of possible locations for a 5-day inter-location interval collar), respectively. I measured MCP areas and path lengths, standardized these to 365 days (areas or length divided by number of days tracked x 365), and normalized them using a log10 transformation. I used analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) pair-wise comparisons (SPSS 11.5, Chicago, Illinois, USA; Maier and White 1998) to determine if MCP areas and path lengths varied significantly among ecotypes, study areas (boreal caribou), and subpopulations (migratory and tundra-wintering barren-ground caribou). I analyzed DS and GPS collar data separately because MCP areas and path lengths are influenced by sample size (Borger et al. 2006).

Results

I obtained full years of data for 360 barren-ground, 140 boreal, 10 mountain woodland, and 25 island caribou (Tables 2-1 and 2-2 and Appendix 2-A). I excluded 11 barren-ground caribou from analyses: seven because they remained on late winter ranges during the calving period, three had insufficient data, and one because its activity areas were located between but overlapped the distribution of the Beverly and Qamanirjuaq barren-ground subpopulations. Cluster analyses produced unusable results when this animal was included. For barren-ground caribou with $\geq$1.95 years of data, 91.4% (180/197), 8.1% (16/197), and 0.5% (1/197) used one, two, and three calving grounds, respectively. A tundra-wintering barren-ground caribou used three calving grounds.

Migratory barren-ground caribou formed six distinct and robust subpopulations including the Cape Bathurst, Bluenose-West, Bluenose-East, Bathurst, Beverly, and Qamanirjuaq (Table 2-3). Tundra-wintering barren-ground caribou formed three distinct subpopulations: the Lorillard was robust but the Queen Maude Gulf and Wager Bay were organized as individuals (Table 2-3). Dolphin and Union island caribou formed one distinct subpopulation that was organized as individuals. Boreal caribou formed two distinct subpopulations that were organized as individuals.

Two factors influenced analyses of east-central caribou data including i) ranges of migratory and tundra-wintering caribou overlapped in this area and ii) the Beverly subpopulation was changing use of calving grounds. By using a two step analytical approach I separated individuals belonging to these ecotypes. Step one indicated three distinct subpopulations dominated by Qamanirjuaq, Beverly, and tundra-wintering caribou (Table 2-3). Step two indicated the Qamanirjuaq dominated subpopulation was robust (Table 2-3). For the Beverly dominated subpopulation, the validity functions for m=1.8-2.2 (moderate level of fuzziness) indicated three distinct subpopulations dominated by i) females that used calving ground F but included some that used E-1 or both (Beverly A), ii) females that used calving ground E-1 but included some that used F or both (Beverly B), and iii) females that used only calving ground E including area E-1 (Queen Maude Gulf A, Table 2-3). Validity functions for the pooled Beverly A and B data indicated that these females formed one of the most robust subpopulations of migratory barren-ground caribou I examined (Table 2-3). The Queen Maude Gulf A females were organized as individuals (Table 2-3). For the tundra-wintering caribou dominated subpopulation, validity functions for m=2.0-2.4 (moderate level of fuzziness) indicated three distinct subpopulations dominated by females that used calving ground H (Lorillard), I (Wager Bay), or E (Queen Maude Gulf B), respectively (Table 2-3). The Lorillard subpopulation was robust (Table 2-3). Although Queen Maude Gulf A (n=11) and B (N=4) females may belong to different subpopulations, I pooled them to increase *n* to test for robustness. The pooled Queen Maude Gulf A and B (n=15) and Wager Bay (n=11) females were organized as individuals (Table 2-3).

All barren-ground caribou subpopulations were dominated by females that used one calving ground except the Beverly (Table 2-3). The Beverly subpopulation included females that used calving grounds F or E-1 or changed use from F to E-1 (Fig. 2-1). The Queen Maude Gulf subpopulation used calving ground E including area E-1. Therefore, I documented the use of two calving grounds by one barren-ground caribou subpopulation and use of one calving ground by two barren-ground caribou subpopulations.

Utilization distributions

Each subpopulation of barren-ground, island, and boreal caribou used distinct core ranges (Fig. 2-3). The mean area of overlap among core ranges of the robust migratory Cape Bathurst, Bluenose-West, Bluenose-East, and Bathurst barren-ground caribou subpopulations was 18% (range 5-27%). In comparison, the mean area of overlap among core ranges of Beverly females that used calving grounds F, E-1, or E-1 and F was 63% (range 56-72%) or about 3 times greater than for other robust migratory subpopulations (Fig. 2-4). These three ranges reflect the Beverly subpopulations change in calving ground use.

Annual home range and path length

Mean annual-range areas (DS collars, ANOVA $F_{4,597}$=466.0, P<0.001) and path lengths (DS collars, ANOVA $F_{4,597}$=339.6, P<0.001) varied significantly among ecotypes (Table 2-4 and 2-5). Annual-ranges used by boreal and migratory barren-ground caribou were significantly smaller and larger, respectively, than those for all other ecotypes (Tukey's HSD pair-wise comparisons, $P<0.05$). For boreal caribou, mean annual-range areas (GPS collars, ANOVA $F_{3,145}=9.7$, $P<0.001$) and path lengths (GPS collars, ANOVA $F_{3,145}=4.8$, $P=0.003$) varied significantly among study areas (Tables 2-4 and 2-5). I did not find a clear pattern for these differences. For migratory barren-ground caribou, mean annual-range areas (DS collars, ANOVA $F_{5,332}=179.9$, $P<0.001$) and path lengths (DS collars, ANOVA $F_{5,332}=185.4$, $P<0.001$) varied significantly among subpopulations (Tables 2-4 and 2-5). A significant west to east positive cline (Cape Bathurst <Bluenose-West < Bluenose-East < Bathurst < Beverly = Qamanirjuaq subpopulations) was evident in annual-range sizes and path lengths for these caribou (Tukey's HSD pair-wise comparisons, $P<0.05$). For tundra-wintering caribou, mean annual ranges (DS collars, ANOVA $F_{2,74}=21.5$, $P<0.001$) and path lengths (DS collars, ANOVA $F_{2,74}=16.2$, $P<0.001$) varied significantly among subpopulations (Table 2-4 and 2-5). The eastern-most Lorillard and Wager Bay subpopulations had significantly smaller annual ranges and shorter path lengths than the western-most Queen Maude Gulf subpopulation (Tukey's HSD pair-wise comparisons, $P<0.05$).

Discussion

The concept of a population as a group of interbreeding individuals that have little or no contact with other similar groups is different from what really occurs (Caughley 1980). Theoretical and empirical evidence indicates that population types range from “classical closed populations to interacting systems of subpopulations" (Thomas and Kunin 1999). The population is a central concept for ecology (Berryman 2002) and its complexities must be taken into account for effective management (Schaefer 2006, Harwood 2009). Because population size and distribution will change over time (Harwood 2009), the temporal and spatial characteristics used to define them must be clear to avoid confusion and misunderstanding (Olexa and Gogan 2007).

Space use patterns and affiliations of individuals indicate how populations are structured (Wells and Richmond 1995) and our ability to document these patterns and affiliations has been enhanced by the availability of continuous high resolution location data acquired through the use of satellite collars. Sufficient numbers of collars must be adequately distributed in the area of interest and tracked long enough at an appropriate resolution so that the resulting observations and conclusions drawn are biological meaningful and not artifacts of sampling design (Klaver et al. 2008, Harwood 2009). At present, our ability to assess variations in space use patterns among individuals at finer temporal and spatial scales in large subpopulations, e.g. barren-ground caribou, is limited by the proportionately small number of animals that have been tracked annually.

Fuzzy classification has enhanced our ability to assign individuals to groups when their affiliations or the boundaries among groups are uncertain or vague (McBratney and Odeh 1997). Schaefer et al. (2001) and Klaver et al. (2008) used fuzzy clustering to define subpopulations of cervids. Using a novel approach, I used fuzzy clustering to identify distinct subpopulations in four behaviourally different caribou ecotypes and described how they were structured. Using this approach, I verified that the migratory Cape Bathurst, Bluenose-West, Bluenose-East, Bathurst, Beverly, and Qamanirjuaq barren-ground caribou subpopulations, that were previously recognized using the calving ground classification system (Banfield 1954, Thomas 1969, Parker 1972, Heard 1983, Nagy et al. 2005) were robust. Data for five of these migratory subpopulations were obtained over 14-17 years indicating that subpopulation structure and area fidelity was maintained over time. In addition, I verified that the tundra-wintering Queen Maude Gulf, Lorillard, and Wager Bay subpopulations previously described by Calef and Heard (1981) and Heard et al. (1987) were distinct but only the Lorillard was robust. Because the movements of the Queen Maude Gulf and Wager Bay subpopulations were unconstrained by habitat discontinuity or barriers to movement, they may be behaviourally different from other barren-ground caribou or sample sizes were inadequate to determine spatial affiliation. Additional satellite-tracking studies are required to understand the subpopulation structure of tundra-wintering caribou.

Females in five of the six robust migratory barren-ground caribou subpopulations used one calving ground and supported the concept of calving ground fidelity. However, by 2010, Beverly females had largely abandoned their “traditional” calving ground in favor of one used by the Queen Maude Gulf subpopulations. This shift in use likely began in the mid 1990’s. The distance between geographic centers of calving grounds used by Beverly females during 2006 to 2008 was approximately 245 km. The Bathurst subpopulation made a similar shift in calving ground use between 1986 and 1996. The distance between geographic centers of calving grounds used by Bathurst females before 1987 and in 1996-2010 was approximately 250 km. Bathurst females also calved on a number of sites between these two areas over a 10 year transition period (Sutherland and Gunn 1996). In Alaska, Hinkes et al. (2005) documented three patterns of calving ground use by barren-ground caribou including subpopulations that: i) maintained annual fidelity to the same calving ground, ii) maintained fidelity to one calving ground for a period, alternated use between this and a new one for a period, and then used only the new one, and iii) following the influx of one subpopulation into the winter range of second, most but not all of the females from the second began using the calving ground of the first. These examples indicate that shifts in calving ground use over time may be common and should be anticipated to ensure that areas that are suitable for calving but are currently unused, are managed for potential future use. In addition, and contrary to Skoog (1968) barren-ground caribou cannot be reliably assigned to subpopulations based on calving ground use alone.

I believe that definitions requiring barren-ground caribou subpopulations to consistently use the same “traditional” calving grounds promote a restricted view of the ecology of the species. Changes in calving ground use over time by subpopulations would, by some definitions, require designation of new subpopulations rather than recognizing the relocation of existing ones. I believe that a more meaningful and robust method of classifying subpopulations of barren-ground caribou is one based on the annual spatial affiliation of females and not just on their calving distribution. Thus I recommend a change in the classification method to one based on my approach. My definition is consistent with, but is less restrictive than Miller's (1982) in that it allows for i) distinct subpopulations to have adjacent calving grounds, ii) one subpopulation to use two or more calving grounds over time, or iii) two or more subpopulations to use the same calving ground.

I documented an east-west cline in annual home range sizes and path lengths among migratory barren-ground caribou subpopulations further supporting the subpopulation structure I identified. This variation may be related to differences in population size, habitat quality, proportions of subpopulation ranges that are above tree line, topography, weather patterns, and predator diversity and density. The more than doubling of annual migratory path lengths between western and eastern migratory subpopulations suggests that the energetic costs to caribou of disturbances that may alter their normal patterns of activity or range use should be considered when effects of petroleum and mineral exploration and development, vehicle traffic, and low level aircraft over-flights are assessed.

Dolphin and Union island caribou were organized as individuals. Because these caribou are migratory and are either geographically or temporally isolated from most other caribou during the year, they are likely structured by migratory connectivity and barriers to movement. These caribou are behaviourally similar to boreal and barren-ground caribou: they are organized as individuals but are structured in part by migratory connectivity.

Boreal caribou formed two subpopulations of females organized as individuals across ranges separated by large areas disturbed by wildfires in the central NT (Government of the Northwest Territories fire history data). This habitat discontinuity may be temporary if natural habitat regeneration occurs. My findings are consistent with the observations of Bergerud (1996) that boreal caribou tend to form a near-continuum across a region of favorable calving sites.

Mean annual home ranges for boreal caribou in my study areas were 6-14 times larger than the smallest and up to two times larger than the largest mean annual ranges reported in Alberta (Stuart-Smith et al. 1997) and Saskatchewan (Rettie and Messier 2001). Stuart-Smith et al. (1997) obtained caribou locations about every 2 weeks while Rettie and Messier (2001) obtained locations every 2- to 4-days and thus differences among home ranges in these areas may in part be a result of sampling frequency (Borger et al. 2006). In many parts of Alberta, forest management practices, agricultural expansion, and oil, gas, and mineral resource exploration and extraction activities have resulted in loss, alteration, and fragmentation of caribou habitat (McLoughlin et al. 2003). In Alberta, boreal caribou currently occupy remnant stands of boreal forest and their movements may be further constrained by development impacts within these areas (Dyer et al. 2002) possibly leading to smaller annual home ranges. In the NT most of the boreal caribou range is comparatively pristine and continuous thus their movements may not be constrained by human impacts possibly leading to larger home ranges.

Harwood (2009) posed the question, that “given a group of individual organisms, dispersed over space and/or time, with a variation in their degree of connectivity to the other individuals, can we (i) subdivide these individuals into two or more subgroups and/or (ii) take a sample of these individuals which is representative of the whole group or subgroups?” I show that an externally imposed classification system, i.e., fuzzy clustering, can be used to assign individuals to distinct well organized subpopulations. Demographic information such as population estimates, pregnancy and parturition rates, and causes and rates of mortality can be obtained by tracking individuals within these subpopulations. The factors structuring these subpopulations, i.e., strong spatial affiliation among its members or environmental conditions will indicate whether these data are representative of robust subpopulations (e.g., migratory barren-ground caribou) or geographic areas (e.g. boreal caribou).

The only way to understand caribou population ecology without influencing their behaviour is by incorporating satellite tracking in study designs. The deployment of satellite collars is initially invasive but well designed long-term high resolution satellite-tracking studies (i.e., using GPS collars), in combination with rigorous analyses of the resulting data using statistical procedures like fuzzy clustering, provide an opportunity to obtain biological information critical for management decisions. Clearly, the benefit of improved technology is that we can define and track changes in population structure and other important ecological processes over time. This is particularly important when considering the potential impacts of natural and anthropogenic disturbances, including climate change, on caribou and their habitats and on the northern people that depend on them.

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Table 2-1. Numbers of female caribou tracked with satellite collars for full years and included in hierarchical and fuzzy cluster analyses by matrix interval, ecotype, subpopulation[1], and calendar years tracked[2] in the Northwest Territories, Nunavut, and northern Alberta, Canada (1993–2008).

Caribou ecotype and subpopulation[1]	Numbers of caribou tracked by calendar year[2]																
	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	total
1) Matrix interval: 12 month x, y coordinates (24 variables)																	
Migratory Barren-ground																	
Cape Bathurst				5	5	4	6	5	1	8	8	4	6	14	21	23	39
Bluenose-West				2	4	5	11	9	4	5	4	2	8	13	20	25	44
Bluenose-East				3	5	9	8	7	2		3	3	17	20	22	28	51
Bathurst				7	7	18	15	14	13	7	11	13	17	16	22	18	52
Beverly			1	4	3	3		1	4	8	5	3	7	19	24	42	62
Total			1	21	24	39	40	36	24	28	31	25	55	82	109	136	248
Boreal										2	10	15	49	62	73	85	140
Dolphin and Union island							16	16	14	11	14	9	1				25
2) Matrix interval: 26 2-week x, y coordinates (52 variables)																	
Migratory and tundra-wintering barren-ground																	
Beverly			2	3	3	2			4	5	3	2	7	18	25	42	53
Quanmanirjuaq	4	5	7	5	9	8	8	8	8	7	6	13	10	22	22	29	61
Queen Maude Gulf				2	2	2			1	2	4	3	3	3	3	9	15
Lorillard						2	9	12	11	13	13	13	9	6	1		21
Wager Bay								4	4	3	8	7	4	2			11
Total	4	5	9	10	14	14	17	24	28	30	34	38	33	51	51	80	161

[1] Assignment of caribou to subpopulations was based on hierarchical and fuzzy (fuzzy exponent m=2) classification.

[2] Year= years when individuals were tracked for all or a portion of a calendar yea

Table 2-2. Numbers of full years female caribou were tracked using satellite collars and included in hierarchical and fuzzy cluster analyses by matrix interval, ecotype, and subpopulation in the Northwest Territories, Nunavut, and northern Alberta, Canada (1993-2008).

Caribou ecotype and subpopulation[1]	Numbers of years caribou tracked							
	1	2	3	4	5	6	7	Total
1) Matrix interval : 12 monthly x, y coordinates (24 variables)								
Migratory Barren-ground								
Cape Bathurst	13	11	8	6	1			39
Bluenose-West	22	11	6	4		1		44
Bluenose-East	25	9	8	9				51
Bathurst	12	17	11	8	4			52
Beverly	32	16	9	4	1			62
Total	104	64	42	31	6	1		248
Boreal	58	57	21	4				140
Dolphin & Union island	9	5	6	5				25
2) Matrix interval: 26 2-week x, y coordinates (52 variables)								
Migratory and tundra-wintering barren-ground								
Beverly	26	13	9	4	1			53
Qamanirjuaq	22	12	21	5		1		61
Queen Maude Gulf	8	5	1	1				15
Lorillard	3	6	5	1	3	2	1	21
Wager Bay	4	3	3	1				11
Total	63	39	39	12	4	3	1	161

[1] Assignment of caribou to subpopulations was based on hierarchical and fuzzy (fuzzy exponent *m*=2) classification.

Table 2-3. Results of hierarchical and fuzzy cluster analyses used to identify distinct and robust subpopulations of barren-ground, Dolphin and Union island, and boreal caribou in the Northwest Territories, Nunavut, and northern Alberta, Canada.

	Tests for distinct subpopulations[1]							
	Concordant classification			**Assignment consistency (fuzzy clustering)**				
Areas and subpopulations (subpopulation calving ground)	**No. subpop-ulations**	**Range of *m* when no. of subpop-ulations concordant**	**No. caribou assigned to same classes by both cluster methods**	**No. caribou classified consistently**	**Range of *m***	**Test for robust subpopulations (range of *m* when validity functions were $\geq$0.90 or minimized at individuals)**[2]	**Subpop-ulation robust**	**No. caribou and calving grounds used**
i) West-central area	5	1.9-2.9	244/248 (98.4%)	247/248 (99.5%)	$1.8 \leq m \leq 2.9$			
Cape Bathurst (A)						$2.3 \leq m \leq 3.0$	yes	n=39 A=36 A&B=1 B=2
Bluenose-West (B)						$2.0 \leq m \leq 3.0$	yes	n=44 B=42 C=2
Bluenose-East (C)						$1.9 \leq m \leq 3.0$	yes	n=51 C=49 B&C=1 D=1
Bathurst (D)						$1.8 \leq m \leq 3.0$	yes	n=52 D=45 C&D=2 D&E=4 E=1
Beverly (E and F)						$2.0 \leq m \leq 3.0$	yes	n=62, E=46 F=9 F & E=7
ii) Central area[3]	4	1.5-3.0	188/191 (98.4%)	190/191 (99.5%)	$1.5 \leq m \leq 3.0$			
Dolphin and Union island						25 individuals for $1.5 \leq m \leq 3.0$	no	n=25 dispersed calving
iii) East-central area	3	1.5-3.0	158/161 (98.0 %)	160/161 (99.4%)	$1.5 \leq m \leq 3.0$			
Qamanirjuaq (G)						$1.7 \leq m \leq 3.0$	yes	n=61 G=61
Beverly (E and F)	3	1.8-2.2	52/64 (82.4%)	61/64 (95.3%)	$1.2 \leq m \leq 2.2$			
Beverly A								n=21 E=7 F=9 F & E=5
Beverly B								n=32 E=29 F=1 F & E=2
Beverly A & B						$1.9 \leq m \leq 3.0$	yes	n=53 E=36 F=10 F & E=7
[4]QMG A (E)						11 individuals for $1.5 < m < 3.0$	no	n=11 E=11
Tundra-wintering	3	$2.0 \leq m \leq 2.4$	33/36 (91.7%)	33/36 (92%)	$1.5 \leq m \leq 3.0$			
QMG B (E)						small n	n/a	n=4 E=3 I=1
Lorillard (H)						$2.0 \leq m \leq 3.0$	yes	n=21 H=18 H & I=2 I=1
Wager Bay (I)						11 individuals for $1.5 \leq m \leq 3.0$	no	n=11 I=8 H & I=2 H=1
QMG A & B (E)						15 individuals for $1.5 \leq m \leq 3.0$	no	n=15 E=14 I=1
iv) Boreal	2	1.5-3.0	140/140 (100%)	131/140 (93.6%)	$1.5 \leq m \leq 3.0$			
Northern						57 individuals for $1.5 \leq m \leq 3.0$	no	n=57 dispersed calving
Southern						83 individuals for $1.5 \leq m \leq 3.0$	no	n=83 dispersed calving

[1] For subpopulations to be distinct, the post-hierarchical clustering Duda-Hart pseudo t-test and both fuzzy clustering validity functions had to indicated the same number of subpopulations (Appendix B and C), $\geq$90% of individuals had to be assigned to the same subpopulations by hierarchical and fuzzy (m=2) clustering (concordant classification; Appendix D); and $\geq$90% of individuals had to be consistently assigned to the same subpopulation by fuzzy clustering for most values of m (assignment consistency). Assignment consistency was determined by comparing each individuals subpopulation assignment at m=2.0 (moderate level of fuzziness) with those at m=1.5-1.9 and m=2.1-3.0.

[2] For a subpopulation to be robust, the fuzzy clustering validity functions (fuzzy performance index and normalized classification entropy) had to be $\geq$0.90 for most $m \geq 2.0$ indicating females were strongly spatially affiliated.

[3] The central area also included the Bluenose-east, Bathurst, and Beverly subpopulations; results of tests for robustness are given under the west-central area.

[4] QMG=Queen Maude Gulf.

Table 2-4. Sizes of annual minimum convex polygons (MCPs) for boreal, mountain woodland, Dolphin and Union island, and barren-ground caribou tracked using satellite collars in the Northwest Territories, Nunavut, and northern Alberta (1993-2009).

Caribou ecotypes[1]	Annual MCPs for GPS[2] satellite collared caribou							Annual MCPs for DS[2] satellite collared caribou						
	Location interval	Caribou (n)	MCPs (n)	Mean area (km^2)	STDEV	Min area (km^2)	Max area (km^2)	Location interval	Caribou (n)	MCPs (n)	Mean area (km^2)	STDEV	Min Area (km^2)	Max Area (km^2)
Ecotypes														
Boreal	8-hr	85	149	2478	1512	249	7466	1- to 5-day	55	104	2122	1644	206	10120
Mountain woodland								3-day	10	31	14460	9513	7	31674
Dolphin and Union island								1- to 20-day	25	52	36844	16409	10502	83025
Tundra-wintering barren-ground	1-day	6	6	93902	33596	65636	158066	1- to 10-day	28	66	43245	29780	3346	125312
Migratory barren-ground	8-hr	133	218	136367	85650	8487	357389	1- to 10-day	154	343	107574	60002	1577	306830
Boreal caribou study areas														
Gwich'in Settlement Area	8-hr	26	48	2951	1528	476	7211	1- to 5-day	12	22	3227	2044	561	10120
Sahtu Settlement Area	8-hr	18	32	1878	1590	659	7466	1- to 5-day	1	4	924	208	738	1157
Cameron Hills/South Slave	8-hr	29	49	2787	1392	434	6217	1- to 5-day	16	23	2061	1473	837	8007
Dehcho	8-hr	12	20	1549	832	249	3391	1- to 5-day	26	55	1792	1388	206	6229
Migratory barren-ground														
Cape Bathurst	8-hr	18	33	21642	8928	8487	64947	1- to 10-day	17	41	19137	7064	1577	36959
Bluenose-West	8-hr	19	33	47859	11654	21456	68267	1- to 10-day	22	50	60504	19563	21407	105696
Bluenose-East	8-hr	15	19	112125	24977	64721	161884	1- to 10-day	31	61	98429	42056	26837	185192
Bathurst	8-hr	1	1	113153		113153	113153	1- to 10-day	38	92	123220	41086	47470	254009
Beverly	12-hr	44	65	172189	55391	93270	355946	1-day	13	30	159693	49041	72298	306830
Qamanirjuaq	1-day	36	67	208323	60252	37797	357389	1- to 10-day	31	64	158726	48373	66769	258710
Tundra-winter barren-ground														
Lorillard								1- to 10-day	18	51	39717	27875	3346	123812
Wager Bay								1- to 10-day	9	14	50235	28741	8497	97502
Queen Maude Gulf	1-day	6	6	93902	33596	65636	158066	1- to 5-day	1	1	125312		125312	125312
Total		224	373						272	596				

[1] Values for migratory and tundra-wintering barren-ground and island caribou are for subpopulations.

[2] GPS=Global Positioning System, DS=Doppler Shift.

Table 2-5. Annual-path lengths for caribou tracked using satellite collars in the Northwest Territories, Nunavut, and northern Alberta, Canada (1993-2009).

Caribou ecotypes[1]	Annual path lengths for GPS[2] satellite collared caribou							Annual path lengths for DS[2] satellite collared caribou						
	Location interval	Caribou (n)	Path lengths (n)	Mean length (km)	Stdev	Min length (km)	Max length (km)	Location interval	Caribou (n)	Path lengths (n)	Mean length (km)	Stdev	Min length (km)	Max length (km)
Ecotypes														
Boreal	8-hr	85	149	1204	245	644	2022	1- to 5-day	55	104	620	182	213	1228
Mountain woodland								3-day	10	31	1140	380	241	1747
Dolphin and Union island								1- to 20-day	25	52	1323	285	774	1800
Tundra-wintering barren-ground	1-day	6	6	2461	238	2111	2791	1- to 10-day	28	66	1678	427	653	2809
Migratory barren-ground	8-hr	133	218	3119	707	1519	4847	1- to 10-day	154	343	2249	646	658	4006
Boreal caribou study areas														
Gwich'in Settlement Area	8-hr	26	48	1263	278	735	2022	1- to 5-day	12	22	744	213	438	1228
Sahtu Settlement Area	8-hr	18	32	1180	213	720	1667	1- to 5-day	1	4	500	62	422	571
Cameron Hills/South Slave	8-hr	29	49	1229	216	684	1659	1- to 5-day	16	23	615	145	383	863
Dehcho	8-hr	12	20	1038	211	644	1417	1- to 5-day	26	55	581	166	213	972
Migratory barren-ground														
Cape Bathurst	8-hr	18	33	2041	193	1593	2461	1- to 10-day	17	41	1155	242	658	1702
Bluenose-West	8-hr	19	33	2488	259	1858	3057	1- to 10-day	22	50	1751	276	1113	2284
Bluenose-East	8-hr	15	19	3256	258	2757	3725	1- to 10-day	31	61	2132	363	1332	2755
Bathurst	8-hr	1	1	2865		2865	2865	1- to 10-day	38	92	2492	346	1746	3592
Beverly	12-hr	44	65	3592	457	2603	4847	1-day	13	30	2820	363	1889	3592
Qamanirjuaq	1-day	36	67	3466	494	1519	4721	1- to 10-day	31	64	2788	502	1849	4006
Tundra-winter barren-ground														
Lorillard								1- to 10-day	18	51	1730	411	653	2809
Wager Bay								1- to 10-day	9	14	1462	438	679	2489
Queen Maude Gulf	1-day	6	6	2461	238	2111	2791	1- to 5-day	1	1	2022		2022	2022
Total		224	373						272	596				

[1] Values for migratory and tundra-wintering barren-ground and island caribou are for subpopulations.

[2] GPS=Global Positioning System, DS=Doppler Shift.

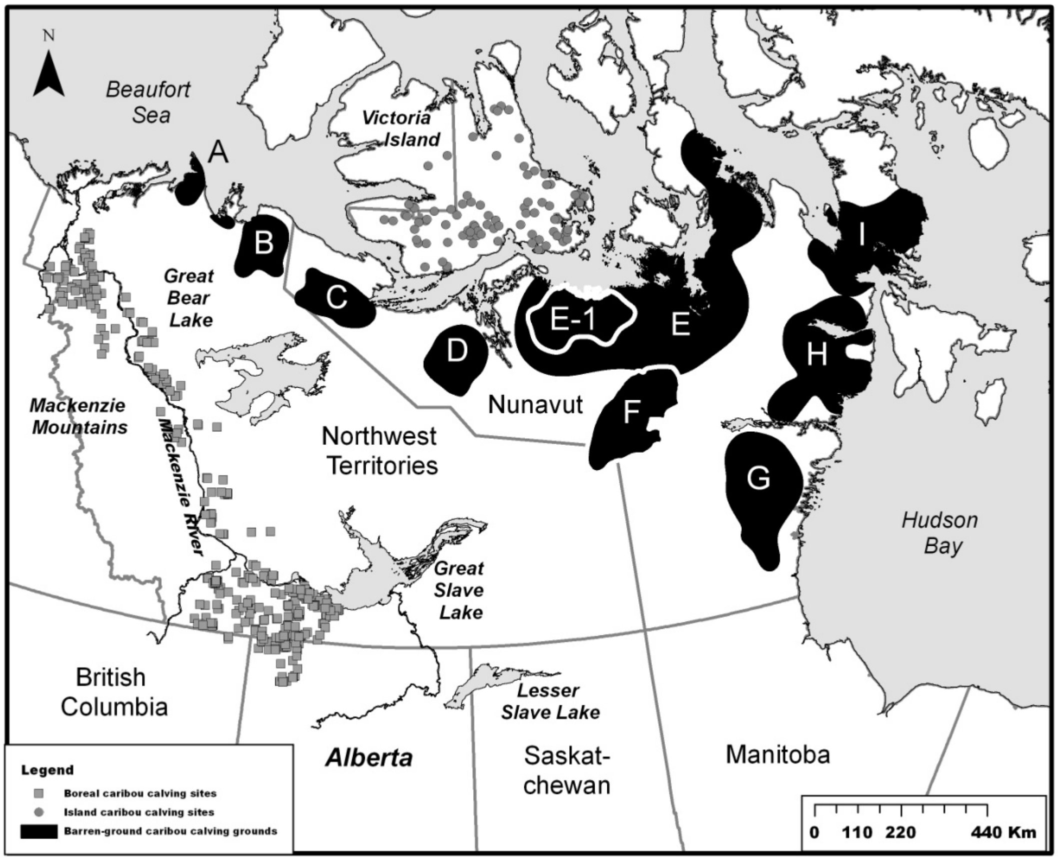

Figure 2-1. Barren-ground, Dolphin and Union island, and boreal caribou calving grounds or calving sites in the Northwest Territories, Nunavut, and northern Alberta (J .A. Nagy, *unpublished data*).

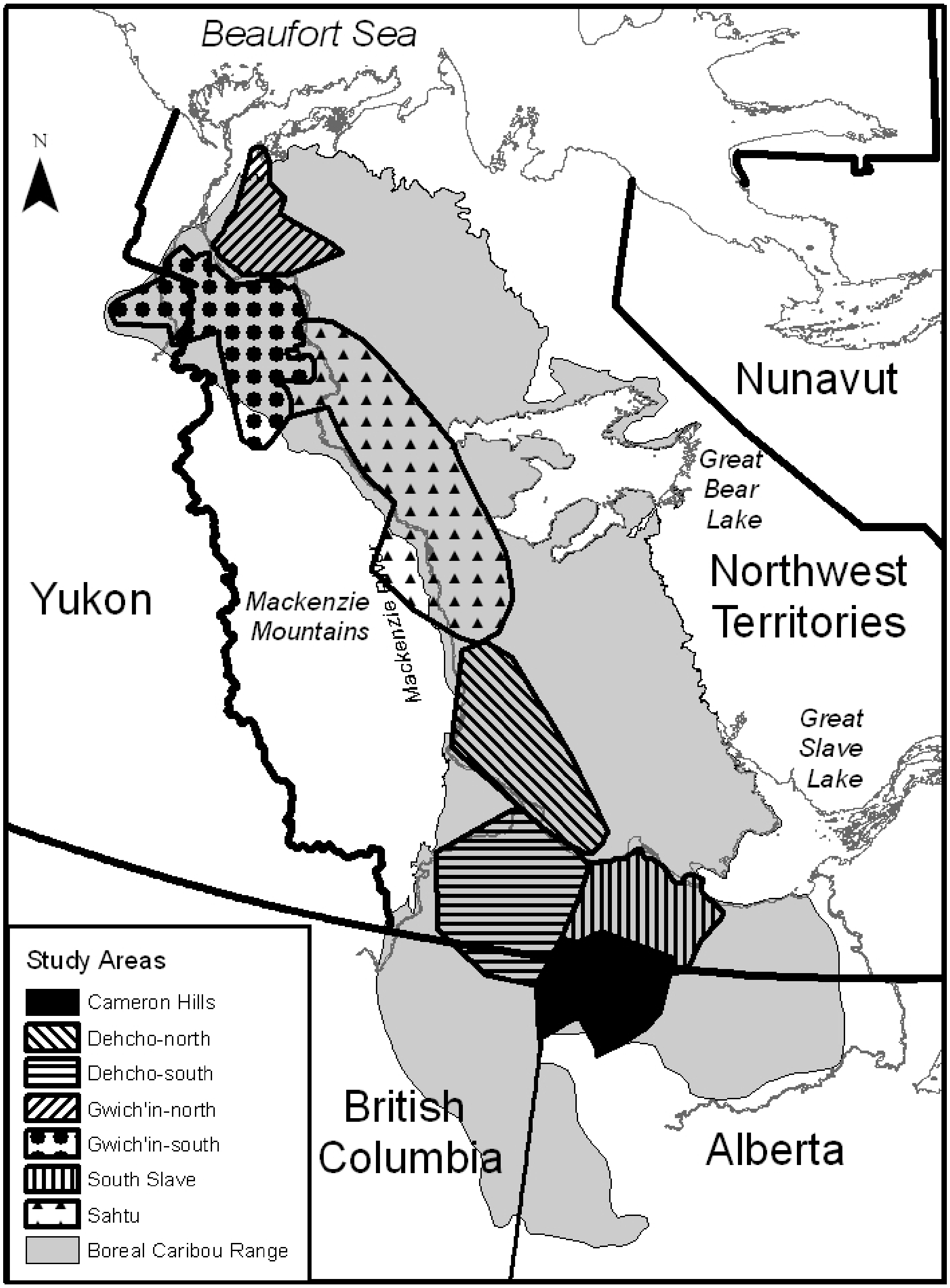

Figure 2-2. Location of the boreal and mountain (Mackenzie Mountains) caribou study areas in the Northwest Territories and northern Alberta, Canada.

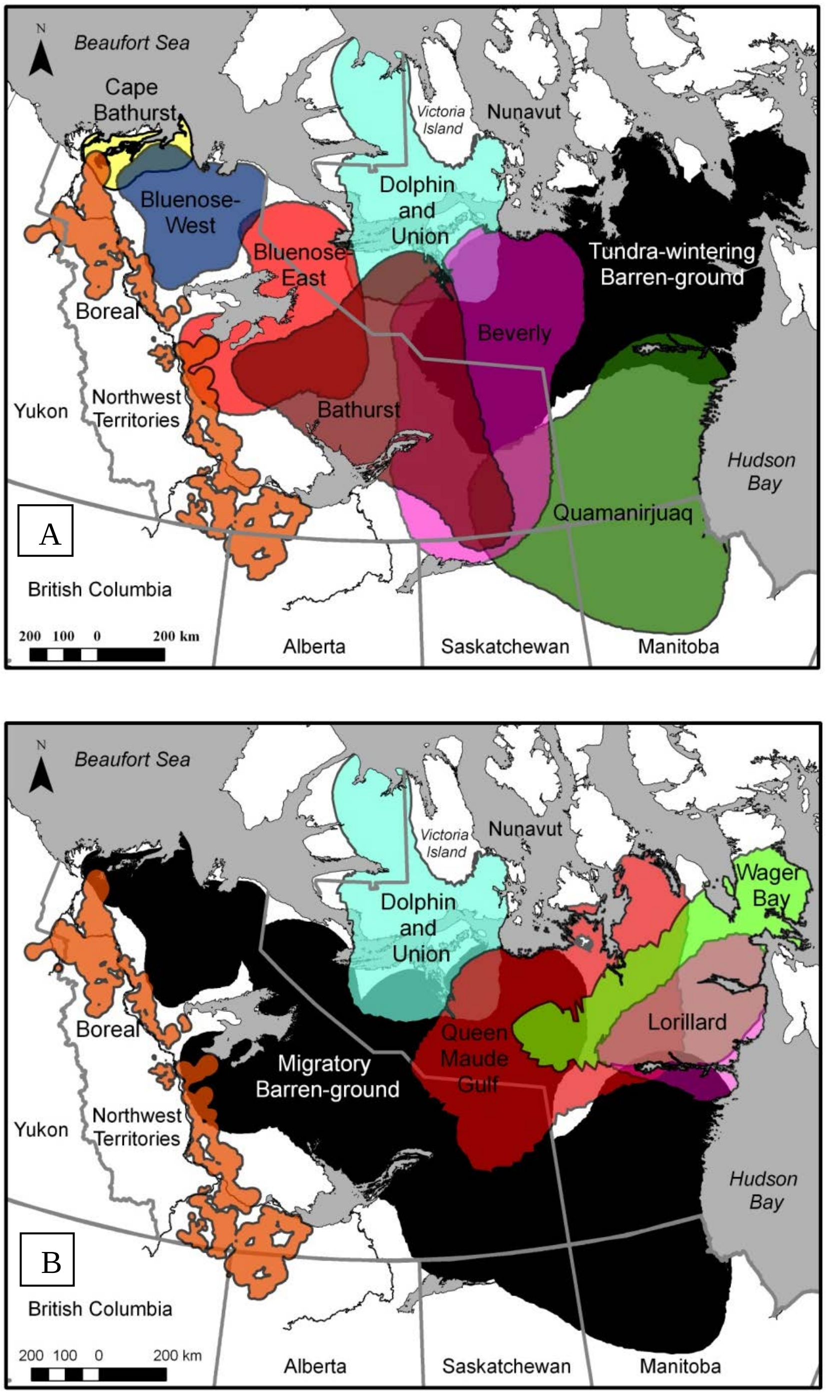

Figure 2-3. Core ranges (mean 90% utilization distribution) used by A) migratory Cape Bathurst, Bluenose-West, Bluenose-East, Bathurst, Beverly, Qamanirjuaq and tundra-wintering barren-ground and boreal and Dolphin and Union island caribou and B) tundra-wintering Queen Maude Gulf, Wager Bay, and Lorillard and migratory barren-ground and boreal and Dolphin and Union island caribou subpopulations in the Northwest Territories and Nunavut, Canada (1993-2009). Portions of ranges extending into Yukon Territory, Alberta, Saskatchewan, and Manitoba, Canada are shown.

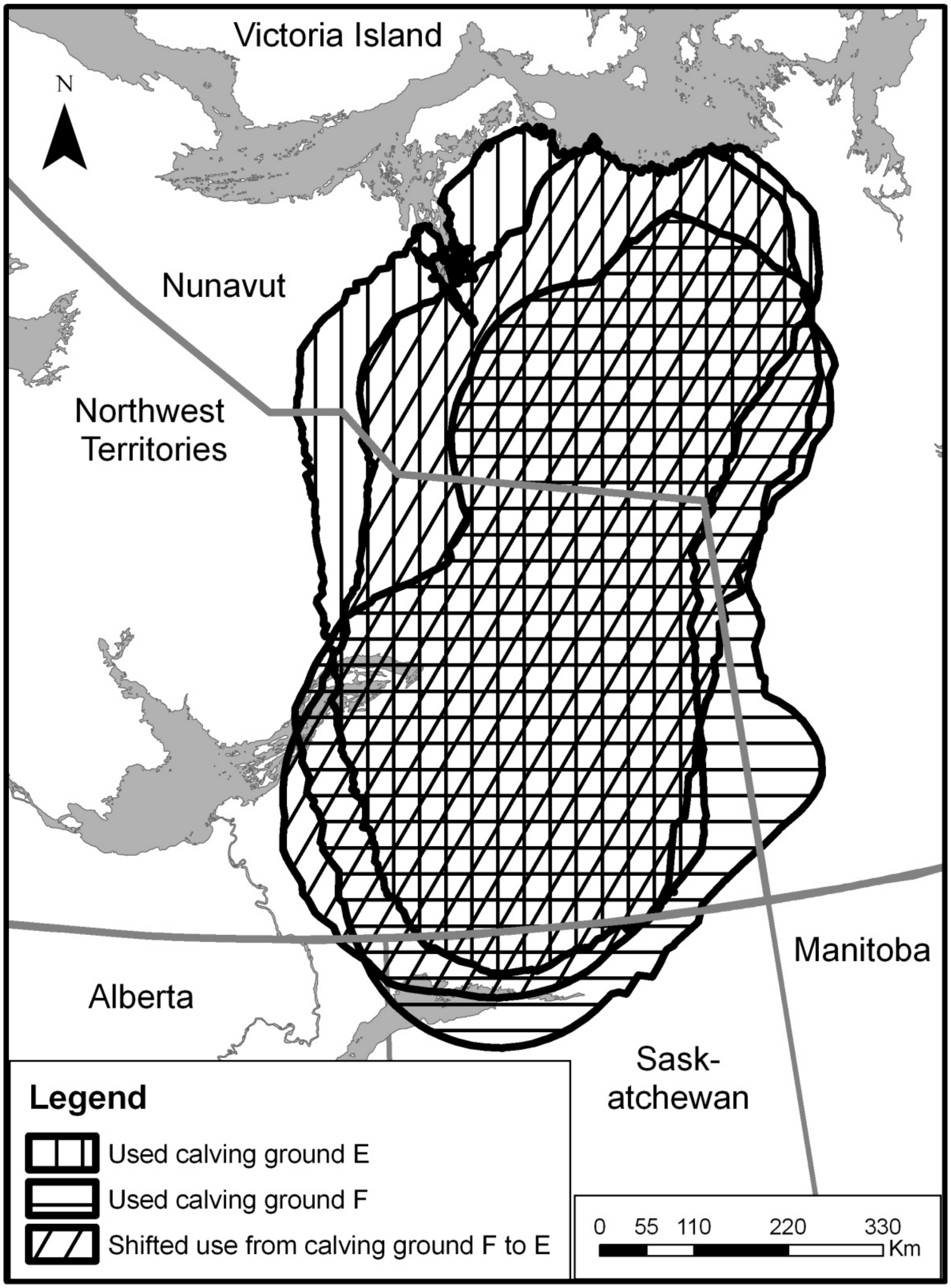

Figure 2-4. Core ranges (90% utilization distribution) of migratory female barren-ground caribou that either used calving grounds E-1 or F or switched use from F to E-1 (Beverly subpopulation) in the Northwest Territories and Nunavut, Canada (1993-2009).

Appendix 2-A. Number of female caribou with full years of satellite tracking data by ecotype, subpopulation, and years tracked in the Northwest Territories, Nunavut, and northern Alberta, Canada, 1993–2009.

Caribou ecotype and subpopulation[1]	Number of caribou tracked by year[2]																	Number of caribou tracked by period	
	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	Total	1993-2005	2006-2008
Barren-ground																			
Cape Bathurst				4	4	3	4	3	1	9	8	3	6	11	19	19	37	18	25
Bluenose-West				3	5	5	12	11	4	5	4	2	9	15	21	24	46	25	29
Bluenose-East				3	5	10	9	7	2		3	3	17	20	16	23	51	31	37
Bathurst				7	7	18	14	13	12	7	9	10	15	13	19	16	50	42	21
Beverly			1	3	3	2			4	5	3	2	7	19	26	44	56	12	48
Qamanirjuaq	4	5	7	6	10	8	7	7	8	7	6	13	10	23	23	32	66	32	39
Queen Maude Gulf				1	2	1			1	2	1		2	3	3	9	14	6	10
Lorillard						2	8	12	9	11	14	13	7	1			21	22	1
Wager Bay								6	6	3	8	8	5	3			12	12	3
Unknown[3]							1	1	1	2	2	1		1	1	4	7	3	4
Total	4	5	8	27	36	49	55	60	48	51	58	55	78	109	128	171	360	203	217
Mountain woodland										8	10	10	7	6			10		
Boreal																			
Cameron Hills													7	10	23	33	46		
Dehcho/South Slave												5	18	30	26	22	37		
Gwich'in										2	8	8	18	12	8	14	33		
Sahtu											2	2	6	10	16	16	24		
Total										2	10	15	49	62	73	85	140		
Dolphin and Union							16	16	14	11	14	9	1				25		

[1] Assignment of caribou to subpopulations was based on first calving ground used subsequent to capture.

[2] Year = 1 March year 1 to 28 February year 2.

[3] Unkown = that did not attend a calving ground during the period it was tracked

Appendix 2-B. Values of the Duda-Hart t-test statistic for Ward's hierarchical clustering of movement data for migratory and tundra-wintering barren-ground, Dolphin and Union island, and boreal caribou in the Northwest Territories, Nunavut, and northern Alberta, Canada.

	Duda-Hart t-test statistic by area				
			Eastern		
No. of Clusters	West-central[1]	Central[2]	East-central [3]	Eastern [4]	Boreal
1	551	150	107	19	846
2	226	218	260	12	108
3	109	109	27	5	127
4	188	32	19	4	69
5	30	17	26	5	51
6	22	21	14	11	50
7	17	20	12	4	41
8	23	23	13	7	23
9	12	12	11	3	22
10	26	14	10	2	18

[1] West-central area=migratory barren-ground caribou that used calving grounds A, B, C, D, E-1, and F.

[2] Central area=Dolphin and Union island and migratory barren-ground caribou that used calving grounds C, D, E-1, and F.

[3] Central and eastern area=tundra-wintering and migratory barren-ground caribou that used calving grounds E including E-1, F, G, H, and I.

[4] Eastern= tundra-wintering caribou that used calving grounds E including E-1, H, and I.

Appendix 2-C. Fuzzy performance indicators of the appropriate number of subpopulations from fuzzy clustering of movement data for female migratory barren-ground caribou that used calving ground A, B, C, D, E-1 and F (west-central) in the Northwest Territories and Nunavut. Results are based on fuzzy clustering of median monthly interval x, y coordinates for each caribou (i.e., 12 months or 24 variables). Numbers in bold indicate optimal number of subpopulations.

Fuzzy Exponent (*m*)	Fuzziness Performance Index, *F’*									Normalized Classification Entropy, *H’*								
	Number of Subpopulations									Number of Subpopulations								
	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
1.5	0.144	0.112	0.118	0.138	0.144	0.181	0.197	0.252	0.286	0.170	0.131	0.130	0.143	0.137	0.160	0.168	0.207	0.223
1.6	0.177	0.163	0.170	0.197	0.229	0.246	0.263	0.285	0.326	0.210	0.189	0.188	0.206	0.215	0.221	0.229	0.244	0.264
1.7	0.209	0.217	0.228	0.231	0.263	0.313	0.367	0.384	0.406	0.252	0.250	0.251	**0.235**	0.255	0.285	0.322	0.324	0.335
1.8	0.243	0.272	0.289	0.290	0.327	0.381	0.465	0.434	0.463	0.296	0.311	0.315	**0.295**	0.318	0.349	0.401	0.383	0.398
1.9	0.278	0.326	0.351	**0.349**	0.425	0.445	0.469	0.524	0.551	0.340	0.370	0.378	**0.353**	0.404	0.411	0.424	0.451	0.473
2.0	0.314	0.379	0.411	**0.406**	0.450	0.505	0.555	0.596	0.621	0.384	0.425	0.438	**0.410**	0.437	0.469	0.501	0.520	0.533
2.1	0.351	0.430	0.467	**0.460**	0.539	0.573	0.616	0.624	0.641	0.427	0.477	0.493	**0.462**	0.515	0.528	0.551	0.564	0.580
2.2	0.388	0.477	0.519	**0.509**	0.589	0.608	0.649	0.697	0.708	0.467	0.525	0.543	**0.510**	0.564	0.570	0.596	0.618	0.627
2.3	0.424	0.521	0.566	**0.555**	0.603	0.651	0.704	0.697	0.751	0.506	0.568	0.588	**0.554**	0.583	0.613	0.640	0.641	0.669
2.4	0.459	0.562	0.608	**0.596**	0.643	0.689	0.709	0.791	0.769	0.542	0.607	0.628	**0.594**	0.623	0.652	0.665	0.703	0.693
2.5	0.492	0.599	0.646	**0.633**	0.679	0.722	0.743	0.769	0.782	0.575	0.642	0.664	**0.630**	0.658	0.686	0.700	0.719	0.725
2.6	0.523	0.632	0.679	0.745	0.711	0.751	0.792	0.799	0.821	0.606	0.674	0.695	0.738	0.690	0.716	0.736	0.750	0.753
2.7	0.553	0.663	0.709	**0.696**	0.738	0.776	0.812	0.812	0.846	0.634	0.702	0.723	**0.692**	0.717	0.741	0.760	0.767	0.784
2.8	0.581	0.690	0.735	**0.723**	0.761	0.796	0.817	0.838	0.855	0.660	0.727	0.747	**0.718**	0.741	0.764	0.778	0.795	0.797
2.9	0.607	0.715	0.758	**0.747**	0.783	0.815	0.835	0.860	0.870	0.683	0.750	0.768	**0.741**	0.763	0.784	0.798	0.808	0.815
3.0	0.631	0.738	0.778	0.826	0.802	0.832	0.859	0.873	0.887	0.705	0.770	0.787	0.819	0.782	0.803	0.815	0.825	0.837

Appendix 2-D. Fuzzy performance indicators of the appropriate number of subpopulations from fuzzy clustering of movement data for female migratory barren-ground caribou that used calving ground A (Cape Bathurst subpopulation) in the Northwest Territories. Results are based on fuzzy clustering of median monthly interval x, y coordinates for each caribou (i.e., 12 months or 24 variables used in analyses). Numbers in bold indicate values ≥0.90 for robust subpopulations.

Fuzzy Exponent (*m*)	Fuzziness Performance Index									Normalized Classification Entropy								
	Number of Subpopulations									Number of Subpopulations								
	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
1.5	0.111	0.038	0.024	0.008	0.007	0.016	0.005	0.007	0.003	0.136	0.044	0.026	0.010	0.007	0.017	0.006	0.008	0.004
1.6	0.256	0.118	0.081	0.056	0.118	0.058	0.062	0.053	0.053	0.289	0.128	0.083	0.056	0.110	0.057	0.062	0.051	0.049
1.7	0.353	0.214	0.385	0.281	0.221	0.232	0.237	0.192	0.195	0.405	0.237	0.375	0.265	0.202	0.215	0.220	0.166	0.179
1.8	0.456	0.325	0.528	0.442	0.455	0.421	0.417	0.385	0.371	0.521	0.361	0.509	0.405	0.423	0.374	0.374	0.333	0.326
1.9	0.558	0.441	0.638	0.545	0.582	0.514	0.554	0.564	0.550	0.627	0.482	0.615	0.503	0.541	0.471	0.496	0.505	0.496
2.0	0.651	0.552	0.727	0.635	0.726	0.719	0.719	0.682	0.656	0.716	0.593	0.703	0.591	0.666	0.655	0.658	0.616	0.594
2.1	0.730	0.658	0.777	0.836	0.856	0.870	0.824	0.835	0.802	0.786	0.697	0.759	0.793	0.811	0.828	0.760	0.776	0.736
2.2	0.794	0.894	0.822	0.868	0.887	0.894	0.851	0.856	0.861	0.840	**0.900**	0.810	0.843	0.848	0.857	0.799	0.808	0.817
2.3	0.846	**0.918**	0.869	0.892	**0.966**	**0.914**	**0.915**	**0.922**	**0.919**	0.883	**0.924**	0.862	0.871	**0.952**	0.882	0.886	0.889	0.889
2.4	0.887	**0.938**	**0.959**	**0.968**	**0.975**	**0.979**	**0.981**	**0.985**	**0.927**	**0.915**	**0.943**	**0.957**	**0.961**	**0.965**	**0.969**	**0.969**	**0.971**	**0.905**
2.5	**0.919**	**0.954**	**0.969**	**0.977**	**0.982**	**0.985**	**0.987**	**0.989**	**0.990**	**0.940**	**0.958**	**0.968**	**0.972**	**0.974**	**0.977**	**0.979**	**0.979**	**0.980**
2.6	**0.945**	**0.967**	**0.978**	**0.984**	**0.988**	**0.989**	**0.990**	**0.992**	**0.993**	**0.959**	**0.970**	**0.977**	**0.981**	**0.985**	**0.983**	**0.984**	**0.985**	**0.986**
2.7	**0.965**	**0.977**	**0.984**	**0.989**	**0.991**	**0.992**	**0.993**	**0.994**	**0.995**	**0.974**	**0.979**	**0.984**	**0.987**	**0.989**	**0.988**	**0.989**	**0.990**	**0.990**
2.8	**0.981**	**0.986**	**0.990**	**0.992**	**0.994**	**0.995**	**0.996**	**0.996**	**0.997**	**0.986**	**0.987**	**0.989**	**0.991**	**0.992**	**0.993**	**0.993**	**0.993**	**0.994**
2.9	**0.993**	**0.993**	**0.994**	**0.995**	**0.996**	**0.997**	**0.998**	**0.998**	**0.998**	**0.995**	**0.994**	**0.994**	**0.994**	**0.995**	**0.996**	**0.996**	**0.996**	**0.997**
3.0	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

Appendix 2-E. Fuzzy performance indicators of the appropriate number of subpopulations from fuzzy clustering of movement data for female migratory barren-ground caribou that used calving ground B (Bluenose-West subpopulation) in the Northwest Territories. Results are based on fuzzy clustering of median monthly interval x, y coordinates for each caribou (i.e., 12 months or 24 variables used in analyses). Numbers in bold indicate values ≥0.90 for robust subpopulations.

Fuzzy Exponent (*m*)	Fuzziness Performance Index									Normalized Classification Entropy								
	Number of Subpopulations									Number of Subpopulations								
	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
1.5	0.598	0.574	0.555	0.594	0.590	0.564	0.554	0.560	0.543	0.668	0.611	0.566	0.591	0.572	0.545	0.527	0.523	0.505
1.6	0.695	0.672	0.654	0.715	0.694	0.683	0.671	0.665	0.649	0.757	0.706	0.665	0.703	0.674	0.659	0.641	0.624	0.607
1.7	0.775	0.753	0.738	0.785	0.816	0.801	0.821	0.761	0.741	0.826	0.781	0.746	0.773	0.792	0.770	0.785	0.726	0.697
1.8	0.839	0.820	0.808	0.840	0.865	0.884	0.868	0.879	0.868	0.878	0.841	0.813	0.829	0.845	0.859	0.836	0.845	0.833
1.9	0.888	0.875	0.869	0.885	**0.902**	**0.914**	**0.923**	**0.929**	**0.932**	**0.917**	0.890	0.870	0.875	0.885	0.894	**0.901**	**0.906**	**0.907**
2.0	**0.927**	**0.923**	**0.923**	**0.956**	**0.962**	**0.939**	**0.943**	**0.946**	**0.948**	**0.946**	**0.931**	**0.921**	**0.946**	**0.950**	**0.922**	**0.925**	**0.927**	**0.930**
2.1	**0.956**	**0.966**	**0.969**	**0.967**	**0.969**	**0.973**	**0.974**	**0.974**	**0.974**	**0.968**	**0.968**	**0.966**	**0.959**	**0.959**	**0.963**	**0.963**	**0.964**	**0.965**
2.2	**0.978**	**0.980**	**0.980**	**0.978**	**0.976**	**0.978**	**0.976**	**0.975**	**0.975**	**0.984**	**0.982**	**0.979**	**0.973**	**0.968**	**0.969**	**0.966**	**0.966**	**0.967**
2.3	**0.995**	**0.992**	**0.990**	**0.988**	**0.982**	**0.983**	**0.985**	**0.976**	**0.980**	**0.996**	**0.992**	**0.989**	**0.986**	**0.976**	**0.975**	**0.977**	**0.968**	**0.973**
2.4	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**0.988**	**0.982**	**0.980**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**0.981**	**0.976**	**0.974**
2.5	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.6	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.7	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.8	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.9	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
3.0	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

Appendix 2-F. Fuzzy performance indicators of the appropriate number of subpopulations from fuzzy clustering of movement data for female migratory barren-ground caribou that used calving ground C (Bluenose-East subpopulation) in Nunavut. Results are based on fuzzy clustering of median monthly interval x, y coordinates for each caribou (i.e., 12 months or 24 variables used in analyses). Numbers in bold indicate values ≥0.90 for robust subpopulations.

Fuzzy Exponent (*m*)	Fuzziness Performance Index									Normalized Classification Entropy								
	Number of Subpopulations									Number of Subpopulations								
	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
1.5	0.502	0.477	0.604	0.623	0.552	0.601	0.526	0.512	0.526	0.584	0.533	0.603	0.612	0.524	0.579	0.495	0.476	0.495
1.6	0.606	0.602	0.707	0.730	0.715	0.700	0.692	0.656	0.667	0.682	0.651	0.703	0.718	0.696	0.674	0.660	0.620	0.623
1.7	0.694	0.706	0.785	0.832	0.849	0.807	0.861	0.841	0.809	0.759	0.746	0.778	0.813	0.821	0.777	0.827	0.800	0.769
1.8	0.765	0.792	0.832	0.873	0.888	**0.898**	**0.898**	**0.902**	**0.899**	0.819	0.820	0.827	0.857	0.865	0.869	0.866	0.865	0.861
1.9	0.822	**0.922**	0.871	**0.901**	**0.922**	**0.929**	**0.936**	**0.942**	**0.937**	0.865	**0.924**	0.868	0.888	**0.905**	**0.907**	**0.911**	**0.917**	**0.911**
2.0	0.867	**0.944**	**0.904**	**0.924**	**0.940**	**0.948**	**0.955**	**0.960**	**0.955**	**0.901**	**0.946**	**0.901**	**0.913**	**0.926**	**0.931**	**0.935**	**0.940**	**0.928**
2.1	**0.902**	**0.958**	**0.932**	**0.943**	**0.954**	**0.963**	**0.968**	**0.971**	**0.975**	**0.927**	**0.960**	**0.929**	**0.934**	**0.943**	**0.950**	**0.953**	**0.955**	**0.958**
2.2	**0.929**	**0.969**	**0.958**	**0.959**	**0.966**	**0.972**	**0.977**	**0.980**	**0.982**	**0.948**	**0.970**	**0.955**	**0.951**	**0.956**	**0.962**	**0.966**	**0.968**	**0.970**
2.3	**0.950**	**0.978**	**0.983**	**0.973**	**0.976**	**0.980**	**0.993**	**0.986**	**0.987**	**0.964**	**0.979**	**0.982**	**0.968**	**0.968**	**0.971**	**0.988**	**0.977**	**0.978**
2.4	**0.967**	**0.984**	**0.989**	**0.992**	**0.993**	**0.994**	**0.995**	**0.996**	**0.996**	**0.976**	**0.985**	**0.988**	**0.989**	**0.991**	**0.991**	**0.992**	**0.992**	**0.993**
2.5	**0.980**	**0.990**	**0.994**	**0.995**	**0.996**	**0.996**	**0.997**	**0.997**	**0.998**	**0.985**	**0.991**	**0.993**	**0.993**	**0.994**	**0.994**	**0.995**	**0.995**	**0.995**
2.6	**0.990**	**0.994**	**0.997**	**0.997**	**0.998**	**0.998**	**0.998**	**0.999**	**0.999**	**0.993**	**0.995**	**0.996**	**0.996**	**0.997**	**0.997**	**0.997**	**0.997**	**0.997**
2.7	**1.000**	**0.998**	**0.999**	**0.999**	**0.999**	**0.999**	**0.999**	**1.000**	**1.000**	**1.000**	**0.998**	**0.999**	**0.999**	**0.999**	**0.999**	**0.999**	**0.999**	**0.999**
2.8	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.9	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
3.0	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

Appendix 2-G. Fuzzy performance indicators of the appropriate number of subpopulations from fuzzy clustering of movement data for female migratory barren-ground caribou that used calving ground D (Bathurst subpopulation) in Nunavut. Results are based on fuzzy clustering of median monthly interval x, y coordinates for each caribou (i.e., 12 months or 24 variables used in analyses). Numbers in bold indicate values ≥0.90 for robust subpopulations.

Fuzzy Exponent (*m*)	Fuzziness Performance Index									Normalized Classification Entropy								
	Number of Subpopulations									Number of Subpopulations								
	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
1.5	0.618	0.630	0.699	0.686	0.628	0.657	0.634	0.647	0.637	0.685	0.640	0.684	0.665	0.601	0.612	0.593	0.601	0.592
1.6	0.716	0.741	0.822	0.827	0.797	0.798	0.814	0.822	0.829	0.774	0.745	0.792	0.791	0.752	0.752	0.768	0.777	0.784
1.7	0.796	0.830	0.864	0.890	0.908	0.886	**0.896**	**0.904**	**0.911**	0.842	0.830	0.839	0.858	0.877	0.847	0.858	0.869	0.877
1.8	0.859	**0.896**	**0.899**	**0.915**	**0.929**	**0.939**	**0.918**	**0.924**	**0.930**	0.893	**0.895**	0.878	0.889	**0.903**	**0.914**	0.888	**0.896**	**0.902**
1.9	**0.907**	**0.934**	**0.926**	**0.934**	**0.945**	**0.952**	**0.958**	**0.961**	**0.964**	**0.931**	**0.935**	**0.911**	**0.913**	**0.924**	**0.933**	**0.939**	**0.944**	**0.947**
2.0	**0.944**	**0.963**	**0.951**	**0.944**	**0.954**	**0.960**	**0.965**	**0.968**	**0.978**	**0.959**	**0.965**	**0.943**	**0.925**	**0.936**	**0.944**	**0.950**	**0.954**	**0.970**
2.1	**0.972**	**0.983**	**0.969**	**0.952**	**0.960**	**0.965**	**0.969**	**0.980**	**0.979**	**0.979**	**0.984**	**0.964**	**0.936**	**0.944**	**0.950**	**0.955**	**0.972**	**0.972**
2.2	**0.992**	**0.995**	**0.996**	**0.985**	**0.994**	**0.969**	**0.983**	**0.981**	**0.980**	**0.994**	**0.996**	**0.995**	**0.980**	**0.992**	**0.956**	**0.976**	**0.975**	**0.974**
2.3	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.4	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.5	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.6	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.7	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.8	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.9	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
3.0	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

Appendix 2-H. Fuzzy performance indicators of the appropriate number of subpopulations from fuzzy clustering of movement data for female migratory barren-ground caribou that used calving ground E-1 and F (Beverly subpopulation) in Nunavut. Results are based on fuzzy clustering of median monthly interval x, y coordinates for each caribou (i.e., 12 months or 24 variables used in analyses). Numbers in bold indicate values ≥0.90 for robust subpopulations.

Fuzzy Exponent (*m*)	Fuzziness Performance Index									Normalized Classification Entropy								
	Number of Subpopulations									Number of Subpopulations								
	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
1.5	0.621	0.481	0.508	0.447	0.511	0.537	0.540	0.527	0.526	0.687	0.521	0.516	0.436	0.481	0.500	0.485	0.475	0.469
1.6	0.708	0.590	0.604	0.546	0.619	0.645	0.652	0.659	0.684	0.766	0.629	0.612	0.534	0.583	0.602	0.599	0.600	0.618
1.7	0.779	0.687	0.686	0.755	0.778	0.811	0.834	0.822	0.775	0.828	0.722	0.692	0.735	0.750	0.776	0.795	0.777	0.707
1.8	0.837	0.773	0.755	0.814	0.847	0.871	0.884	0.881	0.893	0.876	0.800	0.758	0.794	0.819	0.840	0.851	0.840	0.850
1.9	0.884	0.843	0.813	0.855	0.883	**0.903**	**0.917**	**0.927**	**0.925**	**0.913**	0.862	0.814	0.837	0.858	0.875	**0.889**	**0.900**	0.889
2	**0.920**	**0.895**	0.862	0.888	**0.910**	**0.925**	**0.936**	**0.945**	**0.951**	**0.940**	**0.907**	0.861	0.872	0.888	**0.901**	**0.912**	**0.921**	**0.927**
2.1	**0.948**	**0.935**	**0.909**	**0.917**	**0.931**	**0.975**	**0.952**	**0.959**	**0.960**	**0.962**	**0.942**	**0.906**	**0.902**	**0.912**	**0.967**	**0.932**	**0.939**	**0.935**
2.2	**0.970**	**0.962**	**0.962**	**0.969**	**0.975**	**0.980**	**0.960**	**0.986**	**0.988**	**0.978**	**0.966**	**0.960**	**0.964**	**0.969**	**0.973**	**0.942**	**0.979**	**0.981**
2.3	**0.986**	**0.978**	**0.971**	**0.975**	**0.980**	**0.984**	**0.987**	**0.989**	**0.991**	**0.990**	**0.980**	**0.970**	**0.971**	**0.975**	**0.978**	**0.981**	**0.983**	**0.985**
2.4	**1.000**	**0.992**	**0.980**	**0.981**	**0.984**	**0.987**	**0.990**	**0.991**	**0.993**	**1.000**	**0.993**	**0.979**	**0.977**	**0.980**	**0.982**	**0.984**	**0.986**	**0.988**
2.5	**1.000**	**1.000**	**1.000**	**1.000**	**0.988**	**0.990**	**1.000**	**0.993**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**0.984**	**0.986**	**1.000**	**0.989**	**1.000**
2.6	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.7	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.8	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.9	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
3	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

Appendix 2-I. Fuzzy performance indicators of the appropriate number of subpopulations from fuzzy clustering of movement data for female migratory barren-ground that used calving grounds C, D, E-1, and F and Dolphin and Union island caribou (central) in Nunavut. Results are based on fuzzy clustering of median monthly interval x, y coordinates for each caribou (i.e., 12 months or 24 variables used in analyses). Numbers in bold indicate optimal number of subpopulations.

Fuzzy Exponent (*m*)	Fuzziness Performance Index, *F'*									Normalized Classification Entropy, *H'*								
	Number of Subpopulations									Number of Subpopulations								
	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
1.5	0.255	0.200	**0.153**	0.171	0.186	0.187	0.302	0.314	0.331	0.319	0.227	**0.173**	0.182	0.185	0.181	0.259	0.262	0.273
1.6	0.333	0.334	**0.220**	0.246	0.272	0.389	0.395	0.374	0.408	0.404	0.376	**0.248**	0.261	0.275	0.351	0.345	0.327	0.337
1.7	0.404	0.335	**0.292**	0.327	0.358	0.442	0.429	0.479	0.521	0.477	0.379	**0.325**	0.343	0.361	0.414	0.387	0.431	0.446
1.8	0.465	0.468	**0.365**	0.407	0.444	0.505	0.538	0.580	0.604	0.540	0.515	**0.400**	0.423	0.445	0.474	0.490	0.514	0.526
1.9	0.520	0.529	**0.435**	0.483	0.582	0.627	0.637	0.651	0.666	0.594	0.575	**0.469**	0.496	0.563	0.580	0.578	0.584	0.584
2.0	0.568	0.584	**0.500**	0.552	0.645	0.612	0.670	0.711	0.748	0.641	0.628	**0.533**	0.563	0.624	0.590	0.622	0.645	0.672
2.1	0.611	0.633	**0.558**	0.614	0.679	0.736	0.752	0.761	0.765	0.681	0.674	**0.589**	0.621	0.655	0.690	0.695	0.698	0.692
2.2	0.649	0.676	**0.611**	0.668	0.716	0.778	0.792	0.823	0.830	0.716	0.714	**0.638**	0.671	0.704	0.733	0.738	0.756	0.757
2.3	0.683	0.714	**0.657**	0.715	0.784	0.765	0.825	0.839	0.865	0.747	0.748	**0.681**	0.715	0.760	0.739	0.774	0.782	0.798
2.4	0.714	0.747	**0.697**	0.754	0.815	0.842	0.853	0.868	0.885	0.774	0.778	**0.718**	0.752	0.792	0.801	0.805	0.817	0.830
2.5	0.741	0.775	**0.732**	0.787	0.831	0.854	0.874	0.888	0.885	0.797	0.803	**0.750**	0.783	0.815	0.819	0.835	0.841	0.832
2.6	0.765	0.800	**0.762**	0.815	0.857	0.878	0.893	0.904	0.916	0.817	0.825	**0.778**	0.809	0.841	0.845	0.853	0.861	0.867
2.7	0.787	0.822	**0.789**	0.839	0.876	0.899	0.910	0.925	0.935	0.835	0.844	**0.802**	0.832	0.851	0.866	0.873	0.887	0.891
2.8	0.806	0.841	**0.812**	0.858	0.894	0.910	0.922	0.917	0.929	0.851	0.861	**0.823**	0.851	0.875	0.881	0.888	0.878	0.888
2.9	0.823	0.857	**0.832**	0.874	0.906	0.921	0.935	0.941	0.950	0.865	0.875	**0.841**	0.866	0.888	0.893	0.907	0.909	0.917
3.0	0.823	0.857	**0.832**	0.874	0.906	0.924	0.932	0.941	0.949	0.865	0.875	**0.841**	0.866	0.891	0.902	0.900	0.909	0.916

Appendix 2-J. Fuzzy performance indicators of the appropriate number of subpopulations from fuzzy clustering of movement data for female migratory and tundra-wintering barren-ground caribou that showed fidelity to calving ground E including E-1, F, G, H, and I (east-central) in Nunavut. Results are based on fuzzy clustering of median x, y coordinates for 26 14-day periods for each caribou (i.e., 52 variables used in analyses). Numbers in bold indicate optimal number of subpopulations.

Fuzzy Exponent (*m*)	Fuzzy Performance Index									Normalized Classification Entropy								
	Number of subpopulations									Number of subpopulations								
	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
1.5	0.252	**0.091**	0.263	0.182	0.311	0.314	0.323	0.358	0.364	0.314	**0.117**	0.254	0.179	0.266	0.255	0.254	0.283	0.290
1.6	0.320	**0.136**	0.213	0.369	0.394	0.394	0.455	0.477	0.479	0.390	**0.176**	0.236	0.337	0.345	0.329	0.397	0.382	0.378
1.7	0.383	**0.190**	0.293	0.405	0.490	0.470	0.518	0.536	0.563	0.458	**0.241**	0.319	0.378	0.420	0.402	0.439	0.456	0.453
1.8	0.441	**0.249**	0.457	0.416	0.548	0.484	0.592	0.621	0.634	0.520	**0.308**	0.456	0.410	0.496	0.457	0.510	0.523	0.535
1.9	0.495	**0.310**	0.463	0.482	0.608	0.672	0.654	0.679	0.704	0.575	**0.374**	0.481	0.477	0.542	0.605	0.573	0.584	0.607
2.0	0.544	**0.370**	0.570	0.660	0.669	0.709	0.705	0.725	0.740	0.623	**0.436**	0.571	0.617	0.618	0.634	0.628	0.637	0.639
2.1	0.590	**0.427**	0.584	0.703	0.697	0.747	0.747	0.777	0.785	0.666	**0.494**	0.598	0.663	0.639	0.677	0.675	0.701	0.700
2.2	0.631	**0.481**	0.660	0.738	0.732	0.745	0.806	0.811	0.818	0.703	**0.546**	0.662	0.702	0.679	0.689	0.740	0.739	0.737
2.3	0.667	**0.530**	0.695	0.769	0.763	0.790	0.816	0.847	0.842	0.736	**0.592**	0.699	0.735	0.714	0.734	0.752	0.766	0.769
2.4	0.700	**0.575**	0.715	0.795	0.790	0.826	0.850	0.868	0.863	0.765	**0.633**	0.723	0.764	0.745	0.772	0.795	0.804	0.790
2.5	0.730	**0.616**	0.748	0.817	0.813	0.837	0.866	0.886	0.887	0.790	**0.670**	0.754	0.789	0.772	0.791	0.810	0.817	0.826
2.6	0.756	**0.652**	0.780	0.835	0.871	0.860	0.880	0.888	0.910	0.811	**0.702**	0.784	0.810	0.838	0.816	0.829	0.834	0.845
2.7	0.779	**0.684**	0.802	0.850	0.884	0.875	0.893	0.901	0.912	0.831	**0.731**	0.805	0.828	0.853	0.835	0.846	0.852	0.861
2.8	0.799	**0.713**	0.821	0.864	0.863	0.888	0.906	0.912	0.925	0.847	**0.756**	0.824	0.843	0.833	0.851	0.860	0.867	0.874
2.9	0.818	**0.739**	0.836	0.876	0.877	0.899	0.916	0.922	0.934	0.862	**0.778**	0.838	0.857	0.848	0.865	0.881	0.881	0.891
3.0	0.834	**0.761**	0.851	0.887	0.913	0.909	0.922	0.933	0.941	0.875	**0.798**	0.853	0.870	0.890	0.878	0.885	0.895	0.901

Appendix 2-K. Fuzzy performance indicators of the appropriate number of subpopulations from fuzzy clustering of movement data for female migratory and tundra-wintering barren-ground caribou that showed fidelity to calving ground E including E-1 and F (Beverly A and B and Queen Maude Gulf A subpopulations) in Nunavut. Results are based on fuzzy clustering of median x, y coordinates for 26 14-day periods for each caribou (i.e., 52 variables used in analyses). Numbers in bold indicate optimal number of subpopulations.

	Fuzzy Performance Index									Normalized Classification Entropy								
	Number of subpopulations									Number of subpopulations								
Fuzzy Exponent (m)	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
1.5	0.321	0.407	0.513	0.536	0.484	0.530	0.568	0.560	0.585	0.403	0.443	0.511	0.524	0.460	0.490	0.517	0.506	0.524
1.6	0.452	0.513	0.607	0.699	0.635	0.643	0.681	0.714	0.714	0.538	0.547	0.602	0.672	0.600	0.596	0.622	0.651	0.644
1.7	0.590	0.604	0.685	0.769	0.813	0.820	0.757	0.785	0.835	0.669	**0.633**	0.678	0.740	0.779	0.778	0.701	0.725	0.780
1.8	0.728	**0.680**	0.750	0.817	0.854	0.876	0.870	0.872	0.882	0.788	**0.704**	0.740	0.790	0.822	0.844	0.828	0.824	0.829
1.9	0.842	**0.744**	0.803	0.856	0.887	0.906	0.918	0.927	0.937	0.880	**0.763**	0.792	0.832	0.859	0.877	0.890	0.900	0.906
2	0.914	**0.797**	0.846	0.888	0.913	0.929	0.940	0.933	0.937	0.936	**0.811**	0.834	0.866	0.888	0.904	0.916	0.900	0.897
2.1	0.956	**0.842**	0.876	0.907	0.928	0.942	0.951	0.958	0.964	0.968	**0.851**	0.865	0.888	0.906	0.919	0.930	0.937	0.944
2.2	0.983	**0.879**	0.899	0.923	0.940	0.952	0.960	0.966	0.971	0.988	**0.885**	0.889	0.906	0.921	0.932	0.941	0.948	0.953
2.3	1.000	0.999	0.919	0.937	0.951	0.960	0.967	0.972	0.976	1.000	0.999	0.909	0.922	0.933	0.943	0.950	0.956	0.960
2.4	1.000	1.000	1.000	1.000	1.000	1.000	0.980	0.983	0.986	1.000	1.000	1.000	1.000	1.000	1.000	0.968	0.972	0.975
2.5	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.988	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.978
2.6	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2.7	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2.8	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2.9	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Appendix 2-L. Fuzzy performance indicators of the appropriate number of subpopulations from fuzzy clustering of movement data for female migratory barren-ground caribou that showed fidelity to calving ground G (Qamanirjuaq subpopulation) in Nunavut. Results are based on fuzzy clustering of median 14-day period x and y coordinates for each caribou Results are based on fuzzy clustering of median x, y coordinates for 26 14-day periods for each caribou (i.e., 52 variables used in analyses). Numbers in bold indicate values ≥0.90 for robust subpopulations.

Fuzzy Exponent (*m*)	Fuzzy Performance Index									Normalized Classification Entropy								
	Number of subpopulations									Number of subpopulations								
	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
1.5	0.748	0.779	0.761	0.75	0.741	0.732	0.739	0.749	0.763	0.802	0.803	0.77	0.747	0.725	0.706	0.706	0.708	0.716
1.6	0.844	0.886	0.884	0.884	0.89	0.891	0.889	0.888	0.893	0.881	**0.897**	0.884	0.877	0.876	0.87	0.864	0.861	0.864
1.7	**0.916**	**0.95**	**0.963**	**0.971**	**0.976**	**0.98**	**0.982**	**0.984**	**0.985**	**0.937**	**0.954**	**0.961**	**0.966**	**0.969**	**0.971**	**0.972**	**0.973**	**0.974**
1.8	**0.968**	**0.983**	**0.988**	**0.991**	**0.993**	**0.994**	**0.995**	**0.996**	**0.996**	**0.977**	**0.985**	**0.988**	**0.989**	**0.99**	**0.991**	**0.992**	**0.992**	**0.992**
1.9	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.1	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.2	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.3	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.4	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.5	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.6	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.7	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.8	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
2.9	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
3	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

Appendix 2-M. Fuzzy performance indicators of the appropriate number of subpopulations from fuzzy clustering of movement data for female tundra-wintering barren-ground caribou that showed fidelity to calving ground E including E-1, H, and I (Queen Maude Gulf B, Lorillard, and Wager Bay subpopulations) in Nunavut. Results are based on fuzzy clustering of median x, y coordinates for 26 14-day periods for each caribou (i.e., 52 variables used in analyses). Numbers in bold indicate optimal number of subpopulations.

	Fuzzy Performance Index									Normalized Classification Entropy								
Fuzzy Exponent	Number of subpopulations									Number of subpopulations								
(*m*)	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
1.5	0.342	0.227	0.205	0.374	0.379	0.350	0.366	0.373	0.398	0.398	0.263	0.223	0.350	0.344	0.309	0.325	0.318	0.333
1.6	0.404	0.294	0.278	0.460	0.472	0.453	0.477	0.508	0.501	0.468	0.338	0.302	0.430	0.430	0.399	0.422	0.443	0.432
1.7	0.464	0.362	0.355	0.536	0.554	0.534	0.585	0.588	0.591	0.533	0.412	0.383	0.503	0.505	0.474	0.514	0.519	0.513
1.8	0.521	**0.429**	0.435	0.604	0.621	0.682	0.652	0.630	0.646	0.593	0.482	0.464	0.569	0.569	0.617	0.578	0.555	0.583
1.9	0.575	**0.494**	0.517	0.662	0.676	0.718	0.750	0.721	0.735	0.646	0.548	0.543	0.627	0.625	0.657	0.679	0.654	0.669
2	0.623	**0.555**	0.592	0.713	0.722	0.778	0.792	0.810	0.774	0.692	**0.607**	0.615	0.678	0.671	0.714	0.724	0.740	0.714
2.1	0.667	**0.611**	0.660	0.753	0.773	0.819	0.831	0.832	0.816	0.732	**0.660**	0.679	0.720	0.731	0.766	0.775	0.776	0.764
2.2	0.706	**0.663**	0.720	0.786	0.804	0.844	0.855	0.843	0.855	0.767	**0.708**	0.734	0.756	0.766	0.796	0.804	0.788	0.803
2.3	0.740	**0.712**	0.769	0.814	0.829	0.863	0.872	0.885	0.842	0.796	**0.753**	0.778	0.785	0.795	0.820	0.827	0.838	0.790
2.4	0.770	**0.769**	0.846	0.834	0.850	0.878	0.885	0.899	0.907	0.822	**0.803**	0.835	0.809	0.819	0.839	0.845	0.857	0.866
2.5	0.796	0.836	0.869	0.851	0.866	0.888	0.895	0.906	0.914	0.843	0.859	0.856	0.829	0.838	0.854	0.859	0.869	0.879
2.6	0.819	0.864	0.883	0.888	0.893	0.897	0.902	0.911	0.914	0.862	0.883	0.871	0.869	0.867	0.866	0.871	0.879	0.881
2.7	0.839	0.885	0.933	0.900	0.925	0.903	0.908	0.913	0.922	0.878	0.901	0.925	0.883	0.902	0.876	0.881	0.886	0.894
2.8	0.857	0.903	0.942	0.909	0.931	0.909	0.914	0.920	0.922	0.892	0.916	0.936	0.894	0.911	0.885	0.889	0.894	0.896
2.9	0.872	0.917	0.949	0.958	0.936	0.939	0.944	0.923	0.951	0.904	0.928	0.944	0.949	0.918	0.919	0.923	0.900	0.929
3	0.885	0.929	0.955	0.963	0.973	0.976	0.980	0.982	0.984	0.914	0.938	0.950	0.955	0.962	0.964	0.967	0.968	0.969

Appendix 2-N. Fuzzy performance indicators of the appropriate number of subpopulations from fuzzy clustering of movement data for female boreal caribou in the Northwest Territories and northern Alberta, Canada. Results are based on fuzzy clustering of median monthly interval x, y coordinates for each caribou (i.e., 12 months or 24 variables used in analyses). Numbers in bold indicate optimal number of subpopulations.

Fuzzy Exponent	Fuzziness Performance Index, *F'*									Normalized Classification Entropy, *H'*								
	Number of Subpopulations									Number of Subpopulations								
	2	3	4	5	6	7	8	9	10	2	3	4	5	6	7	8	9	10
1.5	**0.060**	0.138	0.083	0.090	0.099	0.147	0.176	0.129	0.124	**0.079**	0.143	0.089	0.091	0.092	0.122	0.137	0.104	0.099
1.6	**0.081**	0.167	0.117	0.129	0.139	0.190	0.223	0.186	0.175	**0.107**	0.176	0.126	0.132	0.134	0.164	0.179	0.154	0.143
1.7	**0.104**	0.197	0.156	0.174	0.187	0.238	0.272	0.236	0.234	**0.140**	0.212	0.168	0.178	0.182	0.210	0.224	0.202	0.196
1.8	**0.131**	0.230	0.198	0.223	0.286	0.289	0.344	0.317	0.307	**0.176**	0.251	0.213	0.229	0.265	0.260	0.291	0.265	0.256
1.9	**0.160**	0.264	0.241	0.274	0.337	0.384	0.394	0.372	0.364	**0.214**	0.291	0.259	0.280	0.315	0.337	0.339	0.317	0.309
2.0	**0.191**	0.300	0.286	0.325	0.389	0.432	0.442	0.426	0.421	**0.254**	0.331	0.306	0.332	0.365	0.384	0.385	0.368	0.362
2.1	**0.223**	0.336	0.330	0.376	0.433	0.477	0.487	0.477	0.476	**0.293**	0.371	0.352	0.382	0.413	0.429	0.429	0.417	0.413
2.2	**0.256**	0.371	0.374	0.425	0.479	0.520	0.529	0.523	0.526	**0.332**	0.410	0.397	0.431	0.458	0.471	0.471	0.462	0.461
2.3	**0.289**	0.406	0.416	0.472	0.554	0.560	0.574	0.565	0.573	**0.370**	0.447	0.440	0.476	0.516	0.511	0.518	0.504	0.507
2.4	**0.322**	0.440	0.457	0.516	0.595	0.596	0.608	0.602	0.605	**0.407**	0.482	0.481	0.519	0.552	0.548	0.553	0.542	0.539
2.5	**0.354**	0.473	0.496	0.556	0.625	0.630	0.639	0.634	0.639	**0.442**	0.515	0.519	0.558	0.584	0.582	0.585	0.575	0.573
2.6	**0.386**	0.504	0.532	0.593	0.653	0.660	0.668	0.664	0.671	**0.475**	0.547	0.555	0.593	0.613	0.614	0.616	0.607	0.606
2.7	**0.416**	0.533	0.566	0.626	0.680	0.688	0.694	0.692	0.700	**0.505**	0.576	0.588	0.625	0.641	0.643	0.643	0.636	0.636
2.8	**0.445**	0.561	0.598	0.656	0.703	0.714	0.718	0.718	0.734	**0.534**	0.603	0.618	0.653	0.666	0.669	0.669	0.663	0.671
2.9	**0.472**	0.587	0.627	0.682	0.725	0.737	0.740	0.741	0.750	**0.562**	0.628	0.646	0.678	0.689	0.694	0.692	0.688	0.690
3.0	**0.499**	0.611	0.654	0.706	0.745	0.758	0.761	0.762	0.772	**0.587**	0.651	0.672	0.702	0.711	0.716	0.714	0.711	0.713

Chapter 3 - Timing and Synchrony of Activities Among Caribou in Northern Canada

Introduction

Movement is one of the main biological functions that links animals to their environment (Bergman et al. 2000) and movement rates are measures of an individual's response to environmental factors, innate behaviours, and physiological requirements (Johnson et al. 2001, Gurarie et al. 2009). Movement data provide insights into the behaviours that allow organisms to use environments that vary over time and space (Maier and White 1998, Schick et al. 2008, Gurarie et al. 2009). Ecologists have examined how individuals interact with their environments to help them understand and predict the effects of habitat loss and climate change (Schick et al. 2008). To assist such understanding, radio-tracking data have been widely used to interpret animal behaviours including seasonal movements (Grigg et al. 1995, Dawson and Starr 2009), habitat selection (Boyce et al. 2003, Gustine and Parker 2008), response to anthropogenic disturbances (Dyer et al. 2001, Ito et al. 2005), responses to habitat conditions (Lydersen et al. 2004, Stokesbury et al. 2005), foraging behaviour (Thompson et al. 1980, Hebblewhite and Merrill 2009), area fidelity (Mauritzen et al. 2001, Edwards et al. 2009), response to noise (Merrill and Erickson 2003); daily activity (Kolowski et al. 2007), birthing (Bertrand et al. 1996, Bowyer et al. 1999), movement states (Gurarie et al. 2009, Van Moorter et al. 2010), and activity periods (Ferguson and Elkie 2004b) .

Herbivore activities are influenced by their daily needs for maintenance, growth, and reproduction (Horn and Rubenstein 1984) and reduction of predation risk (Stuart-Smith et al. 1997, Ferguson and Elkie 2004a, Gustine et al. 2006) . Herbivore activities are further influenced by seasonal variations in biotic (e.g., availability and quality of food, insect harassment) and abiotic (e.g., temperature, precipitation, and wind) factors and photoperiod (Maier and White 1998). Russell et al. (1993) described 15 activity periods for Porcupine caribou (*Rangifer tarandus granti*) based on snow, plant, and insect phenology and changes in daily movements. Maier and White (1998) identified similar periods for interior Alaska barren-ground caribou (*R.t. granti*) based on activity patterns of captive and wild radio-collared animals. Five activity periods were described for boreal caribou (*R. t. caribou*) based on linear and polynomial regression analyses of movement data (Ferguson and Elkie 2004b). The dates for and duration of activity periods may vary among subpopulations within ecotype ranges (Maier and White 1998).

I examined the daily movement rates of five caribou ecotypes including boreal (*R. t. caribou*) , barren-ground (migratory and tundra-wintering; *R. t. groenlandicus*), mountain woodland (*R. t. caribou*), and island caribou (*R. t. groenlandicus x pearyi*) in the Northwest Territories (NT), Nunavut (NU), and northwestern Alberta (AB; Fig. 3-1 and 3-2). These include subpopulations of six migratory barren-ground (Cape Bathurst, Bluenose-West, Bluenose-East, Bathurst, Beverly, and Qamanirjuaq), three tundra-wintering barren-ground (Queen Maude Gulf, Lorillard, and Wager Bay), two boreal (northern and southern), one mountain woodland (Mackenzie Mountain), and one island (Dolphin and Union) caribou (Nagy et al. *In press*). I hypothesized that i) if female caribou movement rates declined around parturition (calving; Long et al. 2009) I could estimate parturition and, by backdating, conception (breeding) dates for subpopulations of each ecotype, ii) if individual caribou responded similarly to the same environmental and physiological cues and that these responses were manifested in significant changes in movement rates, I could identify ecologically meaningful activity periods for each caribou ecotype, and iii) that changes in movement rates and activity periods should be synchronized among subpopulations of the same caribou ecotypes.

Methods

In 1993-2009, 704 female caribou including 478 barren-ground, 176 boreal, 11 mountain, and 39 island caribou were tracked with either ARGOS Doppler shift (DS) or Global Positioning System (GPS) satellite collars (Telonics, Mesa, Arizona, USA and Service Argos, Landover, Maryland, USA). DS and GPS satellite collars provided locations on 1- to 10-day and 0.33- to 1-day intervals, respectively (Nagy et al. *In press*). Most DS satellite collars on boreal and barren-ground caribou provided locations on a 1-day interval during parturition and on a 5-day interval during the rest of the year. Approximately 430,000 locations were included in analyses. I calculated daily movement rates (km/day) between sequential satellite locations.

Biologists in the Dehcho and South Slave regions, NT and I collected blood from 88 boreal caribou at capture and blood serum progesterone levels were determined at the Western College of Veterinary Medicine, University of Saskatchewan, Saskatoon, Saskatchewan, Canada. Females with progesterone levels >1.3 ng $\cdot$ nL^{-1} were considered to be pregnant (Rettie and Messier 1998). During the Cameron Hills, South Slave, and Gwich'in Settlement Area studies (Fig. 2) biologists in the South Slave Region, NT and I conducted surveys every 3 to 10 days during calving to determine if collared cows were parturient by calf-at-heel (Gustine et al. 2006). Because cervids commonly exhibit marked (i.e., >50%) declines in daily movements immediately following parturition (Long et al. 2009), I examined daily movement rates of boreal caribou between 15 April and 15 June for females known to be pregnant at the time of capture and subsequently verified to be parturient. Once I established the movement patterns of parturient females ±10 days around calving, I examined daily movement rates during 15 April to 15 June for all boreal caribou and 15 May to 15 July for all barren-ground, mountain, and Dolphin and Union island caribou tracked during 1993-2009 to determine if, when, and where (longitude and latitude coordinates) parturition occurred. I estimated conception dates by back-dating 229 days from parturition dates

(Mcewan and Whitehead 1972, Bergerud 1975, Rowell and Shipka 2009). The peak of calving and breeding were estimated as the mean parturition or conception date ±1 standard deviation (SD), respectively, while most calves were born or conceived within ±1.96 SD of the mean parturition or conception dates.

I used analysis of variance (ANOVA) and Tukey’s honestly significant difference (HSD) pair-wise comparisons (SPSS 11.5, Chicago, Illinois, USA) to determine if parturition and conception dates varied significantly among boreal caribou study areas, migratory and tundra-wintering barren-ground caribou, and all ecotypes. I mapped the location of calving sites for boreal and Dolphin and Union island caribou. I calculated and mapped 90% utilization distributions (UD) for calving sites or satellite locations obtained during the calving period separately for each barren-ground caribou subpopulation using the geographic information system (GIS) program Home Range Tool (HRT; (Rodgers et al. 2007). I used ArcMap 9.3 (Environmental Systems Research Institute, Inc., Redlands, California, USA) for all GIS analyses.

The inter location intervals were 0.33 to 1 day or 1 to 5 days for most GPS and DS collars, respectively. I selected daily movement rates with inter-location intervals of <5 days to obtain the most accurate daily movement rates possible for each collar type and to include the maximum number of animals and subpopulations in the analyses. I subdivided the data into 73 5-day periods. Because I had a large data set of locations (n=430,432) I was able to subdivide the data into shorter time intervals with adequate sample sizes for analysis. This allowed me to treat the data as "continuous" and to more precisely identify when significant changes in movement rates occurred. I used ANOVA and Tukey’s honestly significant difference (HSD) pair-wise comparisons to identify all sequential 5-day periods when movement rates were not significantly different. These gave the start and end dates for each activity period. Because Tukey’s HSD pair-wise comparisons are limited to multiple comparisons among 50 groups, I subdivided the data into three overlapping 50 5-day periods for analysis (1 Jan-6

Sep, 25 Apr-30 Dec, and 28 Aug-5 May). I used the first and last known or estimated parturition and conception dates to define the calving and breeding periods, respectively. I used the activity periods identified by Russell et al. (1993) for Porcupine caribou to validate analyses for migratory barren-ground caribou.

Results

Parturition

I examined the daily rates of movements around calving for 51 female boreal caribou that were pregnant at capture and verified to be parturient. These females exhibited three movement states ±10 days around parturition including: 1) high daily movements (up to 40 km on some days), 2) precipitous decline in daily movement rates to near zero on or just before parturition, and 3) gradual increase in daily movement rates. Fig. 3-3a illustrates the movement rates of 149 female boreal that were known (n=51) or predicted (n=98) to have been parturant. Overall 93% (82/88) of females predicted to be pregnant based on progesterone levels exhibited daily movements during the calving period consistent with those in Fig. 3-3a. The remaining 6 females exhibited movement states 1 and 2 but then movement rates increased rapidly. This suggests that parturition had occurred, but the calves of these females died shortly after birth.

Overall, 95-100% of the boreal caribou tested were pregnant at the time of capture (Table 3-1). Mean observed (visual surveys) and predicted (movement rates) parturition rates were 69-74% and 82-89 %, respectively, indicating that actual parturition rates would have been underestimated by 12 to 19 percent had visual surveys been used alone (Table 3-1). Parturition dates for boreal caribou varied significantly among study areas ($F_{3,263}$=15.66, $P<0.001$), with the peak of calving for southern (Cameron Hills, South Slave, Dehcho-north, and Dehcho-south) females being significantly earlier (14 May ±7 days, *n*=151) than those of northern (Gwich'in-south, Gwich'in-north, and Sahtu) ones (20 May ±7 days, *n*=116; Tukey's HSD pair-wise comparisons, *P*<0.05; Fig. 3-2). This indicates a north-south cline, with parturition and conception occurring on average 6 days later in the north (Table 3-2 and 3-3). Most boreal caribou calves were born over 28 days in each of the northern and south areas (Table 3-2).

Movement states around parturition for migratory barren-ground caribou were similar to those for boreal caribou, although the daily movement rates for barren-ground caribou were much greater before and increased more rapidly after parturition than those for boreal caribou (Fig. 3-3a and 3-3b). Parturition dates varied significantly among migratory barren-ground caribou subpopulations ($F_{5,359}$=38.31, *P*<0.001). Peak of calving for the Cape Bathurst (4 June ±5 days, *n*=71) was significantly earlier than Bluenose-West (9 June ±4 days , *n*=84), Bluenose-East (7 June ±4 days , *n*=71), and Bathurst (8 June ±4 days , *n*=30), and the latter calved significantly earlier than Beverly (13 June ±4 days , *n*=41) and Qamanirjuaq (12 June ±4 days, *n*=68; Tukey's HSD pair-wise comparisons, *P*<0.05; Table 3-2 and 3-4). These subpopulations are organized in decreasing order of longitude indicating a west to east cline in calving and breeding dates for migratory barren-ground caribou. Calving and breeding occurred approximately 8 days earlier in the western (Cape Bathurst) than easternmost subpopulations (Beverly and Qamanirjuaq; Table 3-2). Calving dates for the Bluenose-East, Bathurst, and Beverly subpopulations are consistent with those observed during calving ground surveys (Williams 1995, Nishi et al. 2007). Although the sample size was small, the peak of calving and breeding for tundra-wintering Queen Maude Gulf females was 15 June (±4 days, *n*=15) and occurred significantly later (3-11 days) than for all migratory subpopulations except the Beverly ($F_{6,373}$=37.88, *P*<0.001; Table 3-2 and 3-6). When subpopulations were considered separately, calves in most of the migratory and tundra-wintering barren-ground subpopulations were born within a 16 day period; when subpopulations were considered together range wide, most migratory barren-ground caribou calves were born within a 20 day period (Table 3-2).

Peak of calving for mountain woodland caribou was 3 June (±4 days, *n*=16) with breeding occurring in mid-late October (Table 3-2 and 3-7). Although annual sample sizes were small, the overall predicted parturition rate was 61% (4/7 in 2002, 5/10 in 2003, 6/9 in 2004, 5/7 in 2005, and 2/3 in 2006). Most mountain woodland calves were born over 16 days.

Calving peaked for Dolphin and Union island caribou on 11 June (±4 days, *n*=33), with most calves born over 16 days. The breeding peaked in late October (Table 3-2 and 3-7).

Calving dates varied significantly among ecotypes ($F_{4,691}=572.26$, $P<0.001$). Boreal caribou calved significantly earlier (17 May ±7 days, *n*=267) than mountain woodland (3 June ±4 days, *n*=16), the latter calved significantly earlier than migratory barren-ground (8 June ±5 days, *n*=365), and these calved significantly earlier than tundra-wintering barren-ground caribou (15 June ±4 days, *n*=15; Tukey's HSD pair-wise comparisons, $P<0.05$, Table 3-2). Calving dates for island caribou (11 June ±4 days, *n*=33) were not significantly different from those for migratory and tundra-wintering barren-ground caribou.

Calving sites for boreal and Dolphin and Union island caribou and calving grounds for the migratory and tundra-wintering barren-ground subpopulations are shown in Fig. 3-4. Calving grounds for the Cape Bathurst (A), Bluenose-West (B), Bluenose-East (C), Bathurst (D), Beverly (E-1 and F), Qamanirjuaq (G) and Queen Maude Gulf (E including E-1) barren-ground subpopulations are based on 90% UD generated around calving sites; those for the Lorillard (H) and Wager Bay (I) barren-ground subpopulations are based on satellite locations obtained during the period when most calves were born in the Queen Maude Gulf subpopulation (Fig. 3-4).

Activity periods

I identified eight activity periods for boreal caribou; these were largely synchronized among northern and southern subpopulations (Table 3-3). The most notable deviation was the length of the late winter period: 20 days in the south and 44 days in the north (Table 3-3). This variation is likely due to latitudinal differences in the winter length. Daily movements varied significantly among activity periods for the northern ($F_{7,22198}=810.15$, $P<0.001$) and southern ($F_{7,30306}=1073.99$, $P<0.001$) subpopulations. The highest movement rates for both subpopulations occurred during the early summer to late fall activity periods (including the breeding period; Table 3-3).

I identified 12 activity periods for migratory barren-ground caribou that were largely synchronized among subpopulations in the NT and NU but also with those of Porcupine caribou and other migratory Alaskan caribou (*R. t. granti*; Table 3-4). Daily movement rates varied significantly among activity periods for Cape Bathurst ($F_{11,14469}=309.00$, df, $P<0.001$), Bluenose-West ($F_{11,12497}=733.49$, $P<0.001$), Bluenose-East ($F_{11,8538}=441.46$, $P<0.001$), Bathurst ($F_{11,12635}=658.24$, $P<0.001$), Beverly ($F_{11,24245}=1016.42$, df, $P<0.001$), and Qamanirjuaq subpopulations ($F_{11,25590}=604.57$, $P<0.001$). The highest movement rates for these caribou occurred during post-calving to mid-summer (includes insect harassment period); this was followed by the fall migration to late fall periods (includes pre-breeding to post-breeding periods), respectively (Table 3-5). For all subpopulations these were separated by an 18-24 day late summer period when movement rates were reduce by 44-65% and 28-53%, respectively (Table 3-5). Movement rates of all migratory subpopulations progressively increased during the spring migration (Table 3-5).

I identified eight activity periods for tundra-wintering barren-ground caribou (Table 3-6). Daily movements varied significantly among activity periods for the Queen Maude Gulf ($F_{7,5259}=124.48$, $P<0.001$), Lorillard ($F_{7,4768}=102.67$, *P*<0.001), and Wager Bay ($F_{7,1621}$=46.82, *P*<0.001) subpopulations. The highest movement rates occurred during the fall to late fall periods (includes pre-breeding to post-breeding periods); this was followed by the post-calving to mid-summer periods (including the period of insect harassment; Table 3-6). These were separated by a 40 day late summer period when movement rates were reduced by 30-58% and 47-86% (Tables 3-6). Movement rates for all tundra-wintering caribou increased during late winter and spring (Table 3-6).

I identified 10 activity periods for mountain woodland caribou (Table 3-7). Daily movements varied significantly among activity periods ($F_{9,4030}$=33.05, *P*<0.001) and were most consistent with those of migratory barren-ground caribou. However, they had a 50 day period of low movement rates during mid/late summer (Table 3-7). My analyses were based on a small sample of collared caribou (n=11) and more data are required to verify activity periods.

Discussion

Daily movement rates measured using satellite tracking locations changed significantly as caribou cycled through their annual activities and, as a result, I was able to identify biologically significant activity periods by measuring changes in these movement rates. The number of activity periods I identified varied among ecotypes including eight for boreal and tundra-wintering, 10 for mountain woodland, and 12 for migratory barren-ground caribou and reflect behavioural differences. Russell et al. (1993) identified 15 activity periods for migratory Porcupine caribou based on changes in caribou behaviours and environmental conditions, including changes in movement rates. Although I found 12 activity periods for all migratory barren-ground caribou subpopulations, my classification was similar to that for Porcupine caribou (Russell et al. 1993). My spring migration period included Russell et al.'s (1993) spring, spring migration, and pre-calving periods and my post-calving period included their post-calving and movement periods. In my analyses the spring migration and post-calving periods were characterized by a progressive increase in movement rates. My results, in combination with those of Russell et al. (1993) and Maier and White (1998), suggest that activities of migratory barren-ground caribou are largely synchronized across their range in North America.

I did not find the same degree of consistency among my eight and the five activity periods (calving, post-calving, early winter, late winter, and spring) identified by Ferguson and Elkie (2004b) for boreal caribou in Saskatchewan, Canada. Four of my activity periods (early/mid summer, mid/late summer, breeding, and late fall) fell within Ferguson and Elkie's (2004b) post-calving period, and one (mid winter) fell between their early and late winter periods. Ferguson and Elkie (2004b) obtained DS locations on 2- to 10-day intervals while most of mine were 8-h interval GPS locations. Movements are influenced by inter-location interval (Ferguson et al. 1996) and, as a result, it is reasonable to assume that finer scale changes in movement rates and activity periods can be detected using higher resolution location data.

Annual movement patterns of migratory and tundra-wintering barren-ground and mountain woodland caribou were similar. Most significantly, all of these ecotypes exhibited low movement rates during the late summer period or before the fall pre-breeding activity period. Late summer may be an important ecological period when females are focused on regaining body condition in preparation for breeding and winter (Russell et al. 1993). Boreal caribou did not exhibit a similar period of reduced movement rates during late summer. The peak of breeding for boreal caribou is almost a full month earlier than for barren-ground caribou and these non-migratory caribou may have sufficient time after breeding to regain body condition for winter.

A number of cervids exhibit movement patterns that are diagnostic of parturition including white-tailed deer (*Odocoileus virginianus*; Bertrand et al.

1996, Carstensen et al. 2003) , moose (*Alces alces*; Bowyer et al. 1999, Poole et al. 2007) , elk (*Cervus Canadensis*; Vore and Schmidt 2001), fallow deer (*Dama dama*; Ciuti et al. 2006), and mule deer (*Odocoileus hemionus*; Long et al. 2009). I found that boreal, mountain woodland, island, and migratory and tundra wintering caribou also exhibit changes in movement patterns diagnostic of parturition and that parturition dates can be reliably estimated by examining movement rates during the calving period. This approach provides a cost-effective way to estimate calving dates when females are dispersed over large remote areas and to locate calving sites.

Using my approach for estimating parturition dates, I found clines in this reproductive function within and among ecotypes and subspecies of caribou. These included a north-south cline for boreal caribou, with southern individuals calving earlier than northern ones; an east-west cline for migratory barren-ground caribou subpopulations, with western subpopulations calving earlier than eastern ones; ecotype cline among woodland caribou, with boreal calving earlier than mountain woodland; an ecotype cline among barren-ground caribou, with most migratory subpopulations calving earlier than tundra-wintering; and a subspecies cline with boreal and mountain woodland calving earlier than barren-ground and Dolphin and Union island caribou. The cline for boreal caribou likely follows the south-north warming of the NT during spring and that for migratory barren-ground caribou, in part, mirrors the distance from treeline to calving grounds. Of note, the calving dates of 17-27 May reported for interior Alaska caribou (Maier and White 1998) largely coincides with the peak calving dates for boreal caribou in NT and northern AB.

Most adult female boreal caribou are pregnant and produce calves. In Saskatchewan, 94% of adult females tested were pregnant and a minimum of 86% produced calves (Rettie and Messier 1998). Similarly in AB, 90-100% of adult females tested were pregnant and a minimum of 70-95% produced calves (Stuart-Smith et al. 1997, McLoughlin et al. 2003). I found that 95-100% of radio-collared females tested in the NT and northern AB were pregnant, and based on interpretation of movement rates during the calving period, a minimum of 71-89% produced calves. However, based on differences between observed and predicted calving rates, I would have underestimated calving rates and postnatal mortality rates by 12-19% had only visual surveys been conducted. Important insights on the timing and primary factors affecting early calf survival may be obtained by accurately predicting parturition rates and documenting postnatal mortality rates.

Calving sites for boreal caribou are normally dispersed (Schaefer et al. 2001, Bergerud et al. 2008) and my results concur. My results indicate that calving sites for migratory barren-ground caribou were aggregated on distinct calving grounds as earlier studies have noted (Thomas 1969, Heard et al. 1987). Dolphin and Union caribou calving sites were dispersed over a wide area on Victoria Island indicating that they did not use a distinct calving ground. More satellite tracking data are required to describing the patterns of calving ground use for mountain woodland caribou in the NT and tundra-wintering barren-ground caribou in NU.

Bergerud (1975**)** observed that for caribou that calved in open habitats in the presence of effective predators, 90% of the calves were born over 14 days. In comparison, caribou that were solitary during calving and calved in forest habitats gave birth asynchronously over 30 days possibly to reduce predation risk (Bergerud 1975). My observations were consistent with Bergerud (1975) in that most boreal caribou calves were born over 27 days while those for most other caribou ecotypes that largely occupied open habitats during calving were born over 16 days. Conception among female boreal caribou may be less rigorously synchronized by physiological and environmental factors than for other ecotypes, resulting in asynchronous calving.

Our ability to investigate the link between the movement patterns and changes in physiological and environmental (climatic seasons) factors for caribou has been enhanced significantly by the use of satellite collars. These collars, when deployed in sufficient numbers on individuals within and among subpopulations provide large sample sizes of location data required for descriptive and/or statistical analyses. The large location database obtained by biologists in the NT and NU provided an opportunity to examine these relationships among five caribou ecotypes.

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Table 3-1. Pregnancy and parturition rates for satellite-collared boreal caribou in the Gwich'in-north, Gwich'in-south, and Sahtu and Dehcho-north, Dehcho-south, South Slave, and Cameron Hills study areas, 2002-07. Pregnancy rates were determined by blood serum progesterone levels (>1.3 ng · mL^{-1}) and parturition rates were determined by visual surveys (observed) and changes in movement rates (predicted) during the calving period.

				Parturition rates				
				Females tested for pregnancy		Females observed during visual surveys		All females tracked
Study area	Year	Pregnancy rates	No. females tracked	observed	predicted	observed	predicted	predicted
Gwich'in	2002	n/a	2					100 (2/2)
	2003	n/a	9			78 (7/9)	78 (7/9)	78 (7/9)
	2004	n/a	7			57 (4/7)	86 (6/7)	86 (6/7)
	2005	100 (14/14)	20	100 (14/14)	100 (14/14)	80 (16/20)	100 (20/20)	100 (20/20)
	2006	n/a	13			54 (7/13)	69 (9/13)	69 (9/13)
	2007	n/a	11			n/a		100 (11/11)
	pooled	100 (14/14)	62	100 (14/14)	100 (14/14)	69 (34/49)	86 (42/49)	89 (55/62)
Sahtu	2003		4					100 (4/4)
	2004		4					75 (3/4)
	2005		7					57 (4/7)
	2006		13					77 (10/13)
	2007		19					63 (12/19)
	2008		18					72 (13/18)
	pooled		65					71 (46/65)
Dehcho/South Slave	2004	100 (5/5)	5	na	100 (5/5)	na		100 (5/5)
	2005	89 (8/9)	14	na	89 (8/9)	na		93 (13/14)
	2006	100 (5/5)	17	60 (3/5)	60 (3/5)	57 (8/14)	86 (12/14)	76 (13/17)
	2007	100 (15/15)	29	60 (9/15)	87 (13/15)	63 (17/27)	78 (21/27)	79 (23/29)
	2008	86 (6/7)	32	43 (3/7)	86 (6/7)	83 (25/30)	83 (25/30)	81 (26/32)
	pooled	95 (39/41)	97	56 (15/27)	85 (35/41)	70 (50/71)	89 (63/71)	82 (80/97)
Cameron Hills	2005	100 (6/6)	8	na	100 (6/6)	na	na	100 (6/6)
	2006	100 (7/7)	18	86 (6/7)	100 (7/7)	72 (13/18)	94 (17/18)	94 (17/18)
	2007	100 (11/11)	24	73 (8/11)	100 (11/11)	58 (14/24)	79 (19/24)	79 (19/24)
	2008	100 (9/9)	30	89 (8/9)	100 (9/9)	87 (26/30)	87 (26/30)	87 (26/30)
	pooled	100 (33/33)	80	81 (22/27)	100 (33/33)	74 (53/72)	86 (62/72)	87 (68/78)

Table 3-2. Calving periods derived using calving dates estimated from movement rates around parturition for female boreal, mountain woodland, Dolphin and Union island, and migratory and tundra-wintering barren-ground caribou in the Northwest Territories, Nunavut, and northern Alberta, Canada, 1993-2009. Northern boreal caribou included those in the Gwich'in-north, Gwich'in-south, and Sahtu study areas; southern boreal caribou included those in the Dehcho-north, Dehcho-south, South Slave, and Cameron Hills study areas.

Ecotype/subpopulation	Mean calving date	68% of calves born (±1 SE)			95% of calves born (±1.96 SE)			
		±Days	Min	Max	±Days	Min	Max	Total days
Boreal								
Southern	14 May	7	7 May	21 May	14	30 Apr	28 May	28
Northern	20 May	7	13 May	27 May	14	6 May	3 Jun	28
Migratory barren-ground								
Cape Bathurst	4 Jun	5	30 May	9 Jun	10	25 May	14 Jun	20
Bluenose-West	9 Jun	4	5 Jun	13 Jun	8	1 Jun	17 Jun	16
Bluenose-East	7 Jun	4	3 Jun	11 Jun	8	30 May	15 Jun	16
Bathurst	8 Jun	4	4 Jun	12 Jun	8	31 May	16 Jun	16
Beverly	13 Jun	4	9 Jun	17 Jun	8	5 Jun	21 Jun	16
Qamanirjuaq	12 Jun	4	8 Jun	16 Jun	8	4 Jun	20 Jun	16
Tundra-wintering barren-ground								
Queen Maude	15 Jun	4	11 Jun	19 Jun	8	7 Jun	23 Jun	16
Boreal	17 May	7	10 May	24 May	14	3 May	31 May	35
Mountain woodland	3 Jun	4	30 May	7 Jun	8	26 May	11 Jun	16
Migratory barren-ground	8 Jun	5	3 Jun	13 Jun	10	29 May	18 Jun	20
Tundra-wintering barren-ground	15 Jun	4	11 Jun	19 Jun	8	7 Jun	23 Jun	16
Dolphin and Union island	11 Jun	4	7 Jun	15 Jun	8	3 Jun	19 Jun	16

Table 3-3. Movement rates by activity period for the southern (Dehcho-north, Dehcho-south, South Slave, and Cameron Hills study areas) and northern (Gwich'in-north, Gwich'in-south, and Sahtu study areas) boreal caribou subpopulations in the Northwest Territories and northern Alberta, Canada, 1993-2009.

	Movement rates by subpopulation of boreal caribou							
	Southern				Northern			
Activity periods	Dates	Daily mean (km)	Stdev	Tukey's rank[1]	Dates	Daily mean (km)	Stdev	Tukey's rank
Pre-calving, calving, post-calving	5 Apr - 6 Jun	2.95	4.1	2	25 Apr - 8 Jun	3.08	4	3
Calving	30 Apr - 6 Jun				29 Apr - 8 Jun			
Peak calving	7 May - 21 May				13 May - 27 May			
Early/mid summer	7 Jun - 12 Aug	4.23	4	4	9 Jun - 23 Jul	3.16	2.71	5
Mid/late summer	13 Aug - 12 Sep	4.63	3.62	5	24 Jul - 11 Sep	3.62	2.76	7
Breeding	13 Sep - 20 Oct	4.63	4.52	4	12 Sep - 22 Oct	3.67	3.06	6
Peak breeding	20 Sep - 4 Oct				26 Sep - 10 Oct			
Late fall	21 Oct - 30 Nov	5.03	4.27	5	23 Oct - 30 Nov	4.89	4.22	8
Early winter	1 Dec - 25 Jan	3.25	3.12	3	1 Dec - 20 Jan	3.03	2.84	4
Midwinter	26 Jan - 15 Mar	2.22	2.55	2	21 Jan - 10 Mar	1.71	2.12	2
Late winter	16 Mar - 4 Apr	1.44	1.55	1	11 Mar - 24 Apr	1.12	1.64	1

[1] Tukey's rank: Movement rates for activity periods with different ranks were significantly different (Tukey's HSD pair-wise comparisons, $P<0.05$).

Table 3-4. Activity periods of the Porcupine[1], Cape Bathurst, Bluenose-West, Bluenose-East, Bathurst, Beverly, and Qamanirjuaq subpopulations of migratory barren-ground caribou in the Yukon Territory, Northwest Territories, and Nunavut, Canada, 1993-2009.

	Barren-ground caribou subpopulations						
Activity period	Porcupine[1]	Cape Bathurst	Bluenose-West	Bluenose-East	Bathurst	Beverly	Qamanirjuaq
Calving	1 - 10 Jun	26 May - 16 Jun	29 May - 23 Jun	28 May - 20 Jun	2 - 16 Jun	6 - 19 Jun	9 - 22 Jun
Peak calving		30 May - 9 Jun	5 - 13 Jun	3 - 11 Jun	4 - 12 Jun	9 - 17 Jun	8 - 16 Jun
Post-calving [2]	11 - 30 Jun	17 Jun - 3 Jul	24 Jun - 3 Jul	21 Jun - 3 Jul	17 - 28 Jun	20 Jun - 8 Jul	23 Jun - 3 Jul
Early summer	1 - 15 Jul	4 - 28 July	4 - 23 Jul	4 - 28 Jul	29 Jun - 28 Jul	9 - 28 Jul	4 Jul – 7 Aug
Mid summer	16 Jul - 8 Aug	29 Jul - 17 Aug	24 Jul - 2 Aug	29 Jul - 12 Aug	29 Jul - 17 Aug	29 Jul - 12 Aug	8 - 22 Aug
Late summer	9 Aug - 7 Sep	18 Aug - 6 Sep	3 - 22 Aug	13 Aug - 6 Sep	18 Aug - 6 Sep	13 Aug - 11 Sep	23 Aug - 16 Sep
Fall, pre-breeding	8 Sept - 7 Oct	7 Sep - 9 Oct	23 Aug - 12 Oct	7 Sep - 11 Oct	7 Sep - 16 Oct	12 Sep - 20 Oct	17 Sep - 23 Oct
Breeding	8 - 31 Oct	10 - 31 Oct	13 Oct - 7 Nov	12 Oct - 4 Nov	17 - 31 Oct	21 Oct - 3 Nov	19 Oct - 6 Nov
Peak breeding		13 - 23 Oct	19 - 27 Oct	17 - 25 Oct	18 - 26 Oct	23 Oct - 31 Oct	22 - 33 Oct
Post-breeding, late fall	1-30 Nov	1 - 30 Nov	8 - 30 Nov	5 Nov - 25 Dec	1 - 30 Nov	4 Nov - 15 Dec	7 Nov - 15 Dec
Early winter	1 Dec - 10 Jan	1 Dec - 31 Jan	1 Dec - 25 Jan	26 Dec - 31 Jan	1 Dec - 5 Jan	16 Dec - 14 Feb	16 Dec - 25 Jan
Mid winter	11 Jan - 20 Feb	1 Feb - 15 Mar	26 Jan - 25 Mar	1 Feb - 20 Mar	6 Jan - 24 Feb	15 Feb - 15 Mar	26 Jan - 20 Mar
Late winter	21 Feb - 31 Mar	16 Mar - 14 Apr	26 Mar - 24 Apr	21 Mar - 9 Apr	25 Feb - 19 Apr	16 Mar - 9 Apr	21 Mar - 14 Apr
Spring migration[2]	1 Apr - 31 May	15 Apr - 25 May	25 Apr - 28 May	10 Apr - 27 May	20 Apr - 1 Jun	10 Apr - 5 Jun	15 Apr - 8 Jun

[1] Russell et al. (1993)

[2] Spring migration includes Russell et al.'s (1993) spring, spring migration, and pre-calving periods and post-calving includes Russell et al.'s (1993) post-calving and movement periods.

Table 3-5. Movement rates by activity period determined by satellite telemetry for migratory barren-ground caribou subpopulations in the Northwest Territories and Nunavut, Canada, 1993-2009.

	Movement rates by subpopulations of migratory barren-ground caribou																	
	Cape Bathurst			Bluenose-West			Bluenose-East			Bathurst			Berverly			Qamanirjuaq		
Activity Periods	Daily Mean (km)	stdev	Tukey's rank[1]	Daily Mean (km)	stdev	Tukey's rank	Daily Mean (km)	stdev	Tukey's rank	Daily Mean (km)	stdev	Tukey's rank	Daily Mean (km)	stdev	Tukey's rank	Daily Mean (km)	stdev	Tukey's rank
Calving	5.04	5.39	3	5.64	5.09	4	7.20	5.87	4	6.67	6.4	3	7.18	6.99	4	8.67	9.99	3
Post-calving	6.66	5	7	11.05	6.07	8	14.00	9.54	8	9.32	6.66	7	12.96	8.07	8	14.65	13.01	6
Early summer	12.4	8.23	9	19.15	10.48	9	20.32	9.75	9	15.96	9.13	8	22.69	12.16	9	27.52	21.83	7
Mid summer	7.28	5.64	7	12.18	13.03	7	8.94	7.56	5	8.66	7.68	5	14.18	10.31	7	18.13	18.66	6
Late summer	4.38	2.53	5	6.13	4.72	4	6.82	4.82	4	3.71	3.88	2	7.33	5.5	4	10.44	11.48	4
Fall, pre-breeding	5.12	4.03	6	10.25	8.68	6	11.54	8.95	7	6.77	5.31	4	12.27	8.43	6	13.58	12.86	5
Breeding	9.41	8.6	8	9.22	6.68	6	11.69	8.62	7	8.88	6.41	6	12.06	8.14	6	16.10	14.78	6
Post-breeding, late fall	5.14	5.18	4	7.64	6.9	5	10.06	8.03	5	8.53	6.45	5	9.22	10.47	5	14.22	14.19	5
Early winter	3.45	3.68	2	4.55	4.26	3	5.58	5.39	3	5.59	4.64	3	5.18	4.85	3	7.98	10.20	2
Mid winter	3.5	3.9	2	2.68	2.71	2	4.35	5.90	2	3.53	3.55	2	3.78	3.53	2	4.73	7.77	1
Late winter	2.67	3.24	1	1.76	3.1	1	3.11	3.94	1	1.77	2.42	1	3.22	3.53	1	4.17	5.76	1
Spring migration	5.32	6.38	3	6.44	8.16	3	12.71	9.14	6	10.88	7.98	6	13.01	10.74	3	11.98	14.18	4

[1] Tukey's rank: Movement rates for activity periods with different ranks were significantly different (Tukey's HSD pair-wise comparisons, *P*<0.05).

Table 3-6. Movement rates by activity period determined by satellite telemetry for sedentary barren-ground caribou subpopulations in the Northwest Territories and Nunavut, Canada, 1993-2009.

		Daily movements by subpopulations of sedentary barren-ground caribou								
		Queen Maude Gulf			Lorillard			Wager Bay		
Activity Period	Dates	Daily Mean (km)	Stdev	Tukey's Rank[1]	Daily Mean (km)	Stdev	Tukey's rank	Daily Mean (km)	Stdev	Tukey's rank
Calving	9 Jun - 25 Jun	5.47	8.04	1	3.81	5.15	1	5.67	12.52	1
Peak calving	11 - 19 Jun									
Post-calving/early/mid summer	26 Jun - 12 Aug	13.73	13.45	4	11.62	12.28	3	4.14	5.39	1
Late summer	13 Aug - 21 Sep	8.07	8.80	2	4.88	7.90	1	2.88	4.20	1
Fall, pre-breeding	22 Sep - 23 Oct	16.55	17.13	5	14.54	14.93	3	16.58	18.63	3
Breeding	23 Oct - 8 Nov	18.14	15.80	5	18.30	18.34	4	27.22	19.48	4
Peak breeding	25 Oct - 2 Nov									
Late fall	9 Nov - 15 Dec	12.12	10.66	4	11.89	10.73	3	9.63	9.53	2
Early/mid winter	16 Dec - 15 Mar	4.42	3.85	1	4.59	5.18	2	4.26	6.05	1
Late winter/spring	26 Mar - 8 Jun	9.36	8.62	3	6.36	8.46	2	8.76	10.27	2

[1] Tukey's rank: Movement rates for activity periods with different ranks were significantly different (Tukey's HSD pair-wise comparisons, *P*<0.05).

Table 3-7. Movement rates by activity period determined by satellite telemetry for mountain woodland caribou in the Mackenzie Mountains, Northwest Territories and Yukon Territory, Canada, 1993-2009.

		Daily movements		
Activity periods	Dates	Daily mean (km)	Stdev	Tukey's rank[1]
Calving	26 May - 11 June	1.87	2.36	1
Post-calving	12 June - 23 June	2.24	2.22	2
Early summer	24 June - 23 July	4.16	4.41	3
Mid/late summer	24 July - 11 Sept	2.88	3.15	2
Fall	12 Sept - 8 Oct	4.32	4.65	3
Breeding	9 Oct - 25 Oct	4.90	4.29	3
Late fall	26 Oct - 25 Nov	3.79	3.40	3
Early/mid winter	26 Nov - 10 Mar	2.42	2.56	2
Late winter	11 Mar - 24 Apr	2.02	2.26	1
Spring migration	25 Apr - 25 May	4.77	4.49	3

[1] Tukey's rank: Movement rates for activity periods with different ranks were significantly different (Tukey's HSD pair-wise comparisons, *P*<0.05).

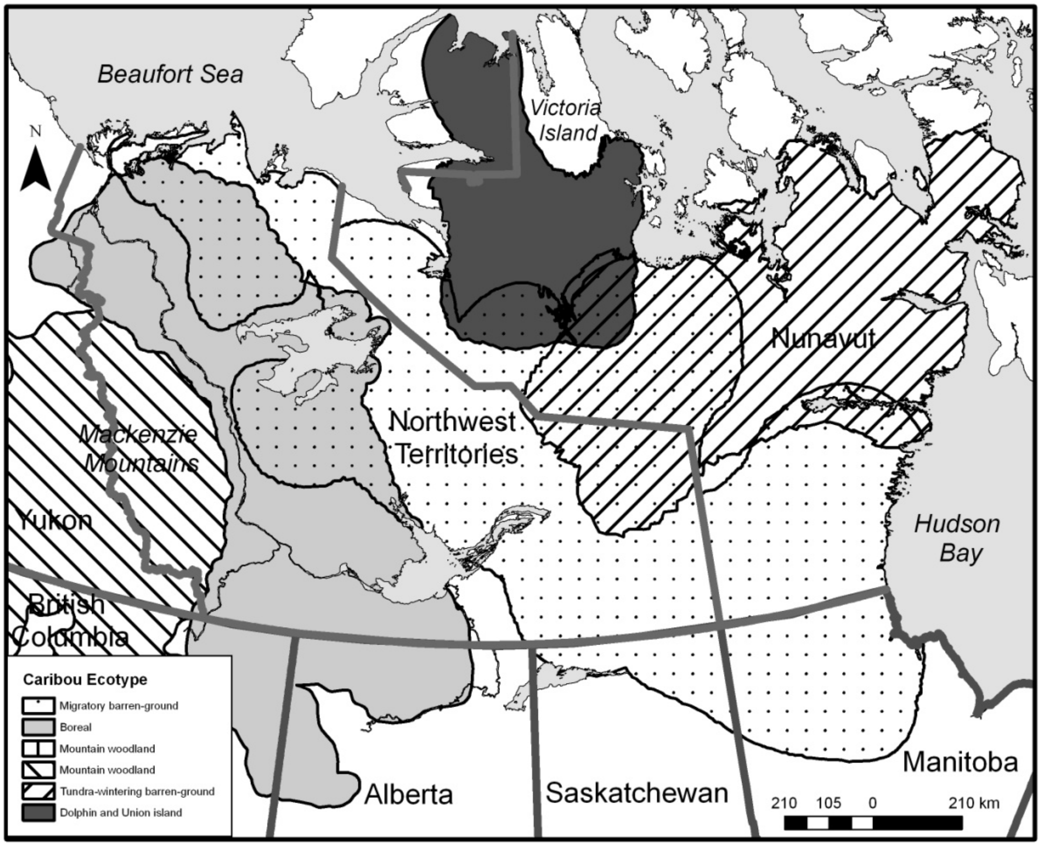

Figure 3-1. Ranges of boreal, mountain woodland, Dolphin and Union island, and migratory and tundra-wintering barren-ground caribou ecotypes in the Northwest Territories and Nunavut, Canada.

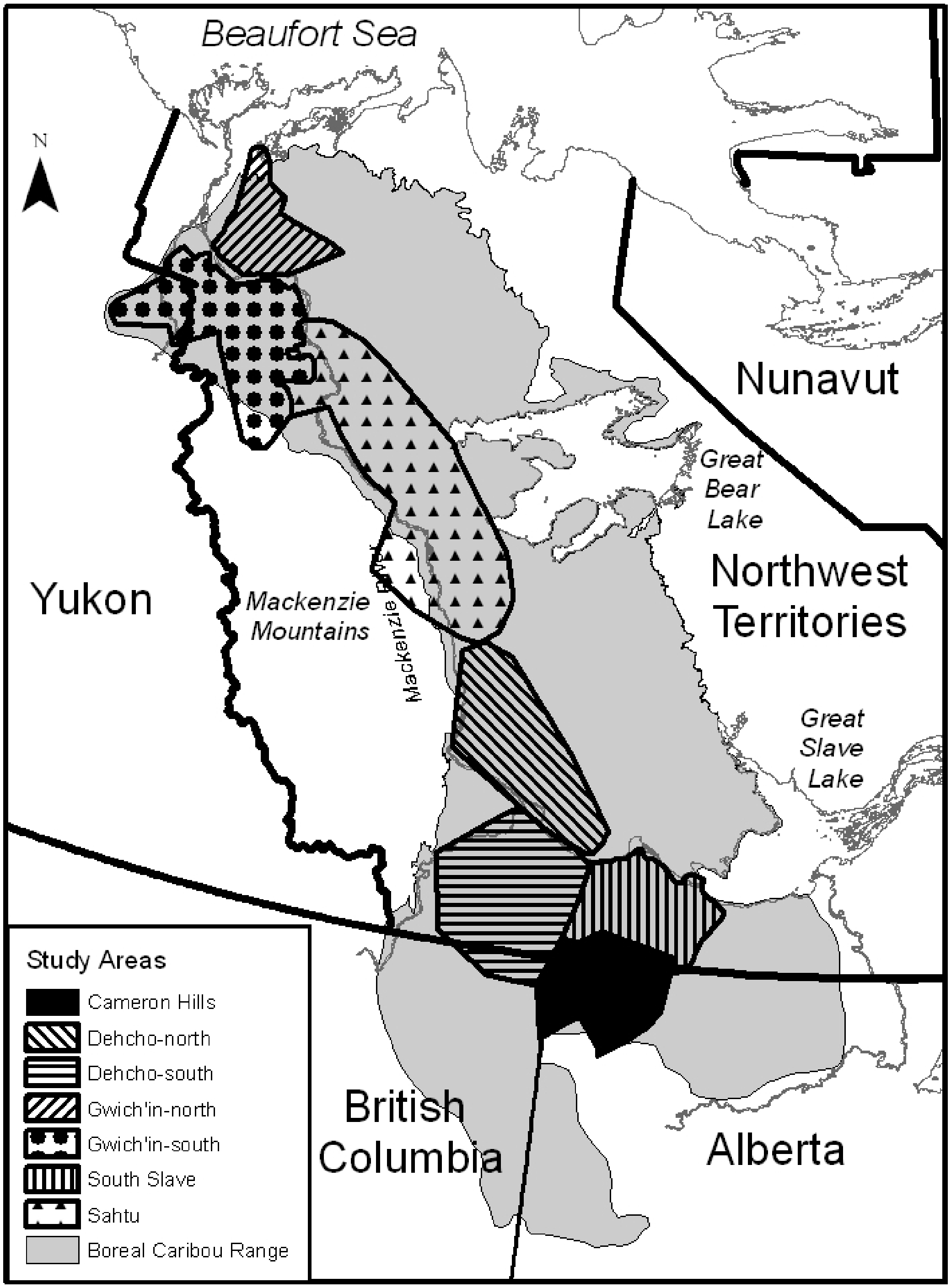

Figure 3-2. Location of Gwich’in-north, Gwich’in-south, Sahtu, Dehcho-north, Dehcho-south, South Slave, and Cameron Hills boreal caribou study areas in the Northwest Territories and northern Alberta, Canada.

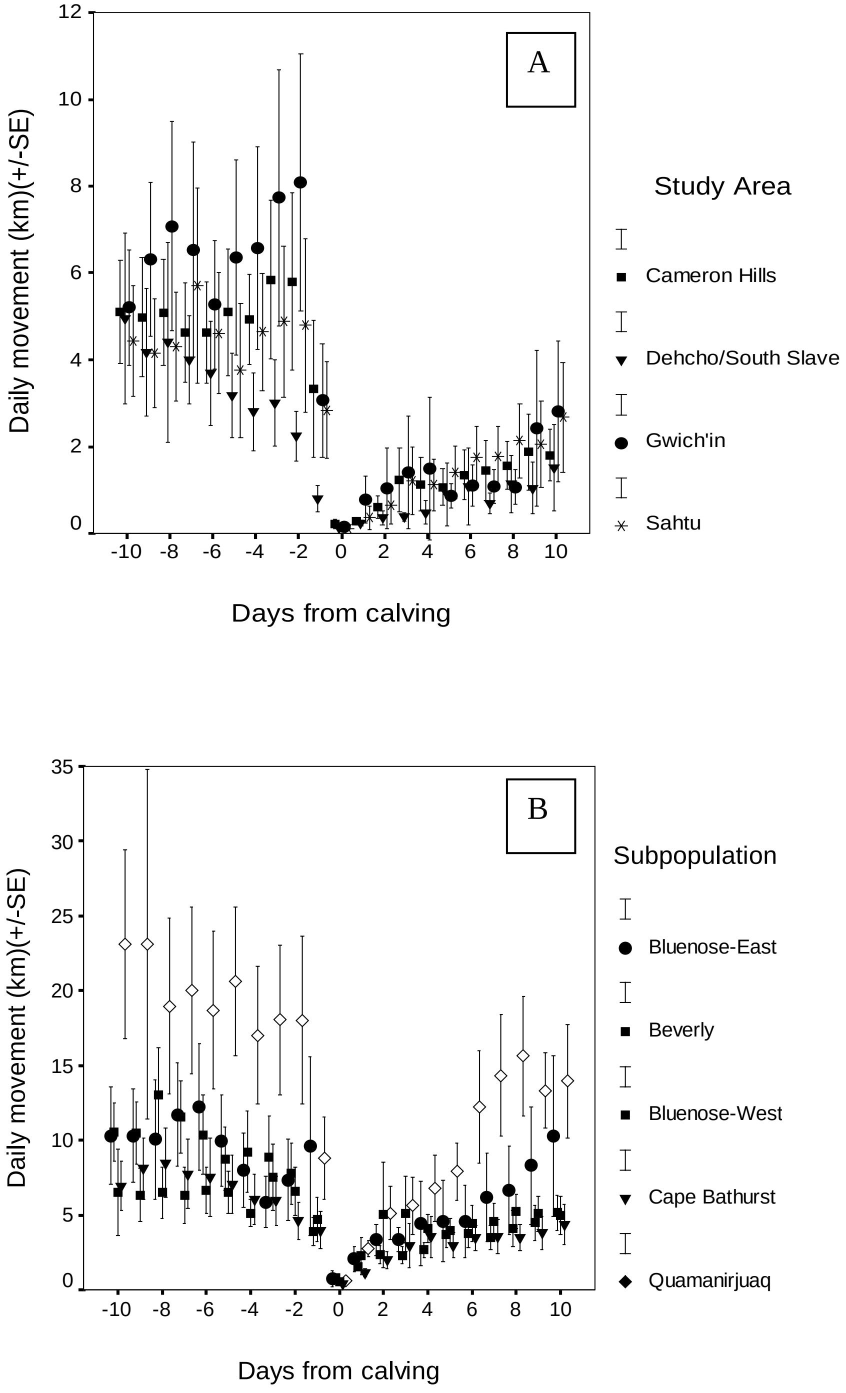

Figure 3-3. Mean daily movements (km)(±1 SE) around the time of calving for GPS-collared a) boreal caribou in the Cameron Hills (n=55), Dehcho/South Slave (n=20), Sahtu (n=41), and Gwich’in (n=33) study areas and b) Cape Bathurst (n=35), Bluenose-West (n=30), Bluenose-East (n=16), Beverly (39), and Qamanirjuaq (n=67) barren-ground caribou.

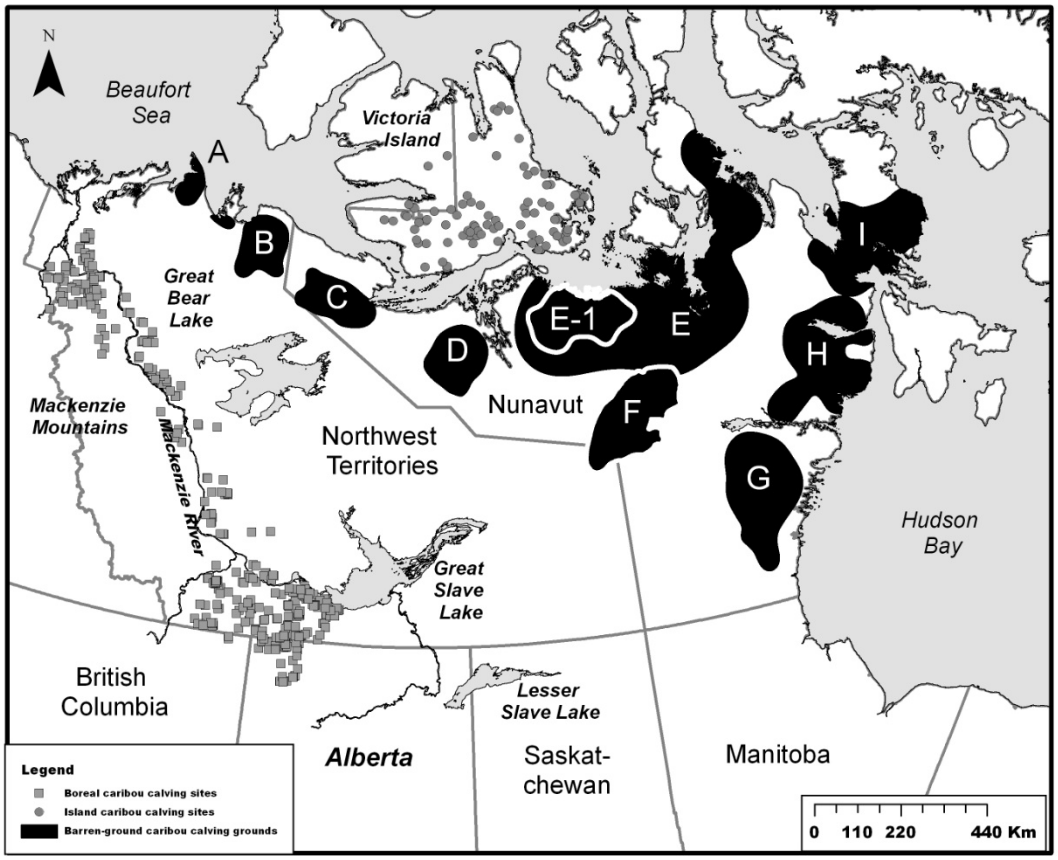

Figure 3-4. Calving grounds of the migratory Cape Bathurst (A), Bluenose-West (B), Bluenose-East (C), Bathurst (D), Beverly (E-1 and F), and Qamanirjuaq(G) and sedentary Queen Maude Gulf (E including E-1), Lorillard (H), and Wager Bay (I) subpopulations of barren-ground caribou and calving sites of boreal and Dolphin & Union caribou in the Northwest Territories, Nunavut, and northwestern Alberta, Canada.

Chapter 4 - Response of Boreal Caribou to Seismic Lines in Northern Canada

Introduction

Rapid development of oil and gas reserves in north-western Canada is resulting in an ever-spreading network of linear features used for resource access. Because seismic lines are the first and most extensive component of this network, understanding how these features affect behaviour (Frid and Dill 2002), habitat connectivity (Franken and Hik 2004), habitat and space use (Dyer 1999), intra- and inter-specific interactions (Orrock et al. 2008), and survival (Vors et al. 2007, Schneider et al. 2010) is important for effective wildlife management. Many species avoid habitats with high densities of linear disturbances (McLellan and Shackleton 1988, James and Stuart-Smith 2000) causing functional habitat loss (Dyer et al. 2001). However, seismic lines are relatively narrow linear features, generally <8 metres wide, leading some to hypothesize that they are unlikely to have major impacts on wildlife. Past studies at local scales have found varying effects of seismic lines on boreal caribou (*Rangifer tarandus caribou*) behaviour (James and Stuart-Smith 2000, Dyer et al. 2001, 2002). Part of this variation could be caused by fundamental differences in the behaviour of boreal caribou in different areas or alternatively, the relatively narrow range of seismic line densities and environments in which most boreal caribou studies have been conducted. Therefore, it is important to know whether observed patterns of use reflect preference or the inability to select optimal habitats (Caughley and Gunn 1996). This is particularly important when vulnerable, threatened, or endangered species and their habitats are targets of management or recovery actions.

Boreal caribou, listed as threatened in Canada (COSEWIC 2002), occur throughout the boreal forests in the Mackenzie River Basin, Northwest Territories (NT), and northern Alberta (AB), Canada. Over 100,000 km of seismic lines were cut within this area in the NT from 1960 to 1990 (National Energy Board Records). Renewed oil and gas exploration in this area will cause higher densities of linear disturbances. Here permafrost is easily degraded (Mackay 1970, Nicholas and Hinkel 1996) and vegetation is slow to recover (Billings 1987, Harper and Kershaw 1996) indicating that forest succession caused by linear disturbances will be slow. The effects of anticipated developments must be effectively managed to ensure that viable populations of boreal caribou survive on these northern landscapes.

Seismic lines do not kill caribou; predators and people do. However, seismic lines increase the efficiency with which predators (Neufeld 2006) and hunters can travel and access areas in the boreal forest. Predator density and diversity vary within the range of boreal caribou in the NT and northwestern AB. In the southern portion of their range, alternate prey included moose (*Alces alces*), beaver (*Castor Canadensis*), bison (*Bison bison*), white-tailed deer (*Odocoileus virginianus*), and elk (*Cervus canadensis*); bison are locally abundant in the southwestern NT, moose are locally abundant throughout the area, while white-tailed deer and elk are rare (N. C. Larter, pers. comm.). Predators including wolves (*Canis lupus*), black bears (*Ursus americanus*), and lynx (*Lynx Canadensis*) are locally abundant, while cougar (*Puma concolor*) are rare (N. C. Larter, pers. comm.). In the extreme northern portion of boreal caribou range in the NT alternate prey species include barren-ground caribou (*Rangifer tarandus groenlandicus*) and moose. However, the distribution of boreal and barren-ground caribou rarely overlap over much in this area (J. A. Nagy *unpublished data*). Moose occur throughout the area but are at very low densities (Benn 1999) and beaver are rare. In the extreme north, predators include wolves, grizzly bears (*Ursus arctos*), black bears, and lynx; wolves, grizzly bears, and black bears occur in low numbers while lynx are cyclic and locally abundant (J. A. Nagy *unpublished data*). Moose and black bears are at the northern most limits of their ranges in Canada. Caribou are harvested opportunistically throughout their range in the NT by aboriginal people hunting and trapping other species. As a result, mortality threats vary throughout boreal caribou range.

My objective is to evaluate the behavioural response of boreal caribou to seismic lines in boreal forests with very different ecological conditions and seismic line densities in the NT and northern AB (Figure 4-1). I hypothesized that if boreal caribou behaviour was not affected by the presence of seismic lines i) caribou should use areas near and cross seismic lines in proportion to their occurrence and ii) caribou travel rates during periods when they were and were not crossing seismic lines should be the same. I assumed that boreal caribou avoided seismic lines if i) caribou locations were significantly further from seismic lines than random locations, ii) caribou paths crossed significantly fewer seismic lines than simulated random caribou paths, and iii) caribou movement rates were significantly greater during periods when they crossed than before and after they crossed seismic lines (Dyer et al. 2002). I refer to times when caribou avoided seismic lines as “avoidance periods” and those when they did not avoid seismic lines as “non-avoidance periods”.

Methods

Seventy-five female boreal caribou were equipped with ARGOS Global Positioning System (GPS) satellite collars (Telonics, Mesa, Arizona, USA and Service Argos, Landover, Maryland, USA) during 2002-2009. Caribou were captured and handled according to the standard operating procedures of the Northwest Territories Wildlife Care Committee following methods in compliance with the Canadian Council on Animal Care. Collars provided locations at 07:00h, 15:00h, and 23:00h or 01:00h, 09:00h, and 17:00h, giving three day-time periods for analyses including morning (23:00h-07:00h and 01:00h-09:00h), mid day (07:00h-15:00h and 09:00h-17:00h), and evening (15:00h-23:00h and 17:00h-01:00h).

Spatial analyses were conducted using ArcMap 9.3 (Environmental Systems Research Institute, Inc., Redlands, California, USA), Hawth's Tools (Beyer 2007), Geospatial Modelling Environment version 0.3.4 Beta (http://www.spatialecology.com/gme), and X-tools Pro 6.0 (Data East LLC, Akademgorodok, Russia). Statistical analyses were conducted using SPSS 11.5 (Chicago, Illinois, USA) and STATA 9 (STATCORP, College Station, Texas, USA). Statistical significance was set at $\alpha \leq 0.05$.

I created minimum convex polygons (MCPs) around the locations obtained for each GPS collared caribou (known range) using Hawth's Tools, removed large water bodies present on 1:2,000,000 scale National Topographic Series (NTS) maps from these ranges using XTools Pro, and merged them into one shapefile using ArcMap. The merge MCP shapefile for GPS collared caribou defined the spatial extent of the study area for this analysis. I generated random locations in each study area at a rate of 1 per km^2 using Hawth's Tools.

I created a linear feature database for the range of boreal caribou in the NT and northwestern AB using digital seismic line data obtained from the National Energy Board, Canada, the NTS map database, the Dehcho Land Use Planning Board, and the Government of Alberta. I measured the distance from caribou and random locations to the nearest seismic line in each study area and subdivided the caribou data into 73 consecutive 5-day periods. The large number of GPS locations obtained in each study area allowed me to partition the data into a larger number of periods and to assess the responses of caribou to seismic lines at a finer time scale. I used Wilcoxon's independent sample signed rank test (Zar 1999) to determine if distances from caribou locations to seismic lines for each 5-day period were i) significantly greater (caribou avoided seismic lines) or ii) significantly shorter than or not significantly different from those for random locations (caribou did not avoid seismic lines).

I assessed the spatial response of caribou to seismic lines by assigning each caribou's locations and random locations within its home range that were ≤1000 m from a seismic line to one of 20 50-meter wide bins; those >1000 m formed one bin. I calculated use:availability ratios (percent use ÷ percent available; U:A ratio) for each bin for each caribou and calculated a mean U:A ratio with 95% confidence intervals (CI) for all caribou for each bin by study area. Use of a bin was significantly different from random if the 95% CI did not include 1.0 (Johnson 1999).

I created polylines or steps between sequential locations for each caribou and calculated their length using Hawth's Tools. I selected all 8-h inter-location interval steps, pooled these among study areas (*n*=107,524 steps), and created an empirical frequency distribution table for the cumulative distribution frequency curve for these step lengths. I used bin widths of 10 m for steps that were 1-110 m, 25 m for those that were 111-1010 m, 100 m for those that were 1011-5110 m, and 1000 m for those that were greater than 5111 m in length to ensure a closer match between the empirical and actual distributions. Using these bin widths I created a unique empirical frequency distribution table for each caribou.

I used the Geospatial Modelling Environment version 0.3.4 Beta movement.simplecrw tool (http://www.spatialecology.com/gme) to simulate random caribou steps. I used the MCP (with large water bodies removed) for each caribou as the reflective boundary for the path simulator and generated random starting locations within these equal to the number of 8-h steps obtained for each caribou. Using the unique empirical step length and a uniform turning angle distribution table I generated one random step at each starting location during each of 10 random path simulations for each caribou (Dyer et al. 2002; Fig. 4-2). The random path for each simulation was the sum of the individual steps generated at the random starting locations. I created intersection points where caribou and random steps crossed seismic lines using Hawth's Tools, spatially joined the intersection points with the shapefiles for caribou and random steps, respectively, and calculated the number of lines crossed by each step and crossing rates for caribou and random paths (crossings/km of path travelled).

I paired the actual and 10 random path crossing rates for each caribou giving 10 replicate data sets for each study area and used these data and Wilcoxon's related sample signed rank test to determine if actual and random crossing rates were significantly different. I used Kruskal-Wallis tests to determine if crossing rates varied significantly among study areas during each seismic-line-response period and Mann-Whitney U tests to identify rates that were significantly different (Gibbons 1985). I used Pearson correlation tests to determine if crossing rates were correlated with the density of seismic lines among study areas during each seismic-line-response period.

I selected all consecutive 8-h-interval steps where step one did not cross a seismic line (pre-crossing), step two crossed ≥ 1 seismic line (crossing), and step three did not cross a seismic line (post-crossing) and calculated travel rates (km/day) for each step. Because caribou movement rates vary during the day and by season (J. A. Nagy, *unpublished data*), I subdivided the data for each study area into two seismic-line-response and 3 day-time periods (morning, mid day, and evening; Appendix 4-B). I used Wilcoxon's related (by animal) and independent sample signed rank tests (among study areas) to determine if i) travel rates during pre-crossing and crossing, crossing and post-crossing, and pre-crossing and post-crossing steps and ii) travel rates during pre-crossing, crossing, and post-crossing steps were significantly different within and among study areas, respectively.

Results

Average seismic lines densities were 3.33, 0.44, 0.41, and 0.12 km/km^2 in the Cameron Hills, Dehcho/South Slave, Gwich'in-south, and Gwich'in-north areas, respectively. In increasing order, average distances to the nearest seismic line (25th and 75th percentiles) were: Cameron Hills 263 m (51-348 m), Dehcho-south 796 m (217-1034 m), South Slave 1347 m (375-1757 m), Dehcho-north 2092 m (468-2575 m), Gwich'in-south 2705 m (478-2360 m), and Gwich'in-north 5066 m (1378-3156 m).

The response of caribou to seismic lines differed significantly among study areas (χ^2 test for independence Q=24.88, df_6, $p<0.05$; Table 4-1) and was not consistent throughout each activity period in most study areas (Fig. 4-3; Chapter 3). Cameron Hills, Dehcho/South Slave, Gwich'in-south, and Gwich'in-north caribou avoided seismic lines during 31/33 (94%), 21/33 (64%), 12/28 (43%), and 4/28 (14%) 5-day periods during pre-calving to late summer/pre-breeding periods, respectively (Fig. 4-3; Appendix 4-A to 4-D). In the Cameron Hills and Dehcho/South Slave, where the diversity and density of predators and primary prey species were highest, caribou avoided seismic lines during all or most of the pre-calving, calving, and early summer periods (Figure 4-3; Appendix 4-A and 4-B). Gwich'in-south caribou avoided seismic lines during most of the calving and early summer periods but also avoided them during late winter and breeding periods (Figure 4-3; Appendix 4-C). Although Gwich'in-north caribou avoided seismic lines for a portion of the calving period, the longest periods of avoidance occurred during late winter and breeding period (Figure 4-4; Appendix 4-D).

The spatial responses of caribou to seismic lines are given by area in Appendices 4-E to 4-H. I pooled data for Dehcho/South Slave (n=16), Gwich'in-south (n=11), and Gwich'in-north (n=13) caribou because area sample sizes were small and seismic line densities were much lower in these areas than in the Cameron Hills (Appendix 4-I). During the seismic-line-avoidance period, Cameron Hills caribou avoided areas ≤100 m from seismic lines (Figure 4-4a; Appendix 4-E); that distance was ≤400 m for Dehcho/South Slave/Gwich'in caribou (Figure 4-4b; Appendix 4-I). During the seismic-line-non-avoidance period, Cameron Hills caribou did not avoid seismic lines (Figure 4-4c; Appendix 4-E); Dehcho/South Slave/Gwich'in caribou avoided areas ≤50 m from seismic lines (Figure 4-4d; Appendix 4-I).

Caribou paths crossed 15, 33, 43, and 35% fewer seismic lines/km during the seismic-line-avoidance period than random paths in the Cameron Hills, Dehcho/South Slave, Gwich'in-south, and Gwich'in-north areas, respectively (Table 4-2). These differences were significant ($p<0.05$) in the Cameron Hills and Gwich'in areas. Crossing rates for caribou and random paths were not significant different during the seismic-line-non-avoidance period (Table 4-2).

Seismic line crossing rates varied significantly among areas during the avoidance (H = 51.60, df_3, $p<0.05$) and non-avoidance periods (H = 52.10, df_3, $p<0.05$). The rank order of crossing rates was i) Cameron Hills > Dehcho/South Slave > Gwich'in-south > Gwich'in-north and ii) Cameron Hills > Dehcho/South Slave = Gwich'in-south > Gwich'in-north for the avoidance and non-avoidance periods, respectively. Crossing rates and seismic line density were not significantly correlated during the avoidance period (Pearson Correlation r=0.875, $n=4$, $p=0.125$) but were during the non-avoidance period (Pearson Correlation r=0.993, $n=4$, $p=0.05$).

Caribou traveled significantly faster ($p<0.05$) during seismic-line-crossing steps than during pre- and post-crossing steps during all day-time and seismic-line-response periods in all areas (Table 4-3). During the seismic-line-avoidance period travel rates during crossing steps were on average 4.3 (range 1.0-8.5), 5.7 (range 3.8-9.9), and 3.9 (range 1.4-7.4) times faster than pre- or post-crossing steps during the morning, mid day, and evening, respectively, and 2.8 (range 1.3-3.8), 5.7 (range 3.7-8.0), and 3.0 (range 1.4-4.8) times greater during these day-time periods, respectively, during the non-avoidance period (Table 4-3).

Travel rates for Cameron Hills caribou were significantly slower during pre-, post-, and crossing steps during all day-time and seismic-line-response periods than in the other areas ($p<0.05$) and those in the Dehcho/South Slave and Gwich'in-south were significantly lower than in the Gwich'in-north area during most day-time periods ($p<0.05$; Table 4-3).

Discussion

In order to develop effective habitat management strategies for boreal caribou we need to consider the diversity and density of predators and primary prey species and wildlife harvesting practises when assessing how mortality risk may increase in an area with the addition of anthropogenic linear features such as seismic lines. Caribou in my study areas exhibited periods when they avoided and did not avoid seismic lines and interacted with them differently during these periods. This response was not consistent throughout entire activity periods in most study areas. Caribou avoided areas near seismic lines and crossed them less frequently when they were vulnerable to the primary mortality threats operating within their ranges (predators, wildlife harvesters). Avoidance of seismic lines may reduce exposure to predators (visual and scent) and other risks (Dyer et al. 2001) such as hunting. Caribou travelled at faster rates when they crossed seismic lines suggesting that these features were permeable barriers to caribou movement throughout the year. Travel rates were inversely related to seismic line densities, however, suggesting that local movements of caribou may be increasingly constrained as seismic line densities increase. The greatest spatial response occurred where seismic line densities were low and caribou could space-away from them.

The longest period of avoidance occurred in the Cameron Hills where predator and primary prey diversity and density was high and seismic line densities were highest (Chapter 5). This period included pre-calving to early summer when most calf and adult mortality occurs due to predation (Stuart-Smith et al. 1997). Although hunting occurred, predators were the primary year-round threat and the duration of this threat may have been prolonged by high seismic line densities. Similarly in the Dehcho/South Slave, predator and primary prey density and diversity were high, hunting occurred, but seismic line densities were low. Here the longest period of avoidance occurred during pre-calving to early summer suggesting that predators were the primary mortality threat. In comparison, the longest periods of avoidance in the Gwich'in areas where predator and primary prey diversity and density was low and hunting was the most significant threat, were during the late winter and breeding periods when local people were actively hunting and/or trapping other species. These behavioural responses suggest that caribou view areas on or near seismic lines as risky habitats and that habitat management strategies should not be based solely on responses of caribou to development features on highly impacted landscapes.

Dyer et al. (2001) found that caribou avoided areas ≤ 250 m from seismic lines leading to functional habitat loss and Sorensen et al. (2008) used this avoidance distance to track cumulative effects of industrial development. Schaefer and Pruitt (1991) found that caribou avoided areas disturbed by fires. My data indicate that caribou avoided areas ≤ 400 m from seismic lines, and if this avoidance is to reduce predation risk, then caribou should perceive unburned areas >400 m from seismic lines as preferred secure habitats. As a result, I suggest that from a caribou perspective, the cumulative effects of industrial development are more appropriately measured by the amount and patch configuration of unburned secure habitats remaining within developed areas than by measurements of the area of the industrial footprint.

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Table 4-1. Number (percent) of 5-day periods during the year when the distances from boreal caribou locations to the nearest seismic line were not significantly different, significantly greater, and significantly less from that for random locations by study area in northern Canada (χ^2 test for independence Q=24.88, df_6, $p<0.05$).

Difference between the distance to the nearest seismic line for caribou and random locations	Number (percent) of 5-day periods during the year by study area			
	Cameron Hills	Dehcho/ South Slave	Gwich'in-south	Gwich'in-north
	n (%)	*n* (%)	*n* (%)	*n* (%)
Not significantly different	22 (30)	39 (53)	34 (47)	26 (36)
Significantly greater	42 (58)	24 (33)	23 (32)	23 (32)
Significantly less	9 (12)	10 (14)	16 (22)	24 (33)

Table 4-2. Number of seismic lines crossed/km travelled by boreal caribou in the Cameron Hills, Dehcho/South Slave, Gwich'in-south and Gwich'in-north areas in northern Canada.

Study areas	Area (km^2)	Average Density of seismic lines (km/km^2)	Path type, seismic-line-avoidance period	n	Number of seismic lines crossed /km travelled			Difference between caribou and random crossing rates (%)		P-values for comparisons of the number of seismic lines crossed/km travelled by period		
					Median	Min	Max	Avoidance	Non-avoidance	Avoidance vs non-avoidance	Avoidance vs random	Non-avoidance vs random
Cameron Hills	21898	3.33	caribou, avoidance	27	1.04	0.37	7.45			$p<0.05$	$p<0.05$	NSD[1]
			caribou, non-avoidance	27	1.20	0.80	8.96					
			random	10	1.23	0.77	7.74	-15.4	-2.6			
Dehcho/South Slave	84373	0.44	caribou, avoidance	16	0.20	0.04	0.54			$p=0.11$	NSD[2]	NSD
			caribou, non-avoidance	16	0.29	0.03	0.57					
			random	10	0.31	0.03	0.47	-33.2	-6.0			
Gwich'in-south	13279	0.41	caribou, avoidance	11	0.18	0.06	0.36			$p<0.05$	$p<0.05$	NSD
			caribou, non-avoidance	11	0.31	0.13	0.40					
			random	10	0.31	0.19	0.43	-42.9	0.8			
Gwich'in-north	13865	0.12	caribou, avoidance	13	0.05	0.03	0.09			$p<0.05$	$p<0.05$	NSD
			caribou, non-avoidance	13	0.08	0.03	0.31					
			random	10	0.08	0.05	0.12	-35.2	2.8			

[1] NSD = not significantly different.

[2] Dehcho/South Slave: $p<0.10$ for 6 of 10 comparisons of avoidance period and random crossing rates.

Table 4-3. Travel rates for boreal caribou during seismic-line-crossing steps and pre- and post-crossing steps during seismic-line avoidance and non-avoidance periods in the Cameron Hills, Dehcho/South Slave, Gwich'in-south, and Gwich'in-north areas in northern Canada.

			Travel rates (km/day)											
			Pre-crossing			Crossing			Post-crossing			P-values for comparisons of travel rates		
Seismic-line-response periods and study areas	Time period[1]	N	Median	Min	Max	Median	Min	Max	Median	Min	Max	Pre- vs crossing	Post- vs crossing	Pre- vs post
Avoidance														
Cameron Hills	morning	346	0.9	0.0	8.1	3.2	0.2	27.0	0.4	0.0	24.3	<0.05	<0.05	<0.05
	mid day	456	1.0	0.0	10.7	4.2	0.1	54.0	1.1	0.0	12.3	<0.05	<0.05	NSD[2]
	evening	380	0.5	0.0	14.2	3.3	0.1	29.0	1.0	0.0	12.7	<0.05	<0.05	<0.05
Dehcho/South Slave	morning	69	1.1	0.1	6.1	3.7	0.1	40.3	0.5	0.0	10.5	<0.05	<0.05	NSD
	mid day	79	1.7	0.0	13.7	7.0	0.4	28.1	1.4	0.1	14.7	<0.05	<0.05	NSD
	evening	84	0.7	0.0	60.2	5.0	0.5	25.2	2.0	0.1	26.3	<0.05	<0.05	<0.05
Gwich'in-south	morning	40	1.0	0.1	23.1	4.5	0.2	49.7	1.3	0.0	5.5	<0.05	<0.05	NSD
	mid day	61	1.2	0.0	13.3	6.2	0.7	68.4	1.6	0.0	14.9	<0.05	<0.05	NSD
	evening	34	1.6	0.1	10.2	3.9	0.7	18.0	1.7	0.1	7.0	<0.05	<0.05	NSD
Gwich'in-north	morning	29	2.4	0.0	13.4	7.1	0.3	62.3	7.3	0.1	30.9	<0.05	NSD	<0.05
	mid day	108	1.6	0.1	27.7	15.6	0.9	71.8	1.7	0.0	32.9	<0.05	<0.05	NSD
	evening	48	3.5	0.1	24.5	4.9	0.3	40.2	0.9	0.1	11.5	<0.05	<0.05	<0.05

[1] Time periods: morning = 23:00h to 07:00h and 01:00h to 09:00h, mid day = 07:00h to 15:00h and 09:00h to 17:00h, and evening = 15:00h to 23:00h and 17:00h to 01:00h.

[2] NSD = not significantly different.

Table 4-3. Travel rates for boreal caribou during seismic-line-crossing steps and pre- and post-crossing steps during seismic-line avoidance and non-avoidance periods in the Cameron Hills, Dehcho/South Slave, Gwich’in-south, and Gwich’in-north areas in northern Canada (continued).

			Travel rates (km/day)											
			Pre-crossing			Crossing			Post-crossing			P-values for comparisons of travel rates		
Seismic-line-response periods and study areas	Time period[1]	N	Median	Min	Max	Median	Min	Max	Median	Min	Max	Pre- vs crossing	Post- vs crossing	Pre- vs post
Non-avoidance														
Cameron Hills	morning	191	0.8	0.0	13.6	1.5	0.0	13.6	1.1	0.0	7.7	<0.05	<0.05	<0.05
	mid day	849	0.5	0.0	13.3	3.7	0.1	43.9	0.7	0.0	10.0	<0.05	<0.05	<0.05
	evening	401	0.9	0.0	22.8	2.2	0.1	58.1	0.5	0.0	12.4	<0.05	<0.05	<0.05
Dehcho/South Slave	morning	87	0.7	0.0	6.9	2.7	0.2	16.7	1.1	0.0	12.8	<0.05	<0.05	NSD
	mid day	432	0.6	0.0	16.0	5.0	0.3	37.7	1.0	0.0	19.8	<0.05	<0.05	NSD
	evening	199	1.7	0.0	20.5	3.3	0.1	35.6	0.8	0.0	17.4	<0.05	<0.05	<0.05
Gwich'in-south	morning	80	1.2	0.0	15.7	4.1	0.2	23.1	1.8	0.1	12.3	<0.05	<0.05	NSD
	mid day	199	1.0	0.0	15.2	6.1	0.3	72.9	1.7	0.0	24.7	<0.05	<0.05	<0.05
	evening	104	2.8	0.1	32.8	4.1	0.7	27.6	1.4	0.0	12.7	<0.05	<0.05	<0.05
Gwich'in-north	morning	196	2.5	0.0	43.2	9.4	0.2	61.5	3.1	0.0	33.1	<0.05	<0.05	NSD
	mid day	303	1.8	0.0	44.5	10.6	0.1	65.5	2.8	0.0	36.5	<0.05	<0.05	<0.05
	evening	186	3.2	0.0	38.3	9.4	0.4	62.9	3.0	0.0	35.4	<0.05	<0.05	NSD

[1] Time periods: morning = 23:00h to 07:00h and 01:00h to 09:00h, mid day = 07:00h to 15:00h and 09:00h to 17:00h, and evening = 15:00h to 23:00h and 17:00h to 01:00h.

[2] NSD = not significantly different.

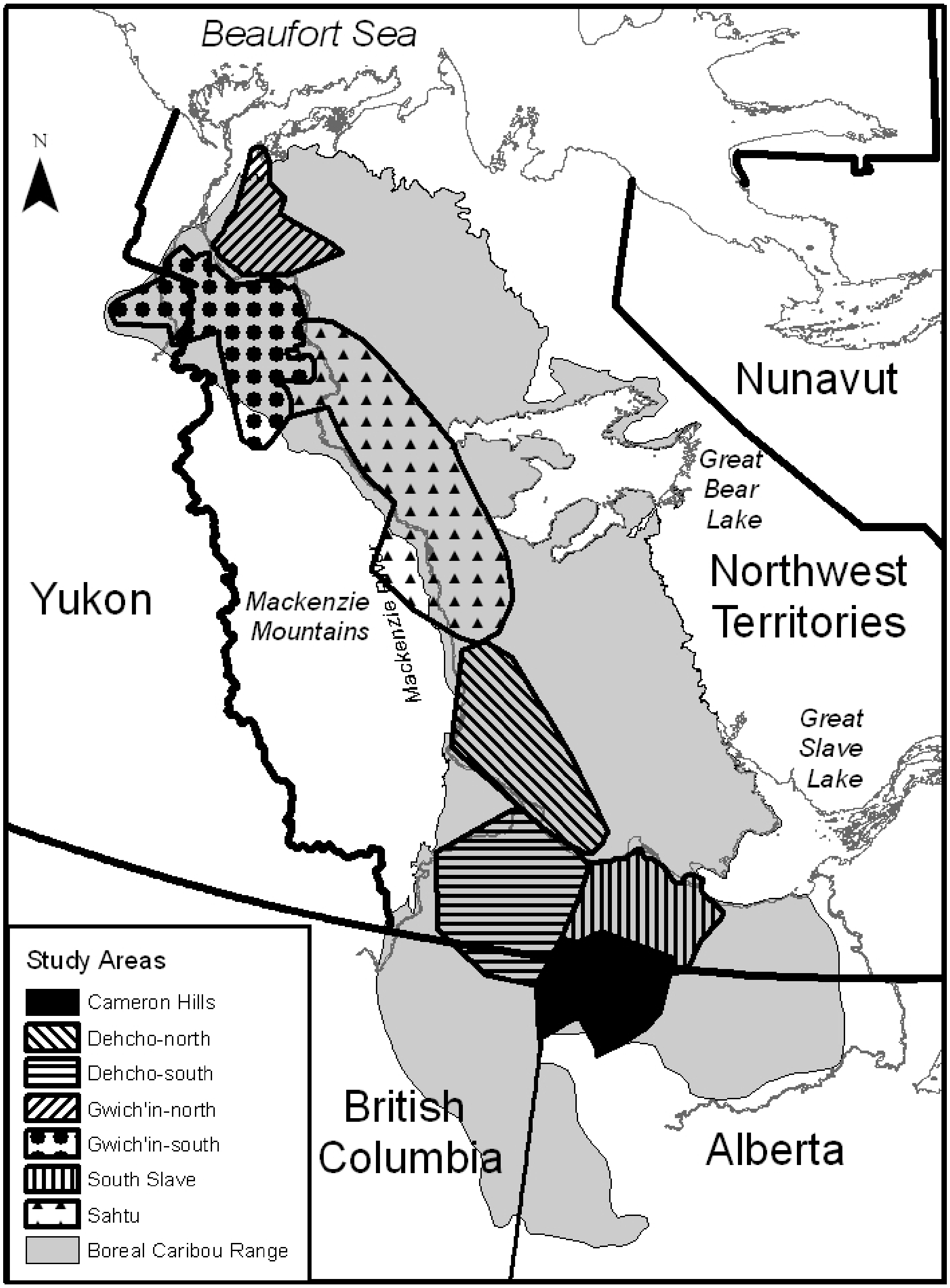


Figure 4-1. Location of the boreal and mountain (Mackenzie Mountains) caribou study areas in the Northwest Territories and northern Alberta, Canada.

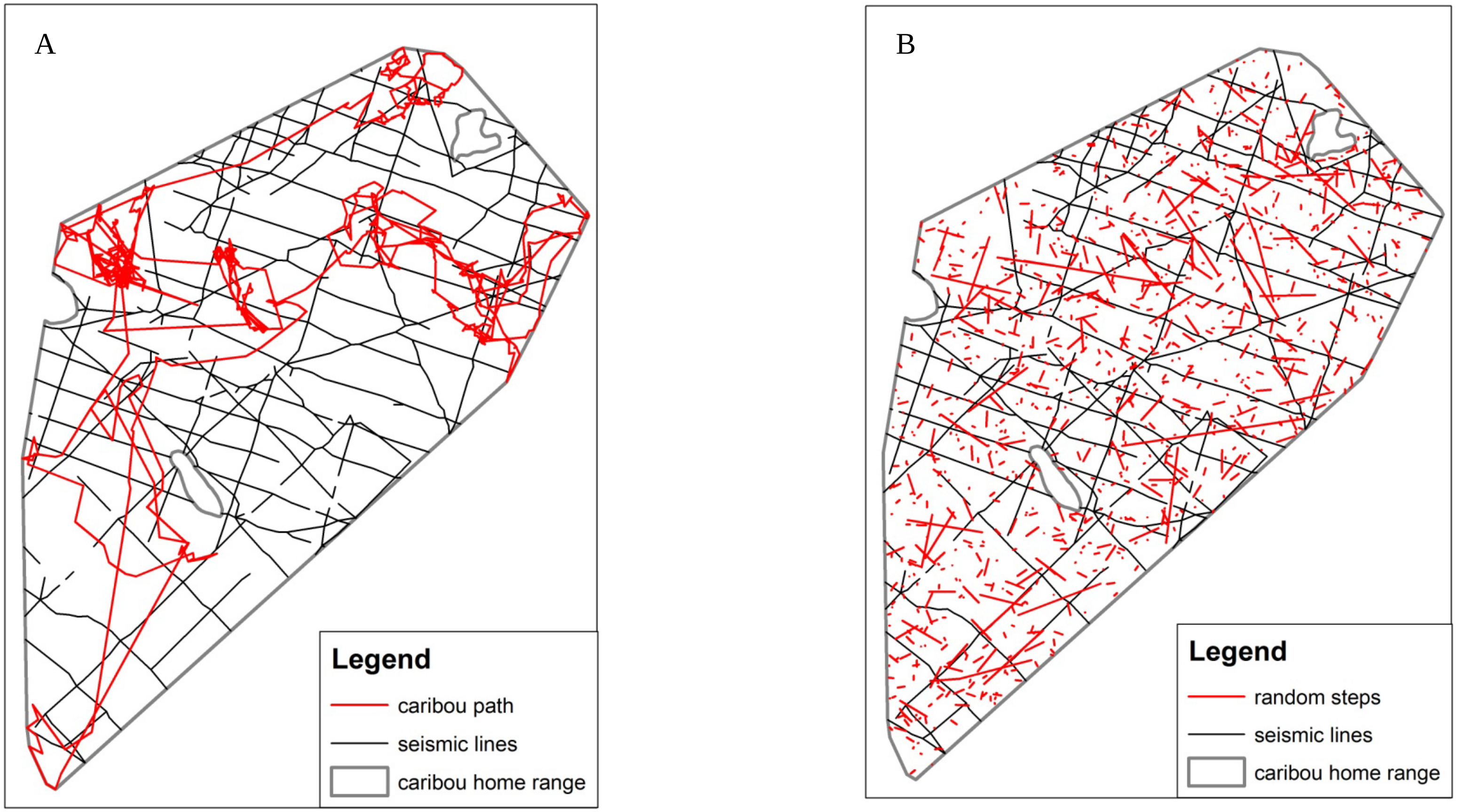


Figure 4-2. Boreal caribou home ranges with actual seismic line network with caribou path (A) and simulated random caribou steps (B).

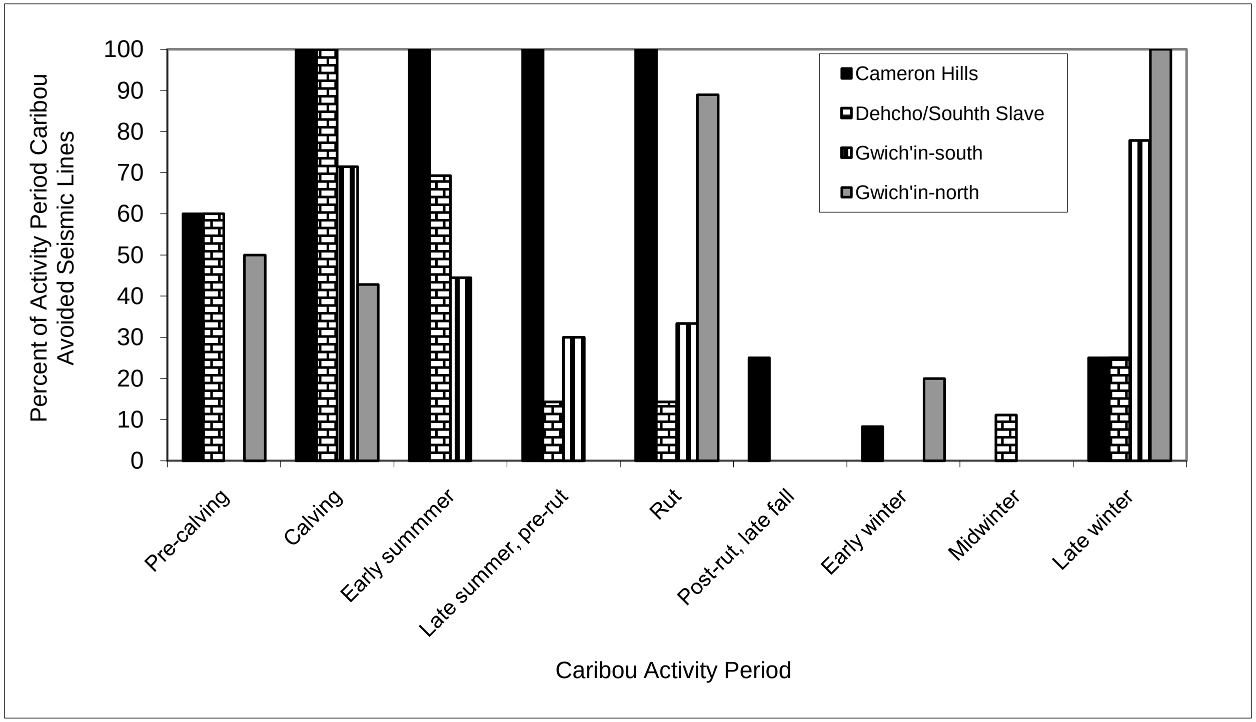


Figure 4-3. Proportion of 5-day periods when caribou avoided seismic lines within each activity period (Chapter32) in the Cameron Hills, Dehcho/South Slave, Gwich'in-south, and Gwich'in-north, Northwest Territories study areas.

Fig. 4-4a. Cameron Hills

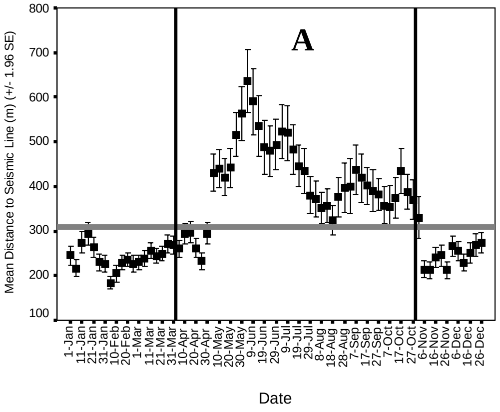


Fig. 4-4b. Dehcho/South Slave

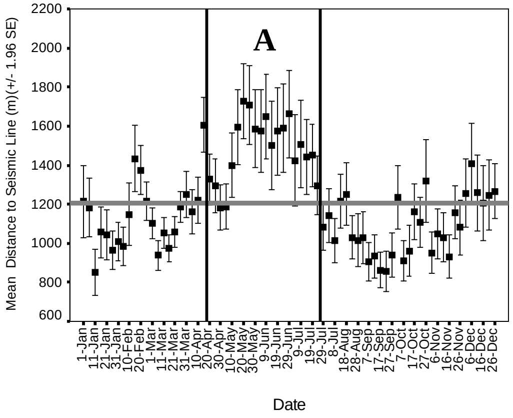


Fig. 4-4c. Gwich'in-south

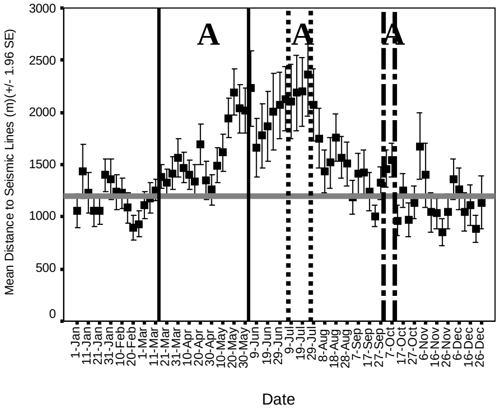


Fig. 4-4d. Gwich'in-north

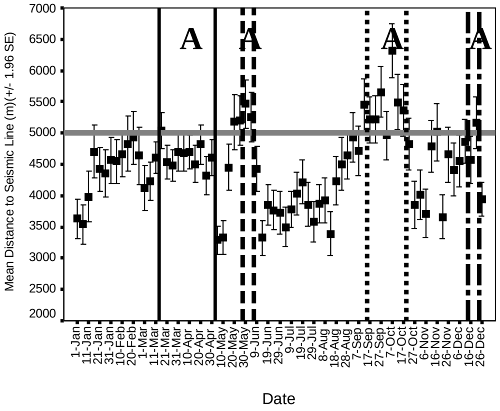
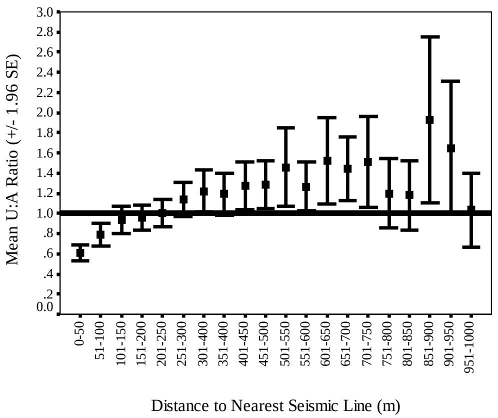


Figure 4-4. Average distance to the nearest seismic line by 5-day periods from 1 January – 31 December for boreal caribou in the a) Gwich'in-north, b) Gwich'in-south, c) Dehcho/South Slave, and d) Cameron Hills study areas, Northwest Territories and northern Alberta and Yukon, Canada. Vertical lines bracket periods of avoidance (A). The grey horizontal reference line indicates the average distance from random locations to the nearest seismic line.

Fig. 4-5a. Avoidance period: Cameron Hills



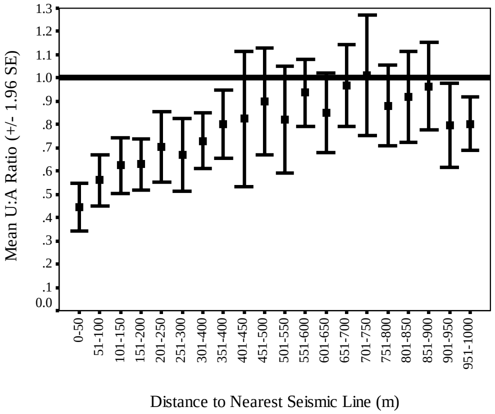


Fig. 4-5c. Non-avoidance period:Cameron Hills

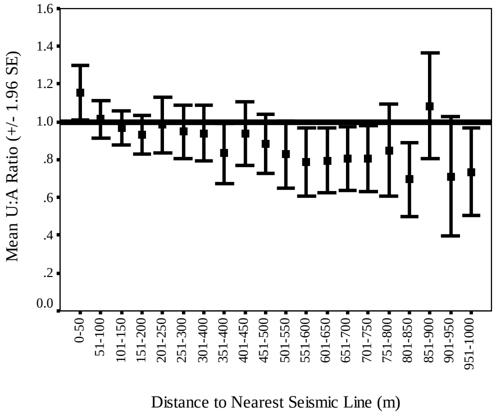


Fig. 4-5d. Non-avoidance period:Dehcho/South Slave/Gwich'in areas

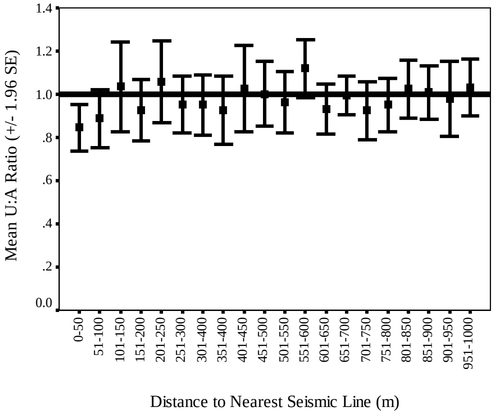


Figure 4-5. Spatial response of boreal caribou (use:availability ratios +95% CI on population mean) to areas within 1000 m of seismic lines in the a) Cameron Hills during the seismic–line-avoidance period (n=29), b) Dehcho/South Slave/Gwich’in areas during the seismic-line-avoidance period (n=40), c) Cameron Hills during the seismic-line-non-avoidance period, and d) Dehcho/South Slave/Gwich’in areas during the seismic-line-non-avoidance period.

Appendix 4-A. Distance to seismic lines for boreal caribou (5-day interval) and random locations (*n*=19088) in the Cameron Hills, Alberta study area, 2005-2009. Shading indicates 5-day intervals when caribou were significantly further from seismic lines than if their distribution was random.

		n	Mean rank			
Activity period	Start Date	Caribou	Caribou	Random	P-value	Difference[1]
early winter	1-Jan	635	9823	9865	0.862	=
early winter	6-Jan	596	9437	9854	0.077	=
early winter	11-Jan	607	10123	9839	0.226	=
early winter	16-Jan	627	10543	9833	0.002	>
early winter	21-Jan	646	10121	9860	0.250	=
mid winter	26-Jan	689	9692	9896	0.357	=
mid winter	31-Jan	803	9371	9970	0.004	<
mid winter	5-Feb	812	8721	10001	0.000	<
mid winter	10-Feb	802	9002	9985	0.000	<
mid winter	15-Feb	983	9760	10048	0.126	=
mid winter	20-Feb	1062	9886	10085	0.276	=
mid winter	25-Feb	905	9577	10017	0.025	<
mid winter	1-Mar	1067	9716	10101	0.037	<
mid winter	6-Mar	1033	9606	10085	0.010	<
mid winter	11-Mar	1043	10013	10069	0.761	=
late winter	16-Mar	1010	10001	10053	0.785	=
late winter	21-Mar	1048	9960	10074	0.533	=
late winter	26-Mar	1034	9990	10064	0.683	=
late winter	**31-Mar**	**803**	**10561**	**9922**	**0.002**	>
pre-calving	**5-Apr**	**750**	**10551**	**9896**	**0.002**	>
pre-calving	**10-Apr**	**708**	**10779**	**9865**	**0.000**	>
pre-calving	**15-Apr**	**708**	**10587**	**9875**	**0.001**	>
pre-calving	20-Apr	693	10042	9886	0.479	=
pre-calving	25-Apr	650	9914	9870	0.841	=
calving	**30-Apr**	**722**	**10887**	**9870**	**0.000**	>
calving	**5-May**	**740**	**12161**	**9828**	**0.000**	>
calving	**10-May**	**787**	**12399**	**9839**	**0.000**	>
calving	**15-May**	**774**	**12204**	**9839**	**0.000**	>
calving	**20-May**	**781**	**12594**	**9828**	**0.000**	>
calving	**25-May**	**750**	**13225**	**9791**	**0.000**	>
calving	**30-May**	**721**	**13038**	**9786**	**0.000**	>
calving	**4-Jun**	**709**	**13239**	**9776**	**0.000**	>
early summer	**9-Jun**	**681**	**12551**	**9791**	**0.000**	>
early summer	**14-Jun**	**677**	**12171**	**9802**	**0.000**	>
early summer	**19-Jun**	**664**	**11836**	**9807**	**0.000**	>
early summer	**24-Jun**	**657**	**11892**	**9802**	**0.000**	>
early summer	**29-Jun**	**693**	**11876**	**9818**	**0.000**	>
Activity period	Start Date	Caribou	Caribou	Random	P-value	Difference
early summer	**4-Jul**	**659**	**11476**	**9818**	**0.000**	>
early summer	**9-Jul**	**653**	**11752**	**9807**	**0.000**	>
early summer	**14-Jul**	**650**	**11818**	**9802**	**0.000**	>
early summer	**19-Jul**	**661**	**11967**	**9802**	**0.000**	>
early summer	**24-Jul**	**610**	**11892**	**9786**	**0.000**	>
early summer	**29-Jul**	**608**	**11819**	**9786**	**0.000**	>
early summer	**3-Aug**	**621**	**11559**	**9802**	**0.000**	>
early summer	**8-Aug**	**642**	**11524**	**9807**	**0.000**	>
late summer, pre-breed	**13-Aug**	**628**	**11471**	**9807**	**0.000**	>
late summer, pre-breed	**18-Aug**	**641**	**11375**	**9812**	**0.000**	>
late summer, pre-breed	**23-Aug**	**617**	**11752**	**9791**	**0.000**	>
late summer, pre-breed	**28-Aug**	**619**	**11496**	**9802**	**0.000**	>
late summer, pre-breed	**2-Sep**	**624**	**11416**	**9807**	**0.000**	>
late summer, pre-breed	**7-Sep**	**637**	**11682**	**9802**	**0.000**	>
late summer, pre-breed	**12-Sep**	**635**	**11533**	**9807**	**0.000**	>
breeding	**17-Sep**	**649**	**11605**	**9812**	**0.000**	>
breeding	**22-Sep**	**643**	**11208**	**9823**	**0.000**	>
breeding	**27-Sep**	**659**	**11870**	**9807**	**0.000**	>
breeding	**2-Oct**	**636**	**10872**	**9828**	**0.000**	>
breeding	**7-Oct**	**655**	**10892**	**9839**	**0.000**	>
breeding	**12-Oct**	**626**	**11170**	**9812**	**0.000**	>
breeding	**17-Oct**	**624**	**11445**	**9802**	**0.000**	>
post-breeding, late fall	**22-Oct**	**617**	**11276**	**9807**	**0.000**	>
post-breeding, late fall	**27-Oct**	**634**	**10807**	**9828**	**0.000**	>
post-breeding, late fall	1-Nov	620	10026	9849	0.446	=
post-breeding, late fall	6-Nov	625	9179	9881	0.003	<
post-breeding, late fall	11-Nov	624	9029	9886	0.000	<
post-breeding, late fall	16-Nov	645	9494	9881	0.091	=
post-breeding, late fall	21-Nov	630	9448	9875	0.065	=
post-breeding, late fall	26-Nov	648	9129	9891	0.001	<
early winter	1-Dec	636	10189	9849	0.142	=
early winter	6-Dec	626	10063	9849	0.359	=
early winter	11-Dec	616	9773	9854	0.725	=
early winter	16-Dec	643	9953	9865	0.694	=
early winter	21-Dec	637	10013	9860	0.500	=
early winter	26-Dec	689	10130	9881	0.260	=

[1] = distances from caribou and random locations to seismic lines were not significantly different, > caribou were significantly further from seismic lines than random locations, and < indicates caribou were significantly closer to seismic lines than random locations.

Appendix 4-B. Distance to seismic lines for boreal caribou (5-day interval) and random locations (*n*=23637) in the Dehcho/South Slave, Northwest Territories study area, 2005-2009. Shading indicates 5-day intervals when caribou were significantly further from seismic lines than if their distribution was random within the study area.

Activity period	Start Date	n	Mean rank		P-value	Difference[1]
		Caribou	Caribou	Random		
early winter	1-Jan	299	11282	11977	0.084	=
early winter	6-Jan	272	12115	11952	0.700	=
early winter	11-Jan	287	9778	11990	0.000	<
early winter	16-Jan	268	11150	11960	0.055	=
early winter	21-Jan	338	11173	11998	0.029	<
early winter	26-Jan	411	10825	12045	0.000	<
mid winter	31-Jan	407	11252	12036	0.024	<
mid winter	5-Feb	411	10951	12045	0.002	<
mid winter	10-Feb	379	10908	12028	0.002	<
mid winter	15-Feb	496	12497	12057	0.165	=
mid winter	**20-Feb**	**625**	**12710**	**12117**	**0.036**	>
mid winter	25-Feb	551	12607	12083	0.081	=
mid winter	1-Mar	634	12168	12134	0.907	=
mid winter	6-Mar	627	10785	12167	0.000	<
mid winter	11-Mar	635	11835	12146	0.271	=
late winter	16-Mar	650	11506	12163	0.019	<
late winter	21-Mar	620	11711	12142	0.132	=
late winter	**26-Mar**	**631**	**12748**	**12117**	**0.026**	>
late winter	31-Mar	378	12375	12002	0.300	=
pre-calving	5-Apr	334	12071	11985	0.821	=
pre-calving	10-Apr	321	12641	11969	0.084	=
pre-calving	**15-Apr**	**312**	**14797**	**11939**	**0.000**	>
pre-calving	**20-Apr**	**307**	**13482**	**11952**	**0.000**	>
pre-calving	**25-Apr**	**296**	**12971**	**11956**	**0.012**	>
calving	**30-Apr**	**305**	**13021**	**11960**	**0.008**	>
calving	**5-May**	**313**	**13249**	**11960**	**0.001**	>
calving	**10-May**	**316**	**12973**	**11964**	**0.010**	>
calving	**15-May**	**325**	**13879**	**11956**	**0.000**	>
calving	**20-May**	**319**	**14938**	**11939**	**0.000**	>
calving	**25-May**	**319**	**14040**	**11952**	**0.000**	>
calving	**30-May**	**309**	**13660**	**11952**	**0.000**	>
calving	**4-Jun**	**304**	**13641**	**11952**	**0.000**	>
early summer	**9-Jun**	**300**	**13617**	**11947**	**0.000**	>
early summer	**14-Jun**	**273**	**12897**	**11943**	**0.023**	>
early summer	**19-Jun**	**281**	**13162**	**11943**	**0.003**	>
early summer	**24-Jun**	**273**	**13349**	**11939**	**0.001**	>
early summer	**29-Jun**	**289**	**13513**	**11943**	**0.000**	>
early summer	4-Jul	262	12207	11947	0.544	=
early summer	**9-Jul**	**271**	**13223**	**11939**	**0.002**	>
early summer	**14-Jul**	**281**	**13352**	**11943**	**0.001**	>
early summer	**19-Jul**	**279**	**14055**	**11935**	**0.000**	>
early summer	**24-Jul**	**269**	**13398**	**11939**	**0.001**	>
early summer	29-Jul	282	12124	11960	0.689	=
early summer	3-Aug	253	12348	11943	0.351	=
early summer	8-Aug	276	11728	11960	0.579	=
late summer, pre-breed	**13-Aug**	**263**	**13045**	**11939**	**0.010**	>
late summer, pre-breed	18-Aug	263	12698	11943	0.077	=
late summer, pre-breed	23-Aug	254	12184	11943	0.580	=
late summer, pre-breed	28-Aug	270	11213	11964	0.076	=
late summer, pre-breed	2-Sep	266	11454	11956	0.237	=
late summer, pre-breed	7-Sep	282	11219	11969	0.070	=
late summer, pre-breed	12-Sep	280	11120	11969	0.041	<
breeding	17-Sep	273	11211	11964	0.073	=
breeding	22-Sep	269	10729	11969	0.003	<
breeding	27-Sep	249	11148	11952	0.067	=
breeding	**2-Oct**	**194**	**12928**	**11909**	**0.040**	>
breeding	7-Oct	222	11167	11939	0.097	=
breeding	12-Oct	184	11416	11914	0.327	=
breeding	17-Oct	248	12129	11943	0.670	=
post breeding/late fall	22-Oct	282	12051	11960	0.825	=
post breeding/late fall	27-Oct	278	12669	11952	0.084	=
post breeding/late fall	1-Nov	269	11239	11960	0.088	=
post breeding/late fall	6-Nov	248	11634	11947	0.478	=
post breeding/late fall	11-Nov	222	11676	11930	0.581	=
post breeding/late fall	16-Nov	273	11173	11964	0.060	=
post breeding/late fall	21-Nov	280	12170	11956	0.608	=
post breeding/late fall	26-Nov	279	11654	11960	0.458	=
early winter	1-Dec	282	12169	11956	0.610	=
early winter	6-Dec	282	12229	11956	0.511	=
early winter	11-Dec	265	11665	11956	0.496	=
early winter	16-Dec	275	11481	11960	0.251	=
early winter	21-Dec	287	11739	11964	0.581	=
early winter	26-Dec	339	12485	11981	0.183	=

[1] = distances from caribou and random locations to seismic lines were not significantly different, > caribou were significantly further from seismic lines than random locations, and < indicates caribou were significantly closer to seismic lines than random locations.

Appendix 4-C. Distance to seismic lines for boreal caribou (5-day interval) and random locations (*n*=20857) in the Gwich'in South, Northwest Territories study area, 2005-2009. Shading indicates 5-day intervals when caribou were significantly further from seismic lines than if their distribution was random within the study area.

		n	Mean rank			
Activity period	Start Date	Caribou	Caribou	Random	P-value	Difference[1]
early winter	1-Jan	139	9275	10505	0.017	<
early winter	6-Jan	141	9973	10505	0.301	=
early winter	11-Jan	121	9870	10495	0.259	=
early winter	16-Jan	160	9479	10519	0.031	<
mid winter	21-Jan	162	10159	10514	0.459	=
mid winter	**26-Jan**	**143**	**12314**	**10486**	**0.000**	>
mid winter	31-Jan	131	11106	10490	0.247	=
mid winter	5-Feb	164	9993	10514	0.272	=
mid winter	10-Feb	164	11228	10505	0.129	=
mid winter	15-Feb	153	10445	10505	0.902	=
mid winter	20-Feb	175	9260	10529	0.006	<
mid winter	25-Feb	140	9578	10505	0.071	=
mid winter	1-Mar	165	10700	10510	0.689	=
mid winter	6-Mar	151	10729	10505	0.649	=
late winter	**11-Mar**	**211**	**11959**	**10519**	**0.001**	>
late winter	**16-Mar**	**246**	**12115**	**10534**	**0.000**	>
late winter	21-Mar	254	11142	10548	0.123	=
late winter	**26-Mar**	**244**	**11500**	**10538**	**0.014**	>
late winter	**31-Mar**	**210**	**11925**	**10519**	**0.001**	>
late winter	**5-Apr**	**222**	**12174**	**10524**	**0.000**	>
late winter	**10-Apr**	**224**	**11335**	**10534**	**0.050**	>
late winter	15-Apr	221	10703	10538	0.688	=
late winter	**20-Apr**	**223**	**11441**	**10529**	**0.026**	>
pre-calving	25-Apr	187	10570	10524	0.915	=
calving	30-Apr	201	10846	10529	0.458	=
calving	**5-May**	**196**	**11913**	**10514**	**0.001**	>
calving	10-May	216	10562	10538	0.953	=
calving	**15-May**	**246**	**12312**	**10534**	**0.000**	>
calving	**20-May**	**256**	**12627**	**10534**	**0.000**	>
calving	**25-May**	**212**	**11684**	**10524**	**0.006**	>
calving	**30-May**	**232**	**12001**	**10529**	**0.000**	>
calving	4-Jun	203	11275	10524	0.080	=
early summer	9-Jun	205	9891	10538	0.129	=
early summer	14-Jun	182	9721	10529	0.075	=
early summer	19-Jun	178	10456	10519	0.891	=
early summer	24-Jun	162	10381	10510	0.786	=
early summer	29-Jun	166	11354	10505	0.073	=
early summer	**4-Jul**	**166**	**12111**	**10500**	**0.001**	>
early summer	**9-Jul**	**173**	**11619**	**10505**	**0.016**	>
early summer	**14-Jul**	**175**	**11684**	**10505**	**0.011**	>
early summer	**19-Jul**	**179**	**12507**	**10500**	**0.000**	>
late summer, pre-breed	**24-Jul**	**148**	**12091**	**10490**	**0.001**	>
late summer, pre-breed	29-Jul	175	11240	10510	0.114	=
late summer, pre-breed	3-Aug	174	11020	10510	0.271	=
late summer, pre-breed	8-Aug	174	9962	10519	0.227	=
late summer, pre-breed	13-Aug	164	10118	10514	0.405	=
late summer, pre-breed	**18-Aug**	**166**	**11980**	**10500**	**0.002**	>
late summer, pre-breed	**23-Aug**	**174**	**12151**	**10500**	**0.000**	>
late summer, pre-breed	28-Aug	178	11259	10510	0.102	=
late summer, pre-breed	2-Sep	175	10334	10519	0.689	=
late summer, pre-breed	7-Sep	178	10866	10514	0.442	=
breeding	12-Sep	168	10721	10510	0.655	=
breeding	17-Sep	189	10436	10524	0.843	=
breeding	22-Sep	164	9503	10519	0.033	<
breeding	**27-Sep**	**176**	**11666**	**10510**	**0.012**	>
breeding	**2-Oct**	**165**	**12023**	**10500**	**0.001**	>
breeding	**7-Oct**	**175**	**12162**	**10505**	**0.000**	>
breeding	12-Oct	145	8732	10514	0.000	<
breeding	17-Oct	145	10398	10500	0.837	=
breeding	22-Oct	154	8440	10519	0.000	<
post-breeding, late fall	27-Oct	168	9058	10524	0.002	<
post-breeding, late fall	1-Nov	163	10379	10510	0.781	=
post-breeding, late fall	6-Nov	158	8946	10519	0.001	<
post-breeding, late fall	11-Nov	127	8506	10505	0.000	<
post-breeding, late fall	16-Nov	144	8879	10514	0.001	<
post-breeding, late fall	21-Nov	155	7928	10524	0.000	<
post-breeding, late fall	26-Nov	150	8679	10519	0.000	<
early winter	1-Dec	140	10173	10500	0.524	=
early winter	6-Dec	152	9643	10510	0.079	=
early winter	11-Dec	149	8611	10519	0.000	<
early winter	16-Dec	142	9471	10505	0.042	<
early winter	21-Dec	159	8130	10529	0.000	<
early winter	26-Dec	159	7704	10529	0.000	<

[1] = distances from caribou and random locations to seismic lines were not significantly different, > caribou were significantly further from seismic lines than random locations, and < caribou were significantly closer to seismic lines than random locations.

Appendix 4-D. Distance to seismic lines for boreal caribou (5-day interval) and random locations (*n*=13184) in the Gwich'in North, Northwest Territories study area, 2005-2009. Shading indicates 5-day intervals when caribou were significantly further from seismic lines than if their distribution was random within the study area.

	Start	n	Mean rank					Start	n	Mean rank			
Activity period	Date	Caribou	Caribou	Random	P-value	Difference[1]	Activity period	Date	Caribou	Caribou	Random	P-value	Difference
early winter	1-Jan	341	6207	6777	0.008	<	early summer	4-Jul	448	5882	6848	0.000	<
early winter	6-Jan	352	6009	6789	0.000	<	early summer	9-Jul	436	6423	6823	0.036	<
early winter	11-Jan	349	6105	6785	0.001	<	early summer	14-Jul	439	6391	6826	0.023	<
early winter	16-Jan	341	6922	6759	0.446	=	early summer	19-Jul	452	6457	6831	0.047	<
mid winter	21-Jan	362	6971	6768	0.331	=	late summer, pre-breed	24-Jul	437	6146	6833	0.000	<
mid winter	26-Jan	372	6655	6782	0.537	=	late summer, pre-breed	29-Jul	444	5851	6847	0.000	<
mid winter	31-Jan	366	6951	6771	0.384	=	late summer, pre-breed	3-Aug	441	6428	6826	0.037	<
mid winter	5-Feb	359	7042	6765	0.185	=	late summer, pre-breed	8-Aug	423	6075	6827	0.000	<
mid winter	10-Feb	368	7122	6767	0.086	=	late summer, pre-breed	13-Aug	415	5330	6846	0.000	<
mid winter	15-Feb	334	6851	6757	0.665	=	late summer, pre-breed	18-Aug	428	6281	6824	0.005	<
mid winter	20-Feb	376	6892	6777	0.575	=	late summer, pre-breed	23-Aug	409	6362	6810	0.023	<
mid winter	25-Feb	312	6643	6751	0.630	=	late summer, pre-breed	28-Aug	427	6818	6806	0.951	=
mid winter	1-Mar	371	6500	6786	0.165	=	late summer, pre-breed	2-Sep	414	7078	6791	0.142	=
mid winter	6-Mar	375	7027	6773	0.215	=	late summer, pre-breed	7-Sep	389	6877	6784	0.644	=
late winter	**11-Mar**	**492**	**7623**	**6809**	**0.000**	**>**	**breeding**	**12-Sep**	**406**	**7388**	**6777**	**0.002**	**>**
late winter	**16-Mar**	**558**	**7778**	**6833**	**0.000**	**>**	**breeding**	**17-Sep**	**428**	**7539**	**6783**	**0.000**	**>**
late winter	**21-Mar**	**547**	**7200**	**6852**	**0.044**	**>**	**breeding**	**22-Sep**	**375**	**7639**	**6756**	**0.000**	**>**
late winter	**26-Mar**	**558**	**7325**	**6852**	**0.006**	**>**	**breeding**	**27-Sep**	**409**	**7797**	**6766**	**0.000**	**>**
late winter	**31-Mar**	**471**	**7332**	**6810**	**0.005**	**>**	**breeding**	**2-Oct**	**409**	**7186**	**6785**	**0.042**	**>**
late winter	**5-Apr**	**486**	**7339**	**6817**	**0.004**	**>**	**breeding**	**7-Oct**	**395**	**8297**	**6745**	**0.000**	**>**
late winter	**10-Apr**	**468**	**7514**	**6802**	**0.000**	**>**	**breeding**	**12-Oct**	**386**	**7395**	**6768**	**0.002**	**>**
late winter	**15-Apr**	**449**	**7210**	**6804**	**0.032**	**>**	**breeding**	**17-Oct**	**378**	**7567**	**6759**	**0.000**	**>**
late winter	**20-Apr**	**424**	**7507**	**6782**	**0.000**	**>**	breeding	22-Oct	361	7068	6765	0.146	=
pre-calving	25-Apr	465	6851	6824	0.885	=	post-breeding, late fall	27-Oct	363	6030	6794	0.000	<
pre-calving	**30-Apr**	**469**	**7331**	**6809**	**0.005**	**>**	post-breeding, late fall	1-Nov	381	6267	6798	0.009	<
calving	5-May	463	6096	6850	0.000	<	post-breeding, late fall	6-Nov	364	5872	6799	0.000	<
calving	10-May	454	5904	6851	0.000	<	post-breeding, late fall	11-Nov	356	7019	6764	0.225	=
calving	15-May	433	6743	6811	0.723	=	post-breeding, late fall	16-Nov	364	6913	6771	0.494	=
calving	20-May	454	7041	6812	0.223	=	post-breeding, late fall	21-Nov	325	6100	6771	0.002	<
calving	**25-May**	**468**	**7269**	**6811**	**0.013**	**>**	post-breeding, late fall	26-Nov	359	6730	6773	0.838	=
calving	**30-May**	**475**	**7598**	**6802**	**0.000**	**>**	early winter	1-Dec	364	6419	6784	0.079	=
calving	**4-Jun**	**472**	**7288**	**6812**	**0.010**	**>**	early winter	6-Dec	369	6767	6777	0.960	=
calving	9-Jun	459	6691	6827	0.468	=	**early winter**	**11-Dec**	**354**	**7521**	**6749**	**0.000**	**>**
early summer	14-Jun	440	5778	6847	0.000	<	early winter	16-Dec	356	7069	6762	0.145	=
early summer	19-Jun	452	6280	6837	0.003	<	**early winter**	**21-Dec**	**370**	**7391**	**6760**	**0.002**	**>**
early summer	24-Jun	445	6214	6835	0.001	<	early winter	26-Dec	404	6761	6796	0.861	=
early summer	29-Jun	441	6050	6839	0.000	<							

[1] = distances from caribou and random locations to seismic lines were not significantly different, > caribou were significantly further from seismic lines than random locations, and < caribou were significantly closer to seismic lines than random locations

Appendix 4-E. Use:availability ratios by seismic-line-response periods and distance-to- seismic-line categories for boreal caribou in the Cameron Hills, Alberta study area. Values in bold are significantly different from a use:availability ratio of 1:1.

Distance to seismic line (m)	Use:availability ratios by seismic-line-response period						
	Avoidance				Non-avoidance		
			95% CI on mean			95% CI on mean	
	n	Mean	Lower	Upper	Mean	Lower	Upper
0 - 50	**29**	**0.582**	**0.495**	**0.67**	**1.155**	**1.002**	**1.308**
51 - 100	**29**	**0.797**	**0.673**	**0.92**	1.014	0.909	1.119
101 - 150	29	0.946	0.798	1.094	0.969	0.873	1.066
151 - 200	29	0.973	0.83	1.116	0.932	0.826	1.037
201 - 250	29	1.021	0.874	1.169	0.985	0.832	1.138
251 - 300	29	1.156	0.962	1.35	0.949	0.800	1.098
301 - 350	29	1.223	0.99	1.456	0.940	0.786	1.094
351 - 400	29	1.2	0.966	1.435	0.835	0.667	1.002
401 - 450	29	1.287	**1.026**	**1.548**	0.939	0.762	1.116
451 - 500	29	1.286	**1.022**	**1.549**	0.885	0.723	1.047
501 - 550	29	1.508	**1.069**	**1.948**	0.829	0.643	1.015
551 - 600	27	1.285	**1.008**	**1.562**	**0.788**	**0.600**	**0.977**
601 - 650	26	1.551	**1.062**	**2.041**	**0.796**	**0.614**	**0.979**
651 - 700	26	1.472	**1.114**	**1.829**	**0.804**	**0.627**	**0.980**
701 - 750	26	1.557	**1.061**	**2.054**	**0.806**	**0.624**	**0.988**
751 - 800	28	1.219	0.823	1.614	0.850	0.596	1.105
801 - 850	26	1.195	0.809	1.581	**0.695**	**0.487**	**0.903**
851 - 900	26	1.968	**1.058**	**2.878**	1.086	0.790	1.381
901 - 950	26	1.699	0.976	2.421	0.711	0.379	1.042
951 - 1000	27	1.06	0.648	1.472	**0.736**	**0.491**	**0.980**
>1000	27	3.162	**0.945**	**5.379**	**0.674**	**0.433**	**0.915**

Appendix 4-F. Use:availability ratios by seismic-line-response periods and distance-to- seismic-line categories for boreal caribou in the Dehcho/South Slave, Northwest Territories study area. Values in bold are significantly different from a use:availability ratio of 1:1.

Distance to nearest seismic line (m)	Use:availability ratios by seismic-line-response period						
	Avoidance				Non-avoidance		
			95% CI on mean			95% CI on mean	
	n	Mean	Lower	Upper	Mean	Lower	Upper
0 - 50	**16**	**0.381**	**0.257**	**0.506**	**0.807**	**0.666**	**0.947**
51 - 100	**16**	**0.477**	**0.308**	**0.646**	0.849	0.651	1.047
101 - 150	**16**	**0.542**	**0.383**	**0.702**	0.925	0.673	1.176
151 - 200	**16**	**0.571**	**0.413**	**0.73**	0.944	0.764	1.125
201 - 250	**16**	0.783	0.552	1.014	1.246	0.960	1.533
251 - 300	**16**	**0.622**	**0.387**	**0.857**	0.957	0.749	1.165
301 - 350	16	0.795	0.571	1.019	1.053	0.753	1.352
351 - 400	16	0.899	0.619	1.178	1.031	0.798	1.264
401 - 450	16	0.889	0.592	1.185	1.114	0.808	1.419
451 - 500	16	1.021	0.736	1.307	1.126	0.871	1.380
501 - 550	16	0.991	0.675	1.307	1.046	0.781	1.310
551 - 600	16	1.179	0.875	1.484	1.126	0.949	1.304
601 - 650	16	1.078	0.738	1.417	0.897	0.714	1.081
651 - 700	16	1.139	0.73	1.548	1.067	0.916	1.217
701 - 750	16	1.114	0.693	1.535	1.044	0.817	1.271
751 - 800	16	1.020	0.735	1.305	1.079	0.855	1.303
801 - 850	16	0.945	0.677	1.212	1.014	0.815	1.214
851 - 900	16	1.114	0.849	1.38	1.117	0.903	1.332
901 - 950	16	0.958	0.585	1.332	0.997	0.830	1.164
951 - 1000	16	0.937	0.698	1.176	1.093	0.879	1.307
>1000	16	1.205	0.948	1.462	0.996	0.771	1.222

Appendix 4-G. Use:availability ratios by seismic-line-response periods and distance-to- seismic-line categories for boreal caribou in the Gwich'in-south, Northwest Territories study area. Values in bold are significantly different from a use:availability ratio of 1:1.

Distance to nearest seismic line (m)	Use:availability ratios by seismic-line-response period						
	Avoidance				Non-avoidance		
			95% CI on mean			95% CI on mean	
	n	Mean	Lower	Upper	Mean	Lower	Upper
0 - 50	**11**	**0.501**	**0.284**	**0.718**	1.035	0.812	1.257
51 - 100	**11**	**0.59**	**0.384**	**0.796**	0.938	0.739	1.138
101 - 150	**11**	**0.587**	**0.329**	**0.846**	1.012	0.690	1.333
151 - 200	**11**	**0.532**	**0.409**	**0.655**	0.942	0.625	1.259
201 - 250	**11**	**0.561**	**0.207**	**0.916**	0.834	0.641	1.028
251 - 300	**11**	**0.486**	**0.313**	**0.659**	0.849	0.644	1.054
301 - 350	**11**	**0.536**	**0.291**	**0.781**	0.916	0.723	1.109
351 - 400	11	0.721	0.439	1.002	0.962	0.747	1.177
401 - 450	11	0.914	0.666	1.162	0.984	0.749	1.220
451 - 500	11	**0.771**	**0.615**	**0.927**	0.984	0.708	1.260
501 - 550	11	**0.583**	**0.42**	**0.746**	0.896	0.733	1.059
551 - 600	11	0.801	0.531	1.071	1.032	0.734	1.330
601 - 650	11	0.82	0.576	1.064	1.039	0.811	1.266
651 - 700	11	0.949	0.628	1.271	0.962	0.788	1.136
701 - 750	11	0.857	0.563	1.152	0.982	0.754	1.209
751 - 800	11	0.88	0.588	1.172	1.046	0.801	1.292
801 - 850	11	**0.691**	**0.447**	**0.935**	0.922	0.751	1.092
851 - 900	11	1.002	0.625	1.379	1.089	0.793	1.385
901 - 950	11	0.735	0.363	1.106	1.033	0.770	1.297
951 - 1000	11	**0.688**	**0.425**	**0.95**	0.901	0.702	1.101
>1000	11	1.423	1.194	1.651	1.069	0.934	1.205

Appendix 4-H. Use:availability ratios by seismic-line-response periods and distance-to- seismic-line categories for boreal caribou in the Gwich’in-north, Northwest Territories study area. Values in bold are significantly different from a use:availability ratio of 1:1.

Distance to nearest seismic line (m)	Use:availability ratios by seismic-line-response period						
	Avoidance				Non-avoidance		
			95% CI on mean			95% CI on mean	
	n	Mean	Lower	Upper	Mean	Lower	Upper
0 - 50	**13**	**0.239**	**0.135**	**0.342**	**0.734**	**0.493**	**0.974**
51 - 100	**13**	**0.275**	**0.124**	**0.427**	0.890	0.535	1.245
101 - 150	**13**	**0.650**	**0.336**	**0.965**	1.194	0.602	1.785
151 - 200	**13**	**0.532**	**0.261**	**0.803**	0.895	0.537	1.254
201 - 250	**13**	**0.710**	**0.42**	**0.999**	1.017	0.519	1.515
251 - 300	13	0.780	0.359	1.201	1.036	0.699	1.373
301 - 350	**13**	**0.707**	**0.483**	**0.932**	0.853	0.616	1.090
351 - 400	13	0.698	0.255	1.141	0.763	0.347	1.178
401 - 450	13	0.809	-0.221	1.840	0.952	0.401	1.504
451 - 500	13	0.801	0.102	1.499	0.864	0.534	1.193
501 - 550	13	0.776	0.141	1.411	0.919	0.580	1.257
551 - 600	13	0.738	0.423	1.054	1.183	0.863	1.502
601 - 650	13	0.815	0.450	1.181	0.880	0.609	1.150
651 - 700	13	0.779	0.400	1.159	0.938	0.737	1.139
701 - 750	13	0.993	0.346	1.640	0.729	0.437	1.021
751 - 800	13	**0.645**	**0.305**	**0.984**	**0.714**	**0.539**	**0.888**
801 - 850	13	0.925	0.391	1.459	1.125	0.765	1.485
851 - 900	13	0.637	0.247	1.028	**0.809**	**0.629**	**0.988**
901 - 950	13	**0.665**	**0.420**	**0.911**	0.904	0.376	1.433
951 - 1000	13	0.812	0.555	1.07	1.059	0.733	1.385
>1000	13	1.097	1.047	1.148	1.034	0.984	1.084

Appendix 4-I. Use:availability ratios by seismic-line-response periods and distance-to- seismic-line categories for boreal caribou in the Dehcho/South Slave and Gwich'in, Northwest Territories study areas combined. Values in bold are significantly different from a use:availability ratio of 1:1.

Distance to nearest seismic line (m)	Use:availability ratios by seismic-line-response period						
	Avoidance				Non-avoidance		
			95% CI on mean			95% CI on mean	
	n	Mean	Lower	Upper	Mean	Lower	Upper
0 - 50	40	**0.445**	**0.341**	**0.549**	**0.846**	**0.735**	**0.956**
51 - 100	40	**0.561**	**0.447**	**0.675**	0.887	0.750	1.024
101 - 150	40	**0.623**	**0.499**	**0.748**	1.036	0.821	1.251
151 - 200	40	**0.628**	**0.513**	**0.743**	0.928	0.781	1.074
201 - 250	40	**0.704**	**0.549**	**0.858**	1.059	0.864	1.253
251 - 300	40	**0.670**	**0.509**	**0.830**	0.953	0.816	1.090
301 - 350	40	**0.730**	**0.609**	**0.852**	0.950	0.808	1.092
351 - 400	40	**0.802**	**0.650**	**0.955**	0.925	0.762	1.088
401 - 450	40	0.825	0.526	1.125	1.026	0.819	1.233
451 - 500	40	0.897	0.660	1.134	1.002	0.847	1.157
501 - 550	40	0.820	0.583	1.057	0.963	0.816	1.110
551 - 600	40	0.936	0.788	1.085	1.119	0.982	1.255
601 - 650	40	0.852	0.675	1.029	0.930	0.810	1.051
651 - 700	40	0.969	0.787	1.151	0.996	0.903	1.089
701 - 750	40	1.012	0.746	1.279	0.924	0.785	1.064
751 - 800	40	0.881	0.701	1.062	0.951	0.825	1.077
801 - 850	40	0.918	0.715	1.122	1.025	0.887	1.163
851 - 900	40	0.965	0.772	1.158	1.009	0.882	1.137
901 - 950	40	**0.796**	**0.611**	**0.982**	0.977	0.797	1.157
951 - 1000	40	**0.804**	**0.687**	**0.921**	1.029	0.893	1.165
>1000	40	1.228	1.109	1.347	1.029	0.937	1.121

Chapter 5 - Defining Critical Habitat for Boreal Caribou

Introduction

Linking the ecology of animals with management strategies is essential for the conservation of large intact landscapes for wide-ranging species like boreal caribou (*Rangifer tarandus caribou*). Boreal caribou are listed as threatened in Canada (COSEWIC 2002) and as such "their critical habitats or habitats that are necessary for their long-term survival or recovery must be identified in the recovery strategies or action plans and be protected" (Statutes of Canada 2003). Boreal caribou are a sedentary forest dwelling species (Bergerud et al. 2008) that avoid areas disturbed by fire (Schaefer and Pruitt 1991, Dalerum et al. 2007). They live in small dispersed bands most of the year (Thomas and Gray 2002). Females are largely organized as individuals (Chapter two). Preferred habitats vary throughout their range but generally include bogs, fens, and areas with low to moderate cover of black (*Picea mariana*) and white (*P. glauca*) spruce around peatlands where terrestrial lichens are abundant (Rettie and Messier 1998, Anderson 1999, Brown et al. 2000, James and Stuart-Smith 2000). Females are solitary or occur in cow:calf pairs during pre-calving to late summer, spacing away from conspecifics and predators to reduce predation risk (Schaefer et al. 2001). They select areas where densities of other females or ungulates are low (Bergerud et al. 2008) rather than specific habitats (James 1999) and avoid areas near anthropogenic linear features such as seismic lines presumably to avoid predation risk (Dyer et al. 2001, Dzus 2001, Dyer et al. 2002). As a result, it has been difficult to define or delineate their critical habitat.

Wildlife and forest managers desire models that can be used to assess the current or future status of resident wildlife populations based on existing or proposed levels of natural and anthropogenic impacts (Sleep and Loehle 2010). With such models a key goal is to maintain landscapes where levels of habitat loss and fragmentation are not severe enough to lead to significant population declines or local extinctions of species. Knowledge of such habitat thresholds would help immensely in managing cumulative effects by allowing development of natural resources to proceed as long as it remained within acceptable levels of risk to species persistence (Sorensen et al. 2008).

Several models have been developed that predict thresholds for sustainable levels of natural and development impacts beyond which viable populations of boreal caribou cannot be maintained. One widely applied threshold model used for management of boreal caribou habitat evaluates the probability of survival of boreal caribou populations affected by varying levels of natural and anthropogenic impacts in Alberta (AB), Canada (Sorensen et al. 2008). A second model predicts calf:cow ratios and population status based on the total percent of caribou range within 500 m of linear features and disturbed by fires within the last 50 years (Environment Canada 2009). Sleep and Loehle (2010) found that Sorensen et al. (2008) model had wide confidence intervals indicating low precision, over-estimated population growth rates, and has low predictive power. Similarly, 38% (9/24) of the data points used to generate the Environment Canada (2009) model fell outside the 95% prediction intervals indicating that this model also has low predictive power (Harrell et al. 1984, Steyerberg et al. 2001). As a result, use of these models may result in management practices that cause outcomes that are contrary to conservation objectives. Both models focus on the amount of habitat disturbed by industry and wildfires.

The spatial configuration of habitat at the range level is very important when assessing habitat quality for woodland caribou (O'Brien et al. 2006). Developments that fragment habitat seem to reduce the effectiveness of the spacing-out strategy that boreal caribou use to avoid other ungulates and concomitant predation risk (Stuart-Smith et al. 1997). Linear features such as seismic lines have been shown to increase the efficiency with which predators and hunters can travel and access areas on the landscape (Dyer et al. 2001, Schaefer 2003, James et al. 2004, Neufeld 2006).

In the Northwest Territories (NT) and northern AB where the boreal forest has been fragmented by seismic lines and other anthropogenic linear features to varying degrees, caribou space away from these features, avoiding use of areas up to 400 m near seismic lines (James and Stuart-Smith 2000, Dyer et al. 2001, Chapter Four). Caribou avoid seismic lines during all or part of the pre-calving to breeding period (Chapter Four) when most mortality occurs due to predation (Stuart-Smith et al. 1997, McLoughlin et al. 2003), and in late winter and the breeding period when people hunt caribou and other species (Mahoney and Virgl 2003, McLoughlin et al. 2003). These avoidance responses are believed to be mechanisms to reduce predation risk (James and Stuart-Smith 2000, Dyer et al. 2002). Therefore, caribou likely perceive areas ≤400 m from seismic lines as risky habitats and those >400 m from these features as being more secure from predators and hunters.

Adult female and calf survival are the two key demographic factors that determine population growth rates (Hatter and Bergerud 1991); therefore habitats or habitat states that allow boreal caribou to successfully employ their anti-predator strategies (i.e., facilitate or enhance adult female and calf survival) should be considered critical for their long-term survival or recovery. Because boreal caribou likely perceive areas >400 m from seismic lines as preferred secure habitats, areas >400 m from seismic lines could be classified as critical habitat. However, some of these areas may have been disturbed by fires within the last 50 years and boreal caribou prefer habitats that have not been disturbed by fires (Schaefer and Pruitt 1991, Dalerum et al. 2007). Therefore caribou range could be classified as risky (areas ≤400 from linear features) and secure unburned and burned habitats (areas >400 m from linear features), with secure unburned habitats being critical for boreal caribou. The security value of patches of secure unburned habitat should increase as patch size increases, and survival of calves and adult females and population growth rates should be higher in areas where they have access to large patches of secure unburned habitat.

The objective of my study is to examine the relationship between population growth rates (λ) and the availability and use of secure unburned habitat in six study areas in the NT and northern AB that were disturbed to varying degrees by fires and the petroleum industry (Figure 5-1 and 5-2). I hypothesized that population growth rates should be directly correlated with habitat configuration and in particular with i) the availability and/or patch size of secure unburned habitats or ii) the frequency of use of secure unburned habitats and/or patch size of secure unburned habitats used. I hypothesized that critical habitat for boreal caribou is a habitat state, i.e., that is “secure” from a caribou perspective and occurs in large contiguous tracts of undisturbed boreal forests that facilitate or promote the effectiveness of their anti-predator strategies and thus calf and adult female survival.

Methods

I used Global Positioning System (GPS) satellite locations for 75 female boreal caribou obtained during studies conducted in the NT and northern AB during 2002-2009 (Fig. 5-1; Chapter 4). I used ArcMap 9.3 (Environmental Systems Research Institute, Inc., Redlands, California, USA) and Hawth’s Tools (Beyer 2007) for spatial analyses and SPSS 11.5 (Chicago, Illinois, USA) and STATA 9 (STATCORP, College Station, Texas, USA) for statistical analyses. I obtained digital linear feature data from the Canadian National Energy Board, the National Topographic Series map database, the Dehcho Land Use Planning Board, and the Government of AB, and fire history data (1957-2008) from the governments of NT and AB. I created a 400 m buffer around all seismic lines, roads, and pipelines and merged these data with those for areas burned and major water bodies (1:2,000,000 scale digital National Topographic Series maps). I mapped and classified all land areas that were ≤400 and >400 m from linear features as risky and secure unburned or burned habitat, respectively (Fig.5-2). I calculated the area of all patches of secure unburned habitat (km^2), and generated a cumulative patch size frequency distribution curve and size classes that best fit that curve (Beyer 2010). Patch size classes were: ≤0.25, >0.25-0.5, >0.5-2.5, >2.5-5, >5-10, >10-25, >25-100, >100-500, >500-1000, >1000-2000, >2000-3000, and >3000 km^2.

For each study area, I used random and caribou locations to calculate the i) availability and frequency of use of secure unburned habitats, ii) availability of secure unburned habitat by patches size class, and iii) percent of secure unburned habitat use that occurred in all patches sizes and iv) percent of secure unburned habitat use that occurred in patches that were >0.25, >0.5, >2.5, >5, >10, >25, >100, >500, >1000, >2000, and >3000 km^2. Random locations were generated at a rate of 1 per km^2.

I calculated geometric mean population growth rates (λ; Sorensen et al. 2008) using annual λ's obtained in the Cameron Hills and South Slave (2006-2010; A. Kelly unpublished data), the Dehcho-south and Dehcho-north (2006-2010; N. C. Larter unpublished data), and the Gwich'in-south (2005-2007; J. A. Nagy *unpublished data*) and Gwich'in-north (2006-2007; J. A. Nagy *unpublished data*) study areas. Annual λ's were calculated using survival rates of radio-collared adult females and their calves following (Hatter and Bergerud 1991). I calculated the mean annual rate of population change as (geometric mean λ - 1) for each study area. I did this because an annual rate of populations change of -0.10 is more intuitive than its reciprocal of 0.90.

I used a Chi-Square Goodness of Fit test to determine if the use of secure habitat was significantly different from available. I fit multiple regressions to determine if there were significant predictive relationships between the mean annual rate of population change and the following variables: i) percent of caribou locations that fell within secure unburned habitats in each study area in total and by patch size classes, ii) percent of secure unburned habitats available in each study area in total and by patch size classes, and iii) percent of the total caribou use of secure unburned habitat that occurred in patches >0.25, >0.5, >2.5, >5, >10, >25, >100, >500, >1000, >2000, or >3000 km^2.

I performed regression analyses of the mean annual rate of population change in 12 subsets of independent variables (Appendix 5-A) using general linear models (GLM) in STATA 9 (STATCORP, College Station, Texas, USA). I ranked the models in each subset using Akaike's Information Criterion (AIC). Because I had a small number of populations (n=6) relative to model parameters, I used corrected AICc scores to select the most parsimonious models (Anderson et al. 2000). This gave me 12 candidate models. I fit standard least squares regression models for each candidate model used JMP 8 (Cary, North Carolina, USA). The best model was the one with the highest explanatory power (R^2), lowest root mean squared error (RMSE), and lowest AICc score.

Results

Annual rates of population change indicated that caribou numbers declined in 4 of 6 study areas (Table 5-1). These declines occurred in areas with the least amount of secure habitat in patches >500 km^2 available and where predator and/or alternate prey species diversity was greatest.

Use of secure unburned habitat was significantly greater (21-75%) than expected ($\chi^2=52.0_{df=5}$, $P<0.05$) in all study areas (Table 5-1). The percent of secure unburned habitat use that occurred in patches >500 km^2 varied significantly among study areas ($\chi=21.48391_{df4}$,$P<0.05$). There were no patches of secure unburned habitat >500 km^2 in the Cameron Hills; use of patches >500 km^2 was greater than expected in the South Slave (92%) and Dehcho-south (33%)

and less than expected in the remaining areas (9-28%). This difference likely occurred because there was 3-6 times less secure unburned habitat in patches >500 km^2 available in the South Slave and Dehcho-south study areas than in the remaining study areas. This is consistent with Fortin et al.'s (2008) observations that animals may adjust their patterns of selection based on habitat availability.

Model 5 that included percent secure unburned habitat use (b_1) and percent unburned secure habitat use occurring in patches >500 km^2 (b_2) for periods when caribou avoided seismic lines, explained 96% (R^2) of the variation in average annual rate of population change among study areas ($F_{2,3}$ =35.5545, P =0.0081; Table 5-2; Figure 5-3). This model had the smallest RMSE (0.034) and was the most parsimonious (Anderson et al. 2000). Assumptions of noncollinearity among the two independent variables were satisfied ($F_{1,4}$=3.3, P>0.14, R^2=0.45). The percent of secure habitat use in patches >500 km^2 (b_2) was the most significant predictor variable (P=0.005; Table 5-2).

My model suggests that viable populations of boreal caribou can be maintained in areas with low predator and alternate prey diversity and where ≥46% of the area is secure unburned habitat and 54% of that secure unburned habitat is in patches >500 km^2 (Gwich'in areas, Table 5-1). In an area with similar habitat conditions but greater predator and alternate diversity, boreal caribou populations were in decline (Dehcho-north, Table 5-1), suggesting that most patches of secure unburned habitat were not large enough or there were not enough of them for caribou to effectively employ their anti-predator strategies.

Discussion

Conservation and management actions for highly mobile species occupying large annual and cumulative ranges should reflect their ecology and be implemented at large landscape scales (Hanski 1998). Because the viability of boreal caribou populations is linked to their ability to space-away from and avoid predators, large areas of undisturbed habitat need to be protected to prevent penetration of habitat by wolves from surrounding areas (Schneider et al. 2010) and allow caribou to effectively employ their anti-predator strategies (Stuart-Smith et al. 1997, Courtois et al. 2004). Habitat configuration and patch size are thus very important (O'Brien et al. 2006, Schneider et al. 2010).

My model accounts for the frequency of use of secure unburned habitat and the proportion of that use that occurred in patches >500 km^2. I found a highly significant correlation of these variables with the rate of population change, with patch size being the most significant explanatory variable. Areas with low diversity of predators and alternate prey where ≥46% of the area was secure unburned habitat from a caribou perspective and ≥54% of this was in patches >500 km^2 provided habitat conditions favorable for zero or positive population growth. This supports the view that large tracts of undisturbed boreal forest need to be protected for boreal caribou (Courtois et al. 2004, Schneider et al. 2010). These areas need to include a variety of habitat components including bogs, fens, wetlands, shrublands, and lichen bearing coniferous forests. These habitat components may be important for a number of activities including foraging, calving, and insect relief or simply to provide connectivity among preferred habitats.

Destruction of natural habitat has occurred at a rapid pace, emphasizing the need for and importance of spatially explicit models (Hanski 1998). The effects of industrial best practices on caribou population dynamics has not been quantified, but in AB it is known that after 30 years of caribou management using industry guidelines, best practices, and restrictions on activities, boreal caribou are closer to extirpation than ever before (Canada 2009, Schneider et al. 2010). These “best” practices are directed at reducing the impact of industry on the landscape, but they are clearly not the best practices required to satisfactorily reduce impacts on caribou. My model suggests that in order to maintain viable boreal caribou populations we need to manage large tracts of secure unburned boreal forest, i.e., not impacted by development, for boreal caribou or alternately we need to aggressively manage other ungulates and predators. Based on this, best practices from a caribou perspective should involve the use of spatially explicit habitat models to manage areas specifically for boreal caribou or industrial activity but not both in the same area. This should be coupled with management studies that use multi-species ecosystem approaches to assess rates and causes of caribou mortality and population trends.

My model should not be viewed as a predictive model but simply one that points us in a new direction, hopefully to better manage human impacts and ensure that viable populations of boreal caribou are maintained on the landscape. Critical habitat for boreal caribou is comprised of a number of habitat components within the boreal forest and the value of these to caribou is influenced by the degree of security they collectively provide from predation risk. In areas that already have a large industrial footprint, aggressive management actions that include predator control may be required to provide secure habitat for boreal caribou.

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Table 5-1. Mortality rates of radio-collared female caribou due to predation, the diversity of predators and alternate prey species, seismic line densities, annual rates of population change, and availability and use of secure habitats by boreal caribou by study areas in the Northwest Territories and northern Alberta.

	Radio-collared caribou predation rates (percent)		Diversity (no. of species)				Percent secure unburned habitat available		Percent use of secure unburned habitat	
Study area	Average annual rate	No. of years	Predators[1]	Alternate prey[2]	Seismic lines per km^2	Annual rate of population change	Total	In patches >500 km^2	Total	in patches >500 km^2
Cameron Hills	15.1	3	7	3	3.32	-12.9	16.4	0	23.8	0
South Slave	17.6	5	7	4	0.36	-5.6	51.9	15.2	79.9	29.2
Dehcho-south	19.6	3	7	5	0.64	-9.7	54.9	13.8	67.4	18.3
Dehcho-north	23.2	3	5	3	0.29	-4.4	45.2	46.0	79.3	36.1
Gwich'in-south	5.2	3	5	2	0.41	8.3	46.4	53.5	56.2	38.5
Gwich'in-north	0	2	5	2	0.12	20	66.1	87.7	80.2	79.4

[1] Predators: wolves, coyotes, black bears, grizzly bears, lynx, wolverine, and cougar.

[2] Major alternate prey: barren-ground caribou, moose, white-tailed deer, bison, elk, and beaver.

Table 5-2. Multiple regression coefficients (*b*), standard errors, statistics (*t*), and probabilities for terms in the regression models used to evaluate relationship between caribou population growth, use and availability of secure habitats, and patch size boreal caribou in 6 study areas in northern Canada. Below are the 12 candidate models; model 5 was the most explanatory model.

Model number	Seismic line avoidance period	Model terms	*b*	SE of *b*	*t*	*P*	R^2	F	RSME	P-value
1	All	Percent use secure unburned habitat (*b*1)	0.000	0.002	0.18	0.857				
1	All	Percent patches >500 km^2 available (*b*2)	0.004	0.001	3.96	0.000				
1	All	intercept (*b*0)	-0.149	0.068	-2.19	0.029	0.910	$F_{2,3}$=14.613	0.049	0.028
2	All	Percent patches >500 km^2 available(*b*1)	0.004	0.001	6.21	0.000				
2	All	intercept (*b*0)	-0.138	0.027	-5.05	0.000	0.910	$F_{1,2}$=38.305	0.043	0.003
3	All	Percent use secure unburned habitat (*b*1)	0.000	0.002	0.01	0.993				
3	All	Percent available secure habitat in patches >500 km^2 (*b*2)	0.006	0.001	4.19	0.000				
3	All	intercept (*b*0)	-0.121	0.067	-1.8	0.072	0.920	$F_{2,3}$=16.228	0.047	0.025
4	All	Percent available secure habitat in patches >500 km^2 (*b*1)	0.006	0.001	6.58	0.000				
4	All	intercept (b0)	-0.121	0.024	-5.05	0.000	0.920	$F_{1,2}$=42.274	0.041	0.003
5	Avoidance	Percent use secure unburned habitat (*b*1)	-0.002	0.001	-2.38	0.017				
5	Avoidance	Percent secure unburned habitat use in patches >500 km^2 (*b*2)	0.006	0.001	7.58	0.000				
5	Avoidance	intercept (b0)	-0.059	0.046	-1.28	0.201	0.960	$F_{2,3}$=35.555	0.034	0.008
6	Avoidance	Percent secure unburned habitat use in patches >500 km^2 (*b*1)	0.004	0.001	5.5	0.000				
6	Avoidance	intercept (*b*0)	-0.156	0.033	-4.68	0.000	0.880	$F_{1,2}$=30.242	0.048	0.005

Table 5-2. Multiple regression coefficients (*b*), standard errors, statistics (*t*), and probabilities for terms in the regression models used to evaluate relationship between caribou population growth, use and availability of secure habitats and patch size boreal caribou in 6 study areas in northern Canada. Below are the 12 candidate models; model 5 was the most explanatory model. (continued)

Model number	Seismic line avoidance period	Model terms	*b*	SE of *b*	*t*	*P*	R^2	F	RSME	P-value
7	Avoidance	Percent use secure unburned habitat (*b*1)	-0.001	0.003	-0.22	0.828				
7	Avoidance	Percent available secure habitat in patches >500 km^2 available (*b*2)	0.006	0.002	2.25	0.024				
7	Avoidance	intercept (*b*0)	-0.113	0.112	-1.01	0.314	0.780	$F_{2,3}=5.476$	0.075	0.100
8	Avoidance	Percent available secure habitat in patches >500 km^2 available (*b*1)	0.005	0.001	3.78	0.000				
8	Avoidance	intercept (*b*0)	-0.135	0.043	-3.14	0.002	0.780	$F_{1,2}=14.315$	0.065	0.019
9	Non-avoidance	Percent use secure unburned habitat (*b*1)	-0.002	0.002	-1	0.319				
9	Non-avoidance	Percent patches >500 km^2 available (*b*2)	0.005	0.002	3.27	0.001				
9	Non-avoidance	intercept (*b*0)	-0.063	0.089	-0.71	0.477	0.820	$F_{2,3}=6.840$	0.068	0.076
10	Non-avoidance	Percent patches >500 km^2 available (*b*1)	0.004	0.001	3.56	0.000				
10	Non-avoidance	intercept (*b*0)	-0.139	0.046	-3	0.003	0.760	$F_{1,2}=12.708$	0.068	0.024
11	Non-avoidance	Percent use secure unburned habitat (*b*1)	-0.002	0.002	-0.65	0.517				
11	Non-avoidance	Percent available secure habitat in patches >500 km^2 available (*b*2)	0.006	0.003	2.39	0.017				
11	Non-avoidance	intercept (*b*0)	-0.055	0.113	-0.49	0.626	0.720	$F_{2,3}=3.819$	0.086	0.150
12	Non-avoidance	Percent available secure habitat in patches >500 km^2 available (*b*1)	0.005	0.002	2.91	0.004				
12	Non-avoidance	intercept (*b*0)	-0.119	0.050	-2.37	0.018	0.680	$F_{1,2}=8.445$	0.079	0.044

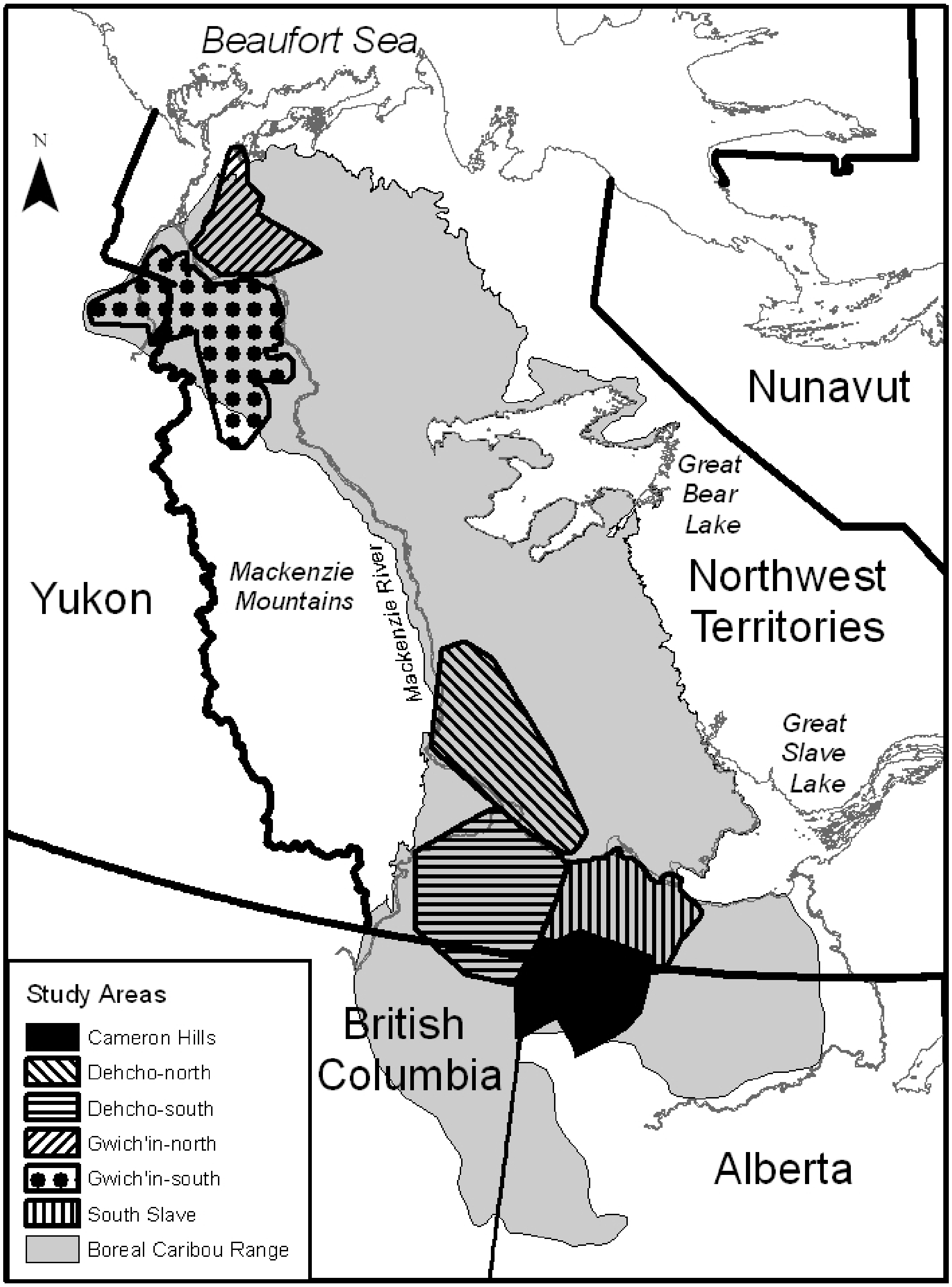

Fig.5-1. Location of boreal caribou study areas in the Northwest Territories and northern Alberta.

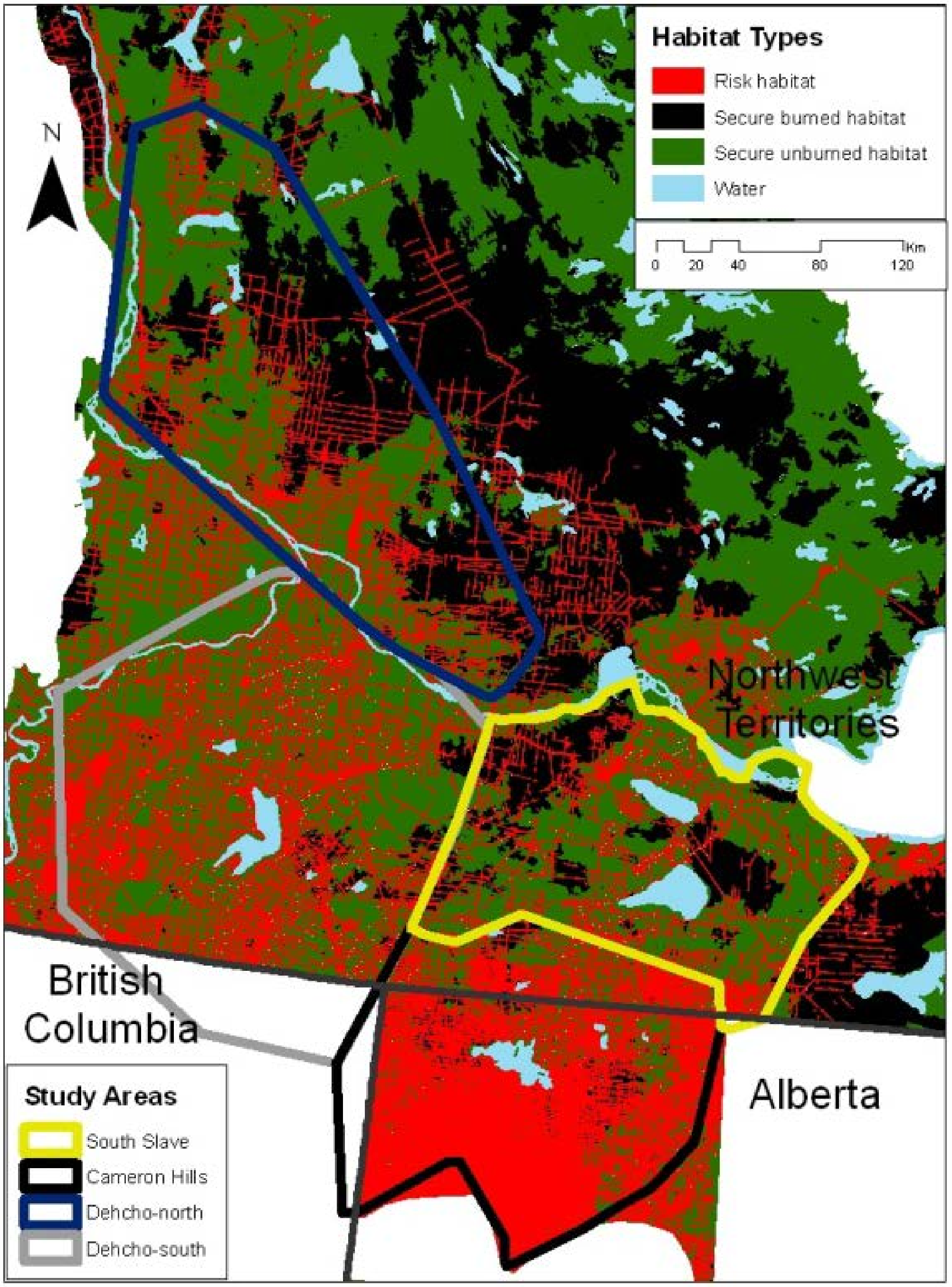

Figure 5-2. Distribution of risk and secure unburned and burned boreal caribou habitat in the Cameron Hills and Dehcho/South Slave study areas in the Northwest Territories and northern Alberta, Canada.

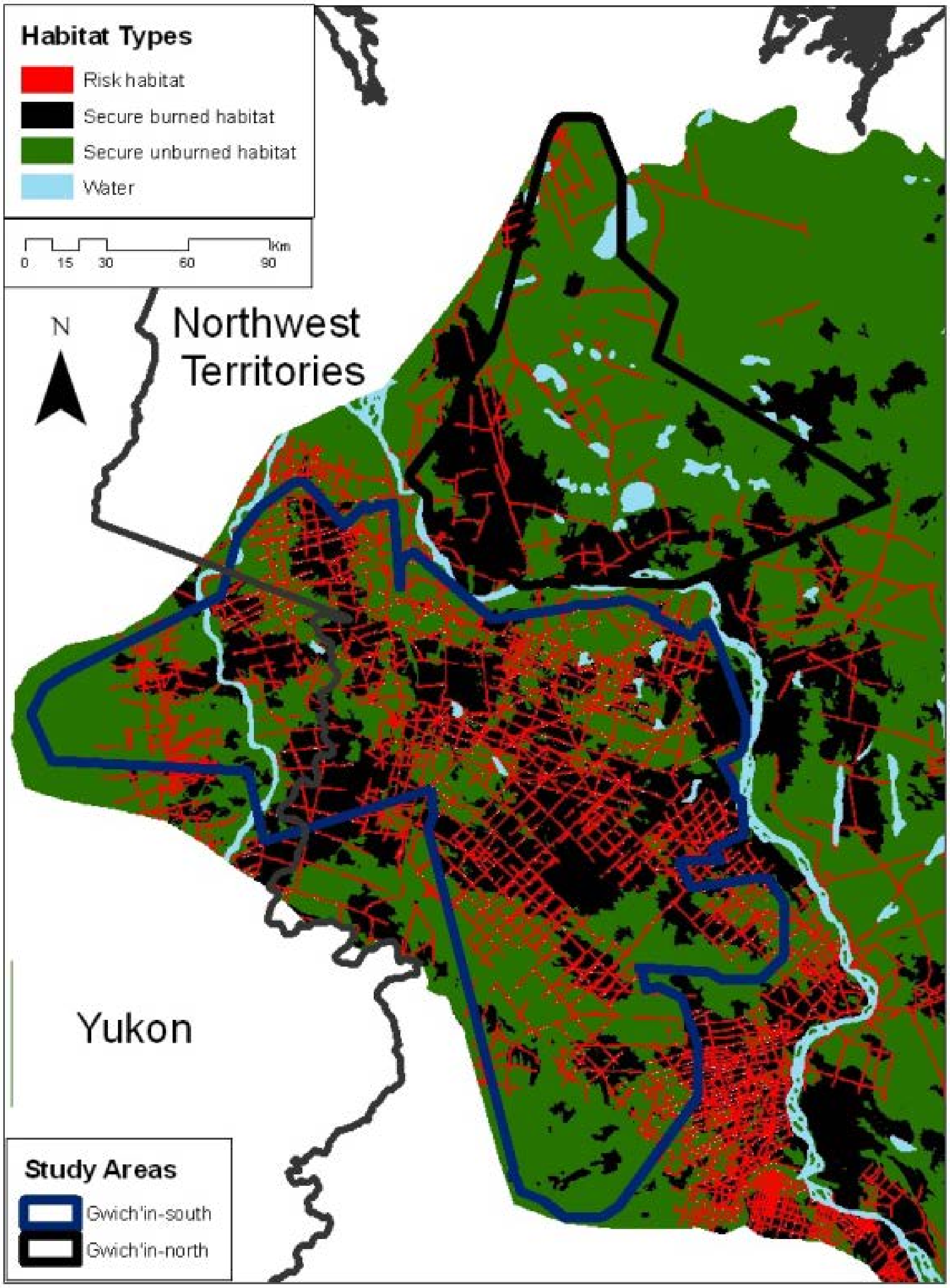

Figure 5-3. Distribution of risk and secure unburned and burned boreal caribou habitat in the Gwich'in study areas in the Northwest Territories and northern Yukon, Canada.

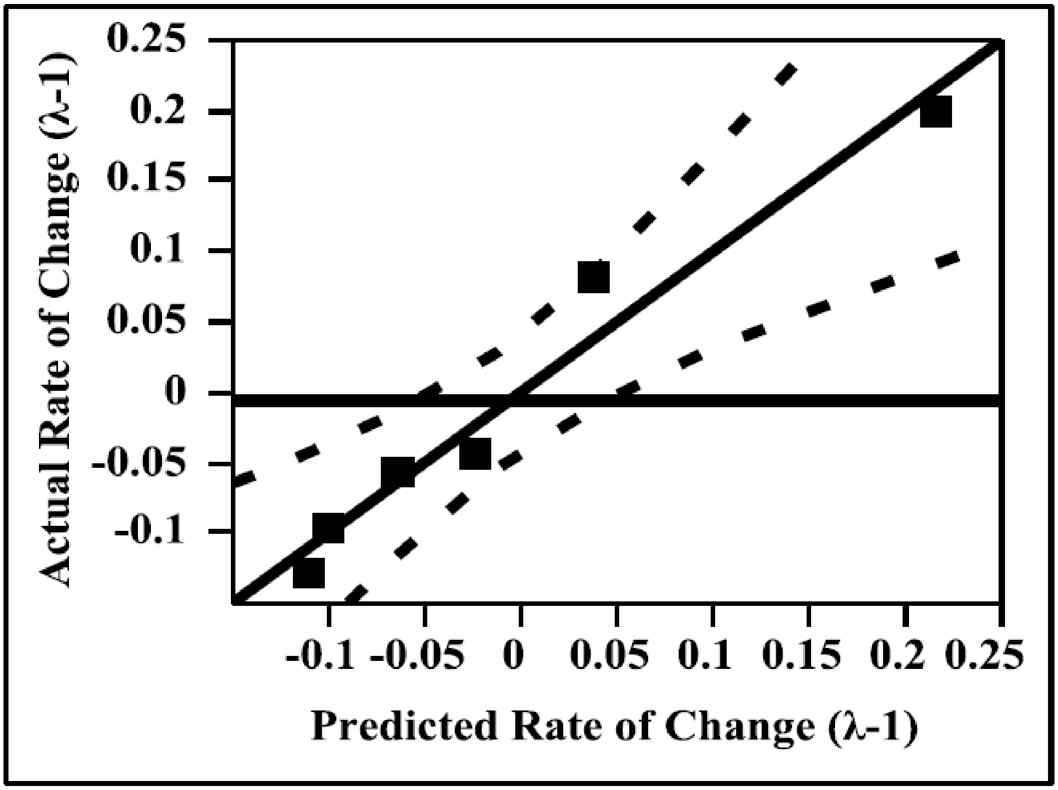

Figure 5-4. Actual rates of population change (λ-1) for boreal caribou populations studied in the Northwest Territories and northern Alberta, Canada, 2003-2009, versus predicted rates of population change (λ-1) from the regression model. The model predicts rates of population change based on 2 variables for the seismic line avoidance period: percentage use of secure unburned habitat and percentage of secure unburned habitat use that occurred in patches >500 km^2 (n=6 study areas; dashed lines are 95% CI).

Appendix 5-A. Models evaluated to examine the relationship between mean annual rate of population change, use and availability of secure habitats, and patch size of secure habitats (km^2). The dependent variable in all models was annual rate of populations change.

Model	Period	Independent variable (b1)	Independent variable (b2)	Log likelihood	AICc[1]
1	All	Percent use secure unburned habitat	Percent patches >0.25 km2 available	6.252	4.334
1	All	Percent use secure unburned habitat	Percent patches >0.5 km2 available	6.268	4.329
1	All	Percent use secure unburned habitat	Percent patches >1 km2 available	6.182	4.357
1	All	Percent use secure unburned habitat	Percent patches >2.5 km2 available	6.215	4.346
1	All	Percent use secure unburned habitat	Percent patches >5 km2 available	6.417	4.282
1	All	Percent use secure unburned habitat	Percent patches >10 km2 available	6.877	4.144
1	All	Percent use secure unburned habitat	Percent patches >25 km2 available	7.810	3.889
1	All	Percent use secure unburned habitat	Percent patches >100 km2 available	9.536	3.490
1	All	Percent use secure unburned habitat	Percent patches >500 km2 available	**11.649**	**3.090**
2	All	Percent patches >0.25 km2 available		5.534	2.578
2	All	Percent patches >0.5 km2 available		5.516	2.585
2	All	Percent patches >1 km2 available		5.675	2.528
2	All	Percent patches >2.5 km2 available		5.984	2.422
2	All	Percent patches >5 km2 available		6.329	2.310
2	All	Percent patches >10 km2 available		6.855	2.150
2	All	Percent patches >25 km2 available		7.810	1.889
2	All	Percent patches >100 km2 available		9.501	1.497
2	All	Percent patches >500 km2 available		**11.616**	**1.095**
3	All	Percent use secure unburned habitat	Percent available secure habitat in patches >0.25 km2	7.009	4.105
3	All	Percent use secure unburned habitat	Percent available secure habitat in patches >0.5 km2	6.414	4.283
3	All	Percent use secure unburned habitat	Percent available secure habitat in patches >1 km2	7.125	4.073
3	All	Percent use secure unburned habitat	Percent available secure habitat in patches >2.5 km2	8.082	3.821
3	All	Percent use secure unburned habitat	Percent available secure habitat in patches >5 km2	8.752	3.662
3	All	Percent use secure unburned habitat	Percent available secure habitat in patches >10 km2	9.006	3.604
3	All	Percent use secure unburned habitat	Percent available secure habitat in patches >25 km2	9.708	3.454
3	All	Percent use secure unburned habitat	Percent available secure habitat in patches >100 km2	10.978	3.208
3	All	Percent use secure unburned habitat	Percent available secure habitat in patches >500 km2	**11.935**	**3.041**
4	All	Percent available secure habitat in patches >0.25 km2		6.182	2.357
4	All	Percent available secure habitat in patches >0.5 km2		6.182	2.357
4	All	Percent available secure habitat in patches >1 km2		6.236	2.339
4	All	Percent available secure habitat in patches >2.5 km2		6.420	2.281
4	All	Percent available secure habitat in patches >5 km2		6.758	2.179
4	All	Percent available secure habitat in patches >10 km2		7.395	1.998
4	All	Percent available secure habitat in patches >25 km2		8.526	1.714
4	All	Percent available secure habitat in patches >100 km2		10.355	1.325
4	All	Percent available secure habitat in patches >500 km2		**11.935**	**1.041**

[1] Akaike's Information Criterion (AIC) scored were corrected for small numbers of variables (Anderson et al. 2000).

Appendix 5-A. Models evaluated to examine the relationship between mean annual rate of population change, use and availability of secure habitats, and patch size of secure habitats (km^2). The dependent variable in all models was annual rate of populations change. (continued)

Model	Period	Independent variable (b1)	Independent variable (b2)	Log likelihood	AICc[1]
5	Avoidance	Percent use secure unburned habitat	Percent secure unburned habitat use in patches >0.25 km^2	5.446	4.610
5	Avoidance	Percent use secure unburned habitat	Percent secure unburned habitat use in patches >0.5 km^2	5.457	4.606
5	Avoidance	Percent use secure unburned habitat	Percent secure unburned habitat use in patches >1 km^2	5.578	4.562
5	Avoidance	Percent use secure unburned habitat	Percent secure unburned habitat use in patches >2.5 km^2	6.419	4.281
5	Avoidance	Percent use secure unburned habitat	Percent secure unburned habitat use in patches >5 km^2	6.909	4.134
5	Avoidance	Percent use secure unburned habitat	Percent secure unburned habitat use in patches >10 km^2	7.199	4.052
5	Avoidance	Percent use secure unburned habitat	Percent secure unburned habitat use in patches >25 km^2	7.297	4.025
5	Avoidance	Percent use secure unburned habitat	Percent secure unburned habitat use in patches >100 km^2	8.389	3.746
5	Avoidance	Percent use secure unburned habitat	Percent secure unburned habitat use in patches >500 km^2	**14.147**	**2.701**
6	Avoidance	Percent secure unburned habitat use in patches >0.25 km^2		5.422	2.619
6	Avoidance	Percent secure unburned habitat use in patches >0.5 km^2		5.430	2.616
6	Avoidance	Percent secure unburned habitat use in patches >1 km^2		5.534	2.578
6	Avoidance	Percent secure unburned habitat use in patches >2.5 km^2		6.005	2.415
6	Avoidance	Percent secure unburned habitat use in patches >5 km^2		6.259	2.332
6	Avoidance	Percent secure unburned habitat use in patches >10 km^2		6.367	2.298
6	Avoidance	Percent secure unburned habitat use in patches >25 km^2		6.556	2.239
6	Avoidance	Percent secure unburned habitat use in patches >100 km^2		7.273	2.032
6	Avoidance	Percent secure unburned habitat use in patches >500 km^2		**10.968**	**1.210**
7	Avoidance	Percent use secure unburned habitat	Percent available secure habitat in patches >0.25 km^{2}available	6.675	4.203
7	Avoidance	Percent use secure unburned habitat	Percent available secure habitat in patches >0.5 km^{2}available	6.662	4.207
7	Avoidance	Percent use secure unburned habitat	Percent available secure habitat in patches >1 km^2 available	6.619	4.220
7	Avoidance	Percent use secure unburned habitat	Percent available secure habitat in patches >2.5 km^2 available	6.313	4.315
7	Avoidance	Percent use secure unburned habitat	Percent available secure habitat in patches >5 km^{2}available	6.210	4.348
7	Avoidance	Percent use secure unburned habitat	Percent available secure habitat in patches >10 km^2 available	6.182	4.357
7	Avoidance	Percent use secure unburned habitat	Percent available secure habitat in patches >25 km^2 available	6.310	4.316
7	Avoidance	Percent use secure unburned habitat	Percent available secure habitat in patches >100 km^2 available	6.810	4.163
7	Avoidance	Percent use secure unburned habitat	Percent available secure habitat in patches >500 km^2 available	**9.137**	**3.575**
8	Avoidance	Percent available secure habitat in patches >0.25 km^2 available		5.143	2.725
8	Avoidance	Percent available secure habitat in patches >0.5 km^2 available		5.152	2.721
8	Avoidance	Percent available secure habitat in patches >1 km^2 available		5.196	2.704
8	Avoidance	Percent available secure habitat in patches >2.5 km^2 available		5.335	2.652
8	Avoidance	Percent available secure habitat in patches >5 km^2 available		5.514	2.585
8	Avoidance	Percent available secure habitat in patches >10 km2^2 available		5.717	2.513
8	Avoidance	Percent available secure habitat in patches >25 km^2 available		5.928	2.441
8	Avoidance	Percent available secure habitat in patches >100 km^2 available		6.566	2.236
8	Avoidance	Percent available secure habitat in patches >500 km^2 available		**9.090**	**1.586**

[1] Akaike’s Information Criterion (AIC) scored were corrected for a small numbers of variables (Anderson et al. 2000).

Appendix 5-A. Models evaluated to examine the relationship between mean annual rate of population change, use and availability of secure habitats, and patch size of secure habitats (km^2). The dependent variable in all models was annual rate of populations change. (continued)

Model	Period	Independent variable (b1)	Independent variable (b2)	Log likelihood	AICc[1]
9	non-avoidance	Percent use secure unburned habitat	Percent patches >0.25 km^2 available	5.457	4.606
9	non-avoidance	Percent use secure unburned habitat	Percent patches >0.5 km^2 available	5.448	4.609
9	non-avoidance	Percent use secure unburned habitat	Percent patches >1 km^2 available	5.470	4.601
9	non-avoidance	Percent use secure unburned habitat	Percent patches >2.5 km^2 available	5.826	4.475
9	non-avoidance	Percent use secure unburned habitat	Percent patches >5 km^2 available	6.474	4.264
9	non-avoidance	Percent use secure unburned habitat	Percent patches >10 km^2 available	7.781	3.897
9	non-avoidance	Percent use secure unburned habitat	Percent patches >25 km^2 available	8.910	3.626
9	non-avoidance	Percent use secure unburned habitat	Percent patches >100 km^2 available	8.174	3.798
9	non-avoidance	Percent use secure unburned habitat	Percent patches >500 km^2 available	**9.673**	**3.461**
10	non-avoidance	Percent patches >0.25 km^2 available		5.424	2.618
0	non-avoidance	Percent patches >0.5 km^2 available		5.416	2.621
10	non-avoidance	Percent patches >1 km^2 available		5.434	2.615
10	non-avoidance	Percent patches >2.5 km^2 available		5.637	2.541
10	non-avoidance	Percent patches >5 km^2 available		5.859	2.464
10	non-avoidance	Percent patches >10 km^2 available		6.356	2.301
10	non-avoidance	Percent patches >25 km^2 available		6.555	2.240
10	non-avoidance	Percent patches >100 km^2 available		7.225	2.045
10	non-avoidance	Percent patches >500 km^2 available		**8.815**	**1.647**
11	non-avoidance	Percent use secure unburned habitat	Percent available secure habitat in patches >0.25 km^2 available	6.781	4.172
11	non-avoidance	Percent use secure unburned habitat	Percent available secure habitat in patches >0.5 km^2 available	6.043	4.402
11	non-avoidance	Percent use secure unburned habitat	Percent available secure habitat in patches >1 km^2 available	6.272	4.328
11	non-avoidance	Percent use secure unburned habitat	Percent available secure habitat in patches >2.5 km^2 available	7.016	4.104
11	non-avoidance	Percent use secure unburned habitat	Percent available secure habitat in patches >5 km^2 available	7.321	4.018
11	non-avoidance	Percent use secure unburned habitat	Percent available secure habitat in patches >10 km^2 available	7.142	4.068
11	non-avoidance	Percent use secure unburned habitat	Percent available secure habitat in patches >25 km^2 available	7.036	4.098
11	non-avoidance	Percent use secure unburned habitat	Percent available secure habitat in patches >100 km^2 available	6.838	4.155
11	non-avoidance	Percent use secure unburned habitat	Percent available secure habitat in patches >500 km^2 available	**8.324**	**3.762**
12	non-avoidance	Percent available secure habitat in patches >0.25 km^2 available		5.130	2.730
12	non-avoidance	Percent available secure habitat in patches >0.5 km^2 available		5.137	2.727
12	non-avoidance	Percent available secure habitat in patches >1 km^2 available		5.157	2.719
12	non-avoidance	Percent available secure habitat in patches >2.5 km^2 available		5.232	2.690
12	non-avoidance	Percent available secure habitat in patches >5 km^2 available		5.356	2.644
12	non-avoidance	Percent available secure habitat in patches >10 km^2 available		5.634	2.542
12	non-avoidance	Percent available secure habitat in patches >25 km^2 available		5.825	2.476
12	non-avoidance	Percent available secure habitat in patches >100 km^2 available		6.371	2.296
12	non-avoidance	Percent available secure habitat in patches >500 km^2 available		**7.931**	**1.858**

[1] Akaike's Information Criterion (AIC) scored were corrected for small numbers of variables (Anderson et al. 2000)

Chapter 6 – Synopsis

Subpopulation Classification of Caribou

The migratory Cape Bathurst, Bluenose-West, Bluenose-East, Bathurst, Beverly, and Qamanirjuaq barren-ground caribou subpopulations were robust. The Lorillard tundra-wintering barren-ground caribou subpopulations was robust while the Queen Maude Gulf and Wager Bay subpopulations were organized as individuals however, more satellite tracking studies are required to verify the subpopulation status of tundra-wintering barren-ground caribou. These subpopulations were previously identified using the calving ground system of classification (Banfield 1954, Thomas 1969, Parker 1972, Calef and Heard 1981, Heard et al. 1987, Nagy et al. 2005). Boreal and Dolphin and Union island caribou subpopulations were organized as individuals. Behaviour was the primary underlying factor that structured different caribou ecotypes into either robust subpopulations (strong annual spatial affiliation) or those that were organized as individuals (spatially independent; Chapter 2). However, environmental conditions played a role in shaping the distribution of subpopulations of all ecotypes. For example, inhospitable landscape features and undesirable habitats such as large water bodies (Bluenose-West and Bluenose-East) and extensive boulder fields (Beverly and Qamanirjuaq) shaped the distribution of some robust subpopulations (Chapter 2). Undesirable habitats such as large areas disturbed by wildfires subdivided boreal caribou into distinct subpopulations (Chapter 2).

Satellite location data and hierarchical and fuzzy cluster analyses proved to be useful tools to objectively identify subpopulation types, to define the subpopulation structure of caribou in the Northwest Territories (NT) and Nunavut (NU), and to proved rigorous statistical criteria by which distinct and robust subpopulations could be identified (Nagy et al. *In press*). However, adequate numbers of satellite collars must be deployed throughout the area of interest to obtain a representative sample of individuals for analysis.

The Cape Bathurst, Bluenose-West, Bluenose-East, Bathurst, and Qamanirjuaq subpopulations each used different calving grounds and consistently used these calving grounds during 1993-2009. However, by 1996 the Bathurst subpopulation had abandoned its "traditional" calving ground in favor of one west of Bathurst Inlet and, similarly, by 2010 the Beverly subpopulation had largely abandoned its “traditional” calving ground in favor one near the Queen Maude Gulf. As a result barren-ground caribou cannot be assigned to subpopulations based on calving ground use alone – satellite tracking data are required to verify their subpopulation affiliations. As a result, I recommend a new definition for barren-ground caribou subpopulations that is based on the annual spatial affiliation of females rather than use of calving grounds alone. Because the annual subpopulation affiliations of individuals that were surveyed on some calving grounds in the past were not verified using satellite tracking data, the results of these surveys may simply provide information on calving distribution rather than estimates of subpopulation size.

Range Management

Most migratory barren-ground caribou subpopulations spent 54-72 days or 15-20% of the year on late summer and fall pre-breeding ranges and 105 to 145 days or 29-40% of the year on winter ranges (Chapter 3). Exploration and development activities are ongoing on late summer and fall pre-breeding ranges of some migratory barren-ground caribou subpopulations in the NT and NU while fires over the last 15-20 years have significantly reduced the amount of winter habitat available below treeline in the NT, Alberta (AB), Saskatchewan (SK), and Manitoba (MB; J. A. Nagy, *unpublished data*). Loss of habitat or disturbances by aircraft over-flights or ground based-exploration and development activities that affect site selection or normal feeding times may negatively impact annual caribou energy budgets. The affects of disturbance on late summer and fall pre-breeding ranges and fire disturbance on winter ranges must be considered in habitat management strategies for barren-ground caribou.

Migratory barren-ground caribou formed distinct and robust subpopulations, have distinct seasonal and annual ranges (J. A. Nagy, *unpublished data*), and as a result can be censused and managed separately. In comparison, boreal caribou are organized as individuals, do not have distinct seasonal or annual ranges, and a census is representative of the geographic area surveyed rather than distinct or robust subpopulations. Habitat for barren-ground caribou should be managed at the subpopulation range level. Habitat for boreal caribou can be managed at multiple scales, but presumably at a suitable scale to support numbers of caribou that are viable for the long-term.

Response of Caribou to Seismic Lines

I examined the spatial and temporal response of boreal caribou to seismic lines on four landscapes with different ecological conditions and seismic line densities. I subdivide my data into 5-day periods for analysis to increase the probability of detecting responses that occur at finer temporal scale. Because I had a large data set of GPS locations I was able to subdivide the data into shorter time intervals and still had adequate location sample sizes for analysis. This allowed me to identify periods when caribou avoided seismic lines that may have gone undetected had I analyzed the data using broad time periods. I then assigned these to activity periods (Chapter 3).

The response of boreal caribou to seismic lines varied during the year and among study areas. Caribou exhibited periods when they did and did not avoid seismic lines. They avoided seismic lines during periods when they were vulnerable to the most significant mortality threats within their ranges (predation or harvesters). They typically avoided areas near seismic lines and crossed significantly fewer times during the avoidance periods. During all times of the year they travelled at significantly faster rates during periods when they crossed seismic lines than when they did not. My results indicate that seismic lines are permeable barriers to caribou movement.

Caribou exhibited the greatest spatial response to seismic lines in areas where these features occurred in the lowest densities and they were able to distance themselves from these features. As suggested by Caughley and Gunn (1996), it is important to know whether observed patterns of use reflect preference or the inability to select optimal habitats. My analyses indicate that development thresholds should not be based on results of work done in areas that are already heavily impacted by industry.

Critical Habitat for Boreal Caribou

Sorensen et al. (2008) and Environment Canada (2009) generated development threshold models based on the area of the industrial footprint and disturbed by wildfires (most recent 50 years). In part, these variables were used to assess range condition by Environment Canada (2009). I took an alternate perspective that I believe links the ecology of boreal caribou with habitat management and helps define critical habitat for this caribou ecotype. Based on the spatial response of caribou to seismic lines I measured (Chapter 4) and areas disturbed by wildfires (Schaefer and Pruitt 1991), I classified boreal caribou range as being comprised of risk, secure unburned, and secure burned habitats (Chapter 5). Using regression analyses I explored the relationship between annual rates of population change, use of secure habitat, and patch size of secure habitat used. My models indicate that caribou that had access to patches of secure habitats that were >500 km^2 during periods when they avoided seismic lines had higher population growth rates than those that did not. My analyses suggest that seismic line densities should not exceed approximately 0.1 km per km^2 or a maximum of 4 percent of the range should be within 400 m of these features with the primary objective of maintaining undisturbed habitat in connected patches >500 km^2 for caribou. This would allow for habitat conditions under which boreal caribou could effectively employ their anti-predator strategies. In comparison, Sorensen et al. (2008) model predicts sustainable caribou populations can be maintained in areas where a maximum of 61 percent of the range is within 250 m of development or when a maximum of 66 percent is naturally disturbed in AB. The fact that most boreal caribou populations in AB are in severe decline (Schneider et al. 2010) suggests that the latter habitat management strategy is not effective for maintaining sustainable boreal caribou populations.

Implications for management

For management purposes it is important to recognize that some migratory barren-ground caribou subpopulations may and some may not maintain fidelity to a specific calving ground. From a habitat management perspective, development activities and impacts on areas that are known or were known to be used by migratory herds for calving should be limited. In addition, development activities and impacts on habitat in areas that based on their characteristic may be used in the future should limited.

Recognizing that shifts in calving ground use may occur ensures that we do not automatically assume that subpopulations have declined to extinction because they no longer calve on what is believed to be their “traditional” calving ground. Recognizing that caribou may change use of calving grounds emphasizes the need to include satellite tracking components in management programs to monitor annual movements and distribution of all migratory barren-ground caribou subpopulations.

Subpopulations of barren-ground caribou cannot be reliably identified based on calving ground use alone; information on the annual spatial affiliation of females in the area of interest must be known. I developed rigorous criteria to objectively define distinct and robust subpopulations of caribou based on their spatial affiliations. These criteria can be used to define distinct and robust subpopulations for other species.

Management strategies should consider the habitats used by barren-ground caribou throughout the year, but in particular late summer, fall pre-rut, and winter ranges, and not just during calving. A shift from the current calving ground centric to a range level habitat management perspective is required. This broader perspective applies to all caribou.

Thresholds for development should be based an evaluation of the ecological requirements of the species affected rather than the requirements of industry. The amount and patch size of preferred habitats unaffected by the industrial footprint is a better measure of the impact of industrial activity than a measure of the industrial footprint. Boreal caribou ranges should be managed using spatially explicit models, with separate areas managed for boreal caribou and industrial activity.

Conclusions and Future Research

The work I present here was achieved only because a number of biologists in the Northwest Territories and Nunavut provided access to their data. Meta-analyses are required to examine large scale ecological processes. Although a significant amount of work has been done to obtain movement data there are still numerous information deficiencies. These could be best addressed by conducting fewer but more comprehensive studies in the NT and NU. In addition to ongoing satellite tracking work future studies should include the following:

- obtaining empirical data on predator and primary prey diversity and density and their influence on caribou populations over a range of ecological conditions
- obtaining information on annual diet of predators over a range of ecological conditions, possibly done through use isotope analysis of body tissues
- obtain information on the dietary and habitat requirements of caribou over a range of ecological conditions
- linking range conditions with reproductive performance and survival rates of individual females and calf survival including response of caribou to varying snow fall and conditions, impact of fire on habitat availability and movement patterns of caribou,
- continuous GPS tracking of caribou to more fully understand their movement patterns in areas impacted by development
- use of "critter cams" to better understand habitat selection
- study designs that ensure adequate sample sizes for statistical tests
- rigorous and timely analysis of data with external peer review

The NT and NU also needs to build a strong northern based wildlife and habitat research program.

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