SNAKE – SAHTANEH
BOREAL CARIBOU STUDY:
CUMULATIVE EFFECT COMPONENT

Prepared for:

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EXECUTIVE SUMMARY

The Snake-Sahtaneh Boreal Caribou study represents the first effort to document boreal-ecotype woodland caribou (*Rangifer tarandus*) ecology in British Columbia (BC). The Snake-Sahtaneh Boreal Caribou study extended from 1999 to 2005 and was composed of two parts: a **Habitat Use/Ecology** component and a **Cumulative Effect** component; the latter is the subject of this report. Habitat use, ecology, and population dynamics of boreal caribou in the Snake-Sahtaneh Range were previously described by Culling et al. (2006).

The Snake-Sahtaneh Cumulative Effect study evaluated boreal caribou response to industrial disturbance and predators using telemetry data from 57 adult female caribou and 18 adult wolves collected between March 2000 and November 2004. Specific objectives of the Cumulative Effect study were to: 1) conduct replicate calving season surveys to determine live-birth rates and neonatal mortality rates; 2) evaluate effects of combined industrial land use on boreal caribou mortality and distribution; 3) evaluate the mitigation measures and assumptions included in the '*Interim Oil and Gas Industry Guidelines for Boreal Caribou in Northeastern British Columbia*' (Culling et al. 2004); and 4) refine landscape and local level cumulative effect modeling and management measures for boreal caribou in northeastern BC.

The Snake-Sahtaneh boreal caribou range is located east of the community of Fort Nelson in the Boreal White and Black Spruce biogeoclimatic zone. This Range is situated entirely within the Etsho Enhanced Resource Development Resource Management Zone where resource development (i.e. oil and gas exploration and development and forest harvest), is the primary designated land use. There are few all weather roads in the study area, so industrial activity is greatest during winter under frozen conditions.

Cumulative effects of industrial resource development and human activity have been implicated in the decline of the boreal-ecotype throughout its range. In areas such as the Snake-Sahtaneh Range where industrial development activity is the designated primary land use, the key management issue is how this activity can be planned, mitigated, or coordinated to reduce cumulative effects risk and sustain the Snake-Sahtaneh herd.

Two cumulative effect pathways are of primary concern for boreal caribou. The first is reduced habitat effectiveness caused by the presence of linear corridors and clearings that caribou avoid. The second is higher mortality resulting from habitat conversion and improved access that leads to increased predator numbers or human/predator hunting efficiency. Both pathways can contribute to short- or long-term population declines. Predation is believed to be the proximate cause of observed population declines in western boreal-ecotype herds, with habitat alternation and loss the ultimate cause.This Cumulative Effect study considered both potential pathways by evaluating the influence of habitat and land use features on mortality as well as habitat use.

Resource selection analyses were undertaken to relate landscape-scale to within-home range scale caribou use and mortality to cumulative effect variables (habitat, linear corridors, clearings, other land use features, and wolf pack home ranges). The analyses

emphasized variables thought to be most practical for cumulative effects assessment and management by all land use sectors. The study area adopted for the Cumulative Effect study comprised a 34,759 km^2 area including a buffer of at least 30 km around the designated Snake-Sahtaneh Range to allow the influence of adjacent features to be considered.

Habitat Use and Effectiveness

In northeast BC, boreal caribou distribution is limited by the presence of suitable habitat. The four currently defined boreal caribou ranges consist of sparsely treed, low gradient wetlands separated by areas of upland and riparian habitat that are consistently avoided by caribou. As quantified here, land use intensity in the Snake-Sahtaneh Range was very high and industrial land use features were concentrated in preferred habitat. Hydrocarbon exploration and development activity increased substantially within the Snake-Sahtaneh Range during the current study and most activity was also concentrated in the most used (core) areas. At the landscape scale, this means that cumulative effects risk is elevated for caribou and other wetland-associated biota. Resource selection relationships for Snake-Sahtaneh caribou therefore reflect habitat with a very high hydrocarbon land use footprint relative to values reported for other western Canadian ranges.

Within home-range scale analyses demonstrate that Snake-Sahtaneh caribou selected areas near most land use features less than expected. Woodland caribou avoidance of comparatively active or large land use features such as roads, wells, and cut blocks appears to occur consistently. Reduced use within 1,000 m of hydrocarbon facilities occurred in the Snake-Sahtaneh Range, the first time that this land use feature has been specifically considered. Available evidence therefore indicates that for cumulative effects modelling and management, roads, wells, hydrocarbon facilities, and cut blocks should be assumed to reduce boreal caribou habitat effectiveness during all seasons.

In contrast, caribou response to seismic lines appears to be inconsistent. This Cumulative Effects study found no reduced use near seismic lines whereas most other studies of mountain- and boreal-ecotype caribou have found reduced use within 100-500 m of seismic lines. Seismic lines represent a comparatively inactive and narrow land use feature that is inordinately important for cumulative effects management within the Western Canadian Sedimentary Basin (Alberta, Saskatchewan, Northwest Territories, and Yukon). Modelling and management assumptions for this land use feature have had, and will continue to have, a profound influence on both predicted impacts and required mitigation and range planning.

Habitat effectiveness models used for research and impact assessment purposes emphasize the indirect effects of local-scale avoidance noted above. A key question for cumulative effects management is whether documented local behavioural responses are translated into population level effects. There is no evidence that reduced habitat effectiveness has affected boreal caribou pregnancy or parturition rates, so any population-level effects of reduced food carrying capacity should be reflected as home range shifts away from areas of increased activity, compensatory increases in home range size, or increased neonatal mortality associated with lower birth rate. Reduced habitat effectiveness in the Snak-Sahtaneh Range was not translated into home range shifts away from areas of increased activity. Reduced habitat effectiveness may have caused compensatory increases in Snake-Sahtaneh caribou home range size. However, proportion of preferred woodland habitat explained almost twice as much variation in home range size and the next best model included only habitat variables. This suggests that influence of land use on home range size was secondary and that any compensatory increases were comparatively minor, consistent with conclusions from northeastern Alberta. Although individuals do appear to change their habitat use in response to industrial land use, there is no clear evidence of population level effects on home range size and location nor range boundaries.

Mortality

More significantly for cumulative effect management, land use features had a much greater influence on caribou mortality risk than on habitat selection. At the local scale, boreal caribou adult female mortality risk was inversely related to distance to the nearest seismic line and directly related to nearby well density. This is consistent with findings from studies in northeast Alberta and the southern Northwest Territories. At the home range scale, adult mortality risk was inversely related to proportion of burns and open spruce habitat and directly related to proportion of disturbed area, well density, and facility density. Active land use features such as wells and facilities affected Snake-Sahtaneh caribou mortality over multiple seasons and years. Most of the reasonable adult survival models for Snake-Sahtaneh home ranges included both habitat and land use variables.

Calf survival trends to 10 months of age were similar between 2002 and 2004 with most mortality occurring during the neonatal period. Wolf predation appears to be the most likely cause of the high calf mortality observed in the Snake-Sahtaneh Range and many other woodland caribou herds. No reasonable home range scale neonatal mortality models were identified, indicating that neonatal mortality risk is best explained at either the local or landscape scale in the Snake-Sahtaneh Range. Although females displayed calving site fidelity, between-year variability in neonate mortality was evident. In one or more years, more mortalities than expected occurred closer to wells and in locations with higher facility density and road density; survival was higher than expected in locations with high well density. Overall neonate mortality between 2002 and 2004 was best explained by distance to the nearest road, with neonatal mortality risk increasing near roads.

While calf mortality continued at a relatively constant rate following the neonatal period, no combination of habitat and land use variables provided a reasonable explanation of calf mortality at the within-home range or home range scales. Locations of calf mortalities were further from roads than expected in 2004, and in areas of lower facility density than expected in 2002. The lack of consistent patterns implies that calf mortality in the Snake-Sahtaneh Range occurs randomly following the neonatal period.

Cumulative Effect study results indicate that industrial land use influenced caribou habitat use and mortality risk on the Snake-Sahtaneh Range. However mortality, not habitat alteration and loss, was the primary source of population level effects on this range during the five year study period. The high calf mortality but relatively low adult mortality observed in the Snake-Sahtaneh study differs from that documented in Alberta boreal caribou herds. Because population persistence is most sensitive to adult female survival, the Snake-Sahtaneh herd is declining more slowly in the short-term than predicted by responses of other herds. Nonetheless, longer term herd decline is inevitable if the calf survival rates calculated for the Snake-Sahtaneh range continue because these are below the level required to replace aging females.

Available evidence suggests that it is the combined land use footprint, rather than specific features which has the greatest influence on adult mortality. This is an important distinction because in the past, the research and mitigation emphasis has reflected individual behavioural response rather than mortality risk. This study supports recent findings that adult mortality risk must be managed at the range or landscape scale, regardless of the specific land use features present in the range.

To summarize, caribou resource selection at the range and home-range scales appears to be based primarily on habitat, regardless of land use intensity. Individual response to land use is reflected at the home range and within-home range scales, while population-level response is reflected at the landscape and range scale. Industrial development of the Snake-Sahtaneh Range appears to have created a situation where caribou continue to select areas with suitable habitat but elevated predation risk. This combination is referred to as an 'ecological trap' or 'attractive sink' because population decline will occur if these conditions persist. A time lag of up to twenty years may occur before land use-related effects are translated into woodland caribou population extirpation.

Impact Management

Most recent western Canadian caribou protection plans have emphasized protection of discrete spatial and temporal attributes (e.g., critical habitat and late winter or calving periods) without explicitly considering larger scale or longer-term factors such as predator numbers and burns that affect habitat supply and predation risk.

The established 'best practices' approach assumes that caribou populations can be protected by minimizing the size of new land use footprints and disturbance during critical life history periods. While best practices will continue to be an essential component of caribou management in northeast BC and elsewhere, there is no evidence that they will be sufficient to maintain the Snake-Sahtaneh herd. Protection of critical habitat and periods on an application-by-application basis has not prevented population declines in other areas where this approach has been applied. This might be attributed to one or more of the following factors: lag times between landscape disturbance/restoration and subsequent declines/recovery; influence of conditions outside caribou ranges on predator numbers and caribou survival; the continuing increase in direct and indirect footprint that has occurred on most ranges; or the overriding influence of short-term mortality rather than habitat alteration on population dynamics.

Results from this study provide no evidence that herds in northeast BC will respond differently. Resource selection modelling indicates that land use intensity and burns have the greatest influence on Snake-Sahtaneh boreal caribou mortality risk. This means that the probability of caribou persistence will decrease as the density of roads, wells, facilities, and seismic lines increases in their range. This highlights the importance of managing the total direct and indirect land use footprint by minimizing incremental land disturbance and encouraging prompt reclamation of existing land use features.

The best practices approach that forms the basis for much of the '*Interim Oil and Gas Industry Guidelines for Boreal Caribou in Northeastern British Columbia*' will slow, but not prevent, an increase in mortality risk. To ensure boreal caribou persistence in northeastern BC, land uses that contribute to cumulative effects must be managed over larger landscapes and longer time frames than has occurred to date. The Interim Guidelines does identify the need for range-specific management plans for all identified boreal caribou ranges as well as range disturbance targets that provide an upper cap to land use disturbance.

Results of the Cumulative Effect study support the need for range-specific management plans including those elements recommended in the Interim Guidelines. This knowledge-based approach focuses on specific factors that affect population persistence, considering both space and time. Predator-prey management and landscape-level targets are two strategies that have been most frequently applied or recommended.

Predator or predator-prey management has been identified as the most practical management option for caribou herds at high risk of extirpation. This approach is used to halt caribou population declines by directly or indirectly reducing predation-related mortality, thereby allowing the population some time to recover. This strategy has been implemented on a range-by-range basis. It requires a good understanding of caribou and alternative prey population dynamics, is very expensive to implement, and can create significant public concern. Although population persistence is most sensitive to adult female survival, management programs that focus on enhancing calf recruitment may be more practical and effective.

In many respects, predator-prey management attempts to treat the clearest symptom, rather than the land use-induced cause of caribou decline. However, this may be the only effective option to ensure woodland caribou persistence in ranges that have high predator or alternative prey densities, are highly disturbed, or consistently have unsustainable calf and adult mortality rates. In the absence of other range-scale measures, predator and/or alternative prey management should be formally evaluated for the Snake-Sahtaneh Range.

Landscape management or performance targets are designed to limit the combined land use footprint and avoid adverse cumulative effects on population persistence. This strategy acknowledges that the influence of land use features persists over multiple years and much larger areas than their direct footprint. It also concedes that to sustain boreal caribou, industrial and non-commercial users will have to accept further access limitations or employ development techniques that are more expensive, riskier, and less convenient than standard industry practice.

The Fort Nelson Land and Resource Management Plan acknowledges the regional and provincial importance of boreal caribou populations and habitats, and suggests that populations will need to be managed in areas such as the Etsho Enhanced Resource Development Resource Management Zone that have an overall development management emphasis. Limiting landscape scale disturbance is the least cost approach for relatively undisturbed areas such as the Calendar Range, where intensive industrial activity has not yet occurred.

Resource selection models from the Snake-Sahtaneh Range suggest that well or facility density and disturbed area (area <250 m from a land use feature) can reasonably be used as land use indices of adult female mortality risk in this area. The utility of the Alberta Boreal Caribou Committee equation combining burned and disturbed area is supported by the Cumulative Effect study as its variables were included in one of the two best caribou survival models for the Snake-Sahtaneh Range. This equation predicts that caribou population decline is likely when more than 66% of the range is burned or more than 61% of the range is <250 m from a land use feature. These values are recommended as interim landscape targets for northeast British Columbia until range-specific responses are confirmed through ongoing monitoring of herd population dynamics.

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1. INTRODUCTION

The Snake-Sahtaneh Boreal Caribou study represents the first effort to document boreal-ecotype woodland caribou (*Rangifer tarandus*; hereafter boreal caribou) ecology in British Columbia (BC). Boreal caribou are Blue-listed in BC and are classified as Threatened (i.e., a "species likely to become endangered if limiting factors are not reversed" by the Committee on the Status of Endangered Wildlife in Canada [COSEWIC; November 2006]). Woodland caribou numbers in southern populations have declined precipitously since 1960 (Harper 1988; Edmonds 1991; Stelfox and Stelfox 1993; Harding and McCullum 1994; Dzus 2001; Thomas and Gray 2002; Wittmer et al. 2005).

While there is increasing concern for boreal caribou in northeastern BC, little was known about their regional population status or habitat requirements (Harrison and Surgenor 1996; Heard and Vagt 1998). In 1999, a boreal caribou habitat study was initiated in the Snake-Sahtaneh watersheds east of Fort Nelson as a joint project between BC Environment and Slocan Forest Products Ltd., with funding provided by Forest Renewal BC (subsequently Forest Investment Account [FIA]) and the BC Habitat Conservation Trust Fund. Additional funding was provided by the OGC Environmental Fund (subsequently Science and Community Environmental Knowledge [SCEK] Fund) during the 2002/2003 fiscal year to consider effects of industrial disturbance. The study ended in 2005.

The Snake-Sahtaneh Boreal Caribou study was divided into two components, whose overall objectives were to:

- Document habitat use, ecology, and population dynamics of boreal caribou in the Snake-Sahtaneh watersheds of northeastern BC (**Habitat Use/Ecology** component); and
- Evaluate boreal caribou response to combined industrial disturbance (**Cumulative Effect** component).

The Habitat Use/Ecology component is presented in Culling et al. (2006). This report discusses work undertaken for the Cumulative Effect component (hereafter the CE study).

1.1 CUMULATIVE EFFECT STUDY OBJECTIVES

The Fort Nelson Land and Resource Management Plan (LRMP; 1997) notes that information on woodland caribou populations and habitats is needed for more detailed strategic or operational planning within caribou range. The combination of a substantial data set of caribou, gray wolf and black bear location data, collected for the Habitat Use/Ecology component in an area of historic and current petroleum development with detailed vegetation and land use inventories available, provided a unique opportunity to analyze boreal caribou population response to human and predator activity and to allow cumulative impact management measures to be evaluated.

Specific objectives of the CE study were to:

1. Conduct replicate calving season surveys to determine live-birth rates and neonatal mortality rates.
2. Evaluate effects of combined industrial land use on boreal caribou resource selection and survival.
3. Evaluate the mitigation measures and assumptions included in the '*Interim Oil and Gas Industry Guidelines for Boreal Caribou in Northeastern British Columbia*' (Culling et al. 2004).
4. Refine landscape and local level cumulative effect modeling and management measures for boreal caribou in northeastern BC.

1.2 STUDY AREA

The 11,980 km^2 Snake-Sahtaneh boreal caribou range (SS Range) is located east of the community of Fort Nelson in the Fort Nelson Lowland and Etsho Plain ecosections of the Taiga Plains ecoprovince. This area is classified as the Boreal White and Black Spruce biogeoclimatic zone, Fort Nelson moist wet variant (BWBSmw2). The SS Range includes the Snake and Sahtaneh river watersheds as well as portions of the Kotcho and Tsea river watersheds (Figure 1). Small waterbodies are abundant. Historically the area has been disturbed frequently by wild fire.

The SS Range is situated entirely within the Etsho Enhanced Resource Development Resource Management Zone (RMZ); resource development is the primary designated land use in this RMZ (Fort Nelson LRMP 1997). There are few all weather roads in the study area, so industrial activity is greatest during winter under frozen conditions. The Etsho RMZ has potential and proven energy reserves and hydrocarbon exploration and development has occurred since the 1950's, resulting in significant natural gas production and infrastructure. Softwood and hardwood forest harvest is the other dominant industrial land use (Fort Nelson LRMP 1997). The intensity of hydrocarbon exploration and development activity increased substantially within the SS Range during the current study.

A larger study area was adopted for the CE study to place the SS Range in a landscape context. A 34,759 km^2 area including a buffer of at least 30 km around the designated SS Range was selected to allow the influence of adjacent features to be considered (Figure 1). This larger 'CE study area' is also within the Taiga Plains ecoprovince and has similar biophysical conditions. It includes portions of the Fontas, Hay, Shekilie, Petitot, and Fort Nelson rivers. The CE study area includes all of the designated BC Calendar boreal caribou range, most of the designated BC Maxhamish boreal caribou range, and the northern extent of the designated BC Chinchaga boreal caribou range (Culling et al. 2004).

Most of the CE study area is also within the Etsho Enhanced Resource Development RMZ (Fort Nelson LRMP 1997), although historic industrial activity has been more limited outside the SS Range.

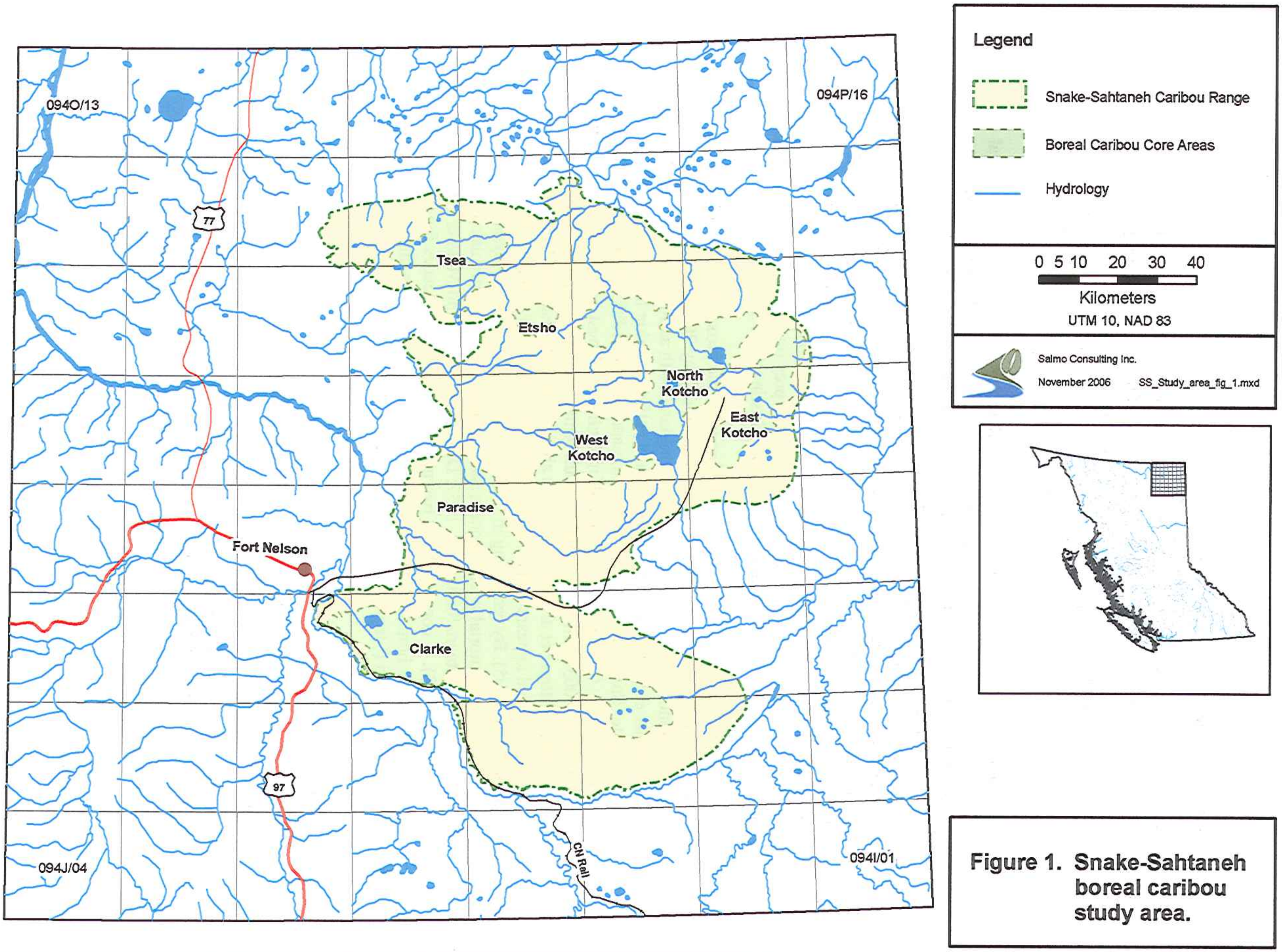

Figure 1. Snake-Sahtaneh boreal caribou study area.

1.3 CARIBOU HABITAT USE AND ECOLOGY

Boreal caribou generally occur in low densities over large ranges. This allows them to persist in areas with a continually changing mosaic of the older habitat types that they rely on. Relative safety from predators is also assumed to be a key feature of habitat used by caribou due to their low productive rate. Their sparse distribution and use of comparatively low productivity habitat is assumed to reduce predation risk by reducing encounter rate (Bergerud and Page 1987; Stuart-Smith et al. 1997).

Caribou populations are naturally prone to wide fluctuations in numbers over several decades (Thomas and Gray 2002). There has been considerable debate as to whether forage availability or mortality from predation and hunting ultimately regulates caribou populations (Bergerud 1974, 1980; Messier 1991). Limiting factors that affect year-to-year abundance include predation, winter snow and weather conditions, and insects (Seip and Cichowski 1996; Rettie and Messier 1998, 2001; Dzus 2001; Anderson et al. 2002; McLoughlin et al. 2003). The most important source of adult boreal caribou mortality is predation by wolves, followed by predation by bears, and legal and illegal hunting (Bergerud and Page 1987; Bergerud and Elliot 1998; Dyer 1999; Thomas and Gray 2002). Wolverine, eagles, lynx, and cougar may also prey on woodland caribou adults and calves (Bergerud 1983; Wittmer et al. 2005; Gustine et al. 2006).

In recent reviews, predation has been concluded to be the proximate cause of boreal-ecotype population declines (Dzus 2001; Thomas and Gray 2002). Woodland caribou population trends appear to be significantly correlated with adult female survival (Smith 2004; Wittmer et al. 2005). Pregnancy rates and calf production have been high in all studies to date (Stuart-Smith et al. 1997; Rettie and Messier 1998; Dunford et al. 2003; Nagy et al., 2005; Culling et al. 2006). Calf mortality is highest immediately after calving (Dunford et al. 2003; Smith 2004), while adult female mortality can vary seasonally (Smith 2004; Wittmer et al. 2005). A cow's ability to avoid predators during the calving and summer period appears to have the greatest effect on both adult and calf survival (Wittmer et al. 2005). By remaining in wetland complexes, boreal-ecotype females are thought to decrease mortality risk from predators that most frequently use uplands and riparian corridors (Stuart-Smith et al. 1997; Dzus 2001; Rettie and Messier 2001; Dunford et al. 2003). A comparison of two northern Alberta landscapes found lower calf survival and smaller home ranges in an area with smaller wetland patches and a higher proportion of upland (Stuart-Smith et al. 1997).

1.3.1 Snake-Sahtaneh Range

The following summary of Snake-Sahtaneh boreal caribou ecology is excerpted from Culling et al. (2006), except where noted.

Prior to 2004, the Snake-Sahtaneh caribou herd (hereafter SS herd or SS caribou) was estimated to include 100 animals based on average regional boreal caribou density estimates. Updated population estimates by Culling et al. (2004) averaged 365 animals (range 359 to 371).

Seasonal habitat use and movements of the SS herd were generally consistent with those reported for boreal caribou from other areas of Canada. Most caribou activity occurred within the defined SS Range and was concentrated in seven isolated 'core areas' comprising approximately 31% of the larger range (Culling et al. 2004; Figure 1). These core areas were typically centred on the largest patches of treed wetlands, and are characterized by very low relief at the headwaters of drainage systems. Burned areas were selected for during snow-free periods. Upland mixedwood and deciduous habitats were avoided, although they were interspersed within home ranges.

The mean annual SS herd minimum convex polygon home range size (1,468 km^2) fell within the range reported for the ecotype. SS caribou were considered sedentary and their seasonal home ranges overlapped significantly, with the largest core areas (Clarke, Paradise, West Kotcho, North Kotcho; Figure 1) used throughout the year. Individual caribou made occasional, sporadic movements both within and between core areas. SS caribou displayed seasonal expansion and contraction; individuals spaced out during the calving and summer seasons and returned to a more concentrated distribution for the rut and winter months. The most significant long range movements occurred during April and May as individuals made pre-calving movements of up to 90 km to traditional calving areas. Movement routes were generally indistinct, however caribou frequently took the most direct path between core habitat areas. A frequently used 3 km-wide travel corridor was identified between the Paradise and Clarke core areas.

High pregnancy and parturition rates and good late winter conditions of female Snake-Sahtaneh caribou observed during capture activities suggest that forage availability and bull:cow ratio were not limiting factors.

SS caribou occur within a multiple-prey system; the wolf population was primarily supported by moose and beaver. In addition, areas with extremely high wolf densities occur immediately to the west, suggesting an ongoing source of immigrants. These conditions may have created a 'predator pit', with predator numbers maintained at relatively high numbers despite the ongoing decline of an individual prey species such as caribou (Bergerud and Elliot 1986; Seip 1989; Messier 1994).

Six wolf packs (Clarke, Gunnell, Kyklo, Komie, Kotcho, and Snake) overlapped the SS Range in late winter 2004 (Figure 3). A minimum population estimate of 69 wolves was obtained during this period based on individuals associated with radio-collared wolves in the six packs. Pack size ranged from to 5 to 15 individuals. This translated to a minimum density of 6.3 wolves/1000 km^2 for the SS Range. Average wolf density above 6.5 wolves/1000 km^2 is predicted to halt caribou herd increases, leading to stable or declining numbers (Bergerud and Elliot 1986; Bergerud 1996).

Considerable spatial and temporal overlap between wolves and caribou was noted. Home ranges defined for all wolf pack home ranges included significant portions of caribou core areas. The Paradise and West Kotcho core areas fell within zones of overlap between adjacent pack territories. Six of eight den sites fell within the SS Range, with the remaining two situated within 3 km of the defined range boundary.

Five of nine black bears made significant use of caribou core areas during the May-June calving period. Black bear locations were strongly associated with mixedwood and deciduous habitats and cutblocks interspersed in core areas.

Observations during spring calf surveys suggest female SS caribou used dense patches of black spruce within open bogs for security cover. Caribou showed relative avoidance of habitat types selected most strongly by wolves and bears (i.e., wetlands and waterbodies, cutblocks, low vegetation, and tall shrub). While a large proportion of wolf activity during the May-June calving period was associated with beaver activity, incidental observations of lone wolves traveling through undisturbed black spruce bogs within caribou core areas were made on 3 separate occasions during the calving period.

All 5 mortalities of collared adult SS herd females occurred between April and October. Wolf predation was confirmed as the cause of 2 of these mortalities; black bear predation was the suspected cause of another.

Calf survival and recruitment rates observed during the study (5 calves:100 cows and 9 calves:100 cows in 2003 and 2004 respectively) were well below the overall value reported for Alberta boreal caribou ranges (17 calves:100 cows; McLoughlin et al., 2003) and the 25 calf:100 cow threshold identified by Bergerud (1996) for population stability. Highest calf mortality occurred between 7 and 21 days of age in 2004. Decreasing calf mortality rates between 21 and 45 days of age coincided with considerably reduced density of remaining calves. Calf survival continued to decline from mid-summer through mid-winter. Although low calf recruitment may be offset by high adult female survival in the short-term, advancing mean age of reproductive females would ultimately result in SS population decline if sufficient recruitment does not occur in future.

Additional information on caribou, wolves, and black bears in the SS Range is provided in Culling et al. (2006).

1.4 CARIBOU RESPONSE TO LAND USE AND HUMAN ACTIVITY

Cumulative effects of industrial resource development and human activity have been implicated in the decline of the boreal-ecotype throughout its range. Considerable research has been conducted on working landscapes in Alberta, Saskatchewan, Manitoba, and Ontario. In all areas, observed declines occurred concurrently with an increase in access and clearing that is believed to have significantly increased mortality from wolves, hunters, other predators, and vehicle collisions (Bergerud et al. 1984; Seip 1992; Harding and McCullum 1994; Wittmer et al. 2005). Population extirpation appears to lag land use activity by two decades (Vors et al. 2007). Recent research in the Northwest Territories provides information on dynamics in landscapes with low predator density (GNWT 2006). Combined research results suggest that mortality-related declines reflect the cumulative effects of habitat loss, fragmentation by linear corridors, and human and predator activity.

The primary concern with industrial land use activities is that proliferation of linear corridors (roads, pipelines, and seismic lines), clearings (cutblocks, wellsites, and facilities), and associated human activity may result in increased predator numbers, predator efficiency, harvest, and/or decreased habitat effectiveness and availability, leading to reduced adult and calf survival (*e.g.*, reviews in Dzus 2001, Thomas and Gray 2002, Smith 2004; James et al. 2004). Low calf recruitment and adult survival rates have recently been documented in intensive population dynamic monitoring programs in northern Alberta where the hydrocarbon and forestry sectors are dominant land users (McLoughlin et al. 2003).

Predation is believed to be the proximate cause of observed population declines in western boreal-ecotype herds, with habitat alteration and loss the ultimate cause (Dzus 2001; Rettie and Messier 2001). Increased predation has been attributed to 3 factors:

1. increased predator density resulting from larger prey populations (moose, deer, beaver) associated with early seral vegetation on disturbed sites (Seip 1992); if true, caribou adult and calf mortality should be higher in areas with high predator density (within home ranges, within home ranges of larger packs, and within areas/seasons where wolf and caribou locations overlap);
2. reduced range as a result of avoidance of land use features and human activity, thereby making their location more predictable (Whitten et al. 1992; James and Stuart-Smith 2000; Dyer et al. 2001, 2002; Dzus 2001); if true, caribou adult and calf mortality should be higher in small patches of suitable habitat; and
3. increased linear corridor frequency, thereby facilitating predation by increasing line of sight and movement/hunting efficiency (Bergerud et al. 1984; Cumming and Beange 1993; James 1999); if true, caribou adult and calf mortality should be higher near linear corridors (Stuart-Smith et al. 1997; James and Stuart-Smith 2000), in areas with high linear corridor density, and near packed trails (winter activity).

In areas such as the SS Range where industrial development activity is the designated primary land use, the key management issue is how this activity can be planned, mitigated, or coordinated to reduce cumulative effects risk and sustain the SS herd. The typical management approach has been to develop and implement woodland caribou protection guidelines that define best practices for specific activities (e.g., forest harvest or seismic exploration). While this approach has successfully reduced the direct and indirect footprint of recent industrial activity, it has not prevented cumulative increases in the land use footprint within caribou ranges because sector-specific activities are inadequately coordinated in space and time. In addition, it has not consistently prevented population declines where predators are present. Because of this, the need for plans with range-specific land use or habitat targets has now been accepted (Adamczewski et al. 2003; Alberta Woodland Caribou Recovery Team 2005; D. Hervieux, pers. comm.).

1.4.1 Cumulative Effect Modeling and Targets

Several modelling approaches have been adopted by resource managers, proponents, and research ecologists to understand and predict impacts on caribou habitat and populations or to define appropriate management approaches and targets. An overview of habitat effectiveness and other modelling approaches is provided below as background for later discussion of cumulative effect modeling and management recommendations for northeast BC.

1.4.1.1 Habitat Effectiveness Modelling

Habitat effectiveness is a measure of habitat availability that reflects both direct habitat loss and indirect loss from reduced use near land use features or activities. Caribou and reindeer have been shown to avoid human developments and activity, but response to human developments and activities appears to vary by sex, season, ecotype, and population. Reduced use has been documented near streams (Oberg 2001), roads (Dau and Cameron 1986; Nelleman and Cameron 1998; Dyer 1999; James and Stuart-Smith 2000: Oberg 2001), seismic lines (Dyer 1999; James and Stuart-Smith 2000 but see Oberg 2001 and Saher 2005), well sites (Dyer 1999), pipelines (James and Stuart-Smith 2000), powerlines (Nelleman et al. 2001), cutblocks (Cumming and Beange 1993; Smith et al. 2000), recreational facilities (Nelleman et al. 2001), snowmobiles (Simpson 1987; Simpson and Terry 2000; Reimers et al. 2003; Wilson and Hamilton 2003), and skiers (Reimers et al. 2003; Wilson and Hamilton 2003).

Reduced use relative to nearby areas of identical habitat is assumed to represent a decrease in overall 'habitat effectiveness' within a defined range area. These cumulative decreases in habitat effectiveness have the potential to reduce ecological carrying capacity and ultimately, caribou numbers (Thomas and Gray 2002).

Caribou habitat effectiveness models are commonly used in environmental assessments (e.g., Axys 2001; Johnson et al. 2005) because they allow project-specific habitat alteration to be readily quantified. These models discount habitat quality within a 'buffer' (also called zone-of-influence) surrounding clearings and linear corridors. Documented reduced use buffers for boreal caribou in north-central Alberta are summarized in Table 1 as an example. Partial use may be reflected by applying a 'disturbance coefficient' to the buffer (e.g., a disturbance coefficient of 0.8 applied to a 250 m buffer indicates that residual habitat 'quality' is reduced by 20% within this buffer).

Habitat effectiveness model output is most sensitive to buffer and disturbance coefficient assumptions. While this modelling tool is theoretically appealing, there is considerable scientific debate about appropriate buffers and disturbance coefficients as well as the utility of this approach. One common criticism is that values developed for one range may not reflect actual response on other ranges because of differences in landscape conditions or caribou ecology. Another criticism is that habitat effectiveness may not be a good predictor of population-level response (Thomas and Gray 2002; Johnson et al. 2005). Recent studies have found no correlation between habitat effectiveness and population change of boreal caribou herds in northern Alberta (BCC 2003). Specific habitat effectiveness targets have not been used or proposed for boreal caribou (Salmo et al. 2004).

Table 1. Boreal caribou reduced-use buffers in north-central Alberta (Dyer 1999).

SEASON	FEATURE				
	ROADS		WELLSITES		SEISMIC LINES
	Open Coniferous Wetland	Closed Coniferous Wetland	New - <15.5 months old (drilling completion date)	Old - ≥15.5 months old (drilling completion date)	
Early Winter Nov 16 - Feb 21	*	*	250 m	0 m	100 m
Late Winter Feb 22 - Apr 30	250 m	250 m	250 m	500 m	250 m
Calving May 1 - Jun 30	100-250 m	0 m	1000 m	500 m	100 m
Summer July 1 - Sep 15	250 m	100 m	0 m	250 m	100 m
Rut Sep 16 - Nov 15	250 m	0 m	250 m	0 m	100 m
Time-weighted Annual Average	215-250 m	93 m	326 m	238 m	129 m

* Insufficient caribou had roads within their home ranges to perform analysis to examine avoidance of roads during this time period.

1.4.1.2 Cumulative Footprint Models and Targets

Cumulative footprint models relate the combined direct and indirect footprint of one or more land use features to population persistence or mortality risk. Land use indicators that have been used include: total cleared/disturbed area; linear corridor density; and area within the reduced use buffer (the 'indirect footprint').

A multiple regression equation developed by the Alberta Boreal Caribou Committee (Sorensen et al. in press.) indicates that there is a statistically significant relationship between caribou population decline and two factors: 1) the 'indirect footprint' calculated as proportion of the landscape within 250 m of clearings and linear features; plus 2) proportion of the landscape burned within the last 50 years. Caribou population growth rate in six Alberta herds was inversely related to industrial footprint and amount of young forest. Embedded in this correlation are numerous effects pathways, which confound efforts to identify the most appropriate mitigation measures (Bentham 2004).

No specific relationships have been developed to relate linear corridor density to woodland caribou habitat effectiveness, although linear corridor density and indirect footprint are highly correlated (Figure 2). Nellemann and Cameron (1998) found that the density of calving barren-ground caribou was inversely related to road density although non-maternal individuals did not display the same relationship (Dau and Cameron 1986). Vehicle traffic influenced barren-ground caribou crossing success more than the presence of elevated pipelines and roads (Murphy 1984). The most easily disturbed group is cows and calves during the calving season (Wolfe et al. 2000).

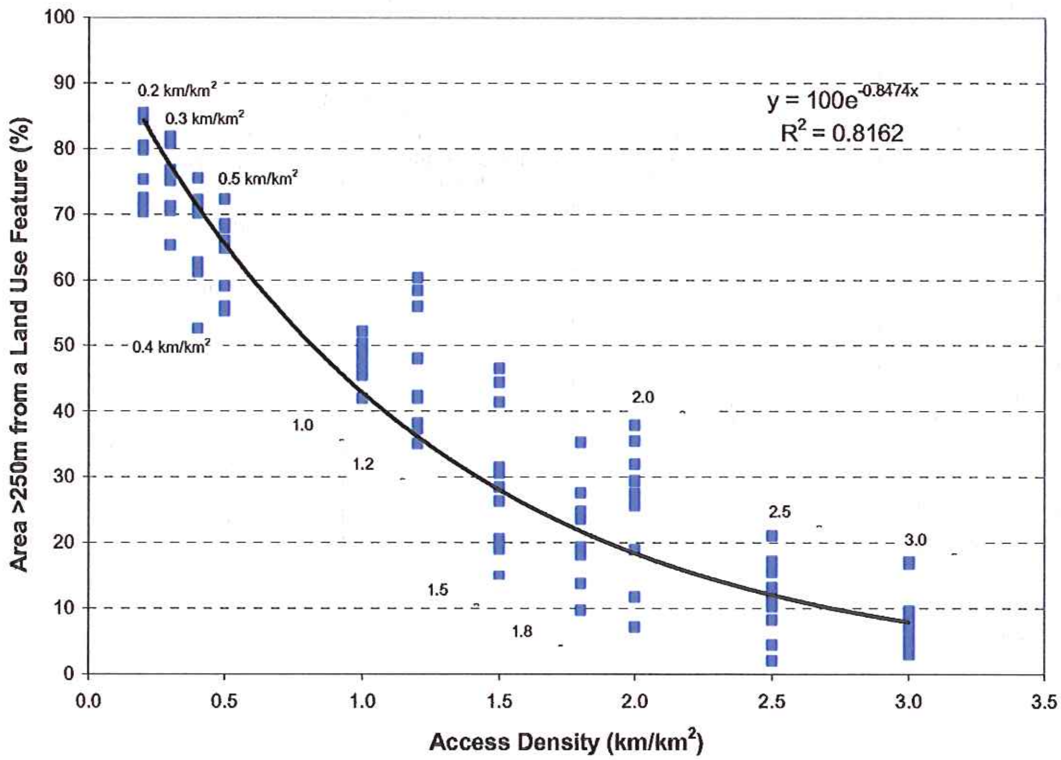

Figure 2. Relationship between linear corridor density and area greater than 250 m from a clearing or corridor in the Snake-Sahtaneh Cumulative Effects study area.

In Alberta boreal caribou populations, linear corridor density and seismic line density were inversely related to adult mortality but were not correlated with calf mortality, the proximate cause of short-term population declines (McLoughlin et al. 2003; Dunford 2003; J. Dunford unpub. data in Bentham 2004). This cumulative effects indicator reflects the amount of relatively undisturbed habitat at the landscape scale or conversely, proximity to linear features.

Weclaw and Hudson (2004) developed a woodland caribou population simulation model to evaluate response to, and interrelationships between, natural factors (predation, forage availability, fire, and snow conditions) and anthropogenic factors (habitat alteration and loss and harvest). Predation by both wolves and black bears was considered. Populations of moose, the primary wolf prey in northern Alberta, were modelled and wolf population density was related to moose density. Four sources of caribou and moose mortality were considered: food limitation; wolf predation; bear predation; and human harvest. Habitat loss included both direct loss to linear features and clearings, and reduced habitat effectiveness. Simulations suggested that under natural conditions, predation limited caribou populations and kept them below calculated carrying capacity (i.e., predation, not habitat regulates populations under natural conditions). Densities under natural conditions were higher than those observed in simulations with resource development. Linear corridor thresholds were very high in the absence of predators, but were low in simulations with both predation and loss of habitat effectiveness. This implies that there is a synergistic response when uncontrolled wolf populations and resource development occur simultaneously. Caribou population decline was predicted when combined seismic line and road density exceeded 1.22 km/km^2.

Smith (2004) found that mortality risk of adult female mountain-ecotype woodland in west-central Alberta was related to cumulative road and cutblock densities. Mortality risk attributed to wolf, and to a lesser extent bear, predation increased with road density; for every 0.1 km/km^2 increase, mortality risk increased by 1.5 times. He concluded that seismic lines would not be expected to have as significant effects as roads in this foothills area. The relationship with timber harvest was J-shaped, with lower mortality risk at low cutblock densities during the initial stages of timber harvest. Mortality risk increased once cutblock density exceeded 3.4 ha/km^2 (3.4% of the landscape) and a threshold response (dramatic increase) was observed above 6.8 ha/km^2.

Adamczewski et al. (2003) proposed maximum development footprints of 30% in the extended range, 25% in the migration zone, and no additional development (i.e., maintain at $\leq$16%) in core winter range for the northern-ecotype Little Rancheria herd in southern Yukon. This was based on combined direct and indirect footprint (i.e., within 250 m of linear features and clearings) documented within Alberta boreal caribou ranges with stable populations.

2. METHODS

An understanding of the effects of combined industrial land use on Snake-Sahtaneh boreal caribou dynamics is a precursor to cumulative effects assessment and management. Land use features can influence caribou and predator behaviour and dynamics at several scales from landscape down to site. These include: SS Range (second-order, *sensu* Johnson 1980), home range (second-order), and within home range (third-order) scales. Most recent boreal caribou studies have investigated habitat selection and land use response at the home range and seasonal range scales (e.g., Stuart-Smith et al., 1997; Dyer 1999; Rettie and Messier 2000, 2001).

This study considers the influence of land use at the range and home range scales as well as a larger landscape scale. A landscape-scale study area (the 34,759 km^2 CE study area) encompassing the SS Range was selected for cumulative effect analyses because surrounding conditions are known to influence predator and primary prey abundance, behaviour, and dynamics (e.g., Seip 1992; Rettie and Messier 2000). The CE study area was defined using 1:50,000 map sheets because these were the reporting base for annual seismic activity, the dominant land use throughout the project area. An area comprised of 64 map sheets was defined to include a buffer of at least 30 km around the designated SS Range (Figure 1). This is sufficiently large to include all wolf packs that could influence caribou dynamics within the SS Range as well as land use features that predict caribou persistence (Vors et al. 2007).

2.1 TELEMETRY

Wildlife capture, collaring, and telemetry methods are provided in Culling et al. (2006). Insufficient black bear data were available for the CE study and this species is not considered further.

2.1.1 Caribou Telemetry

Caribou telemetry data were obtained between March 2000 and November 2004. A yearly target of 20 GPS/VHF collars on adult female caribou was established, representing approximately 20% of the original population estimate, or 5% of the most recent estimate. Actual deployed collars varied from 12 to 20 per year with a total of 57 individuals represented over the five year study period (48 GPS datasets). Most individuals were collared for only 1 year, but multiple datasets were obtained for 11 caribou, providing up to 4 years of data per individual animal.

Caribou GPS collars were programmed to log positions at 4-hour intervals, 7 days per week and detach at the end of their estimated or detected battery life. Collars were equipped with mortality sensors that transmitted upon failing to detect motion for more than 2.5 hours. Caribou capture effort was initially concentrated in the central zone of the SS Range for which digital habitat information was available. Interim analysis of GPS data resulted in expansion of the study area and search effort in 2002 to ensure that collars were deployed as widely as possible in the SS Range (Figure 3) to document intra-range variability. Locational error was calculated to be 17 m within the SS Range; locations were not differentially corrected. Calving dates and locations were defined by marked periods of restricted movement between April and June.

2.1.2 Wolf Telemetry

Wolf telemetry data were obtained between November 2002 and November 2004. A yearly target of 2 GPS/VHF collars for each pack was established; actual deployed collars varied from 12 to 20 per year. Eighteen individual wolves were GPS-collared; 17 for at least 1 season but less than 1 year. Due to collar loss, most wolf locations are from mid- and late winter seasons. GPS collars were programmed to log locational fixes every 3 hours for 240 days.

Six wolf packs (Clarke, Gunnell, Kyklo, Komie, Kotcho, and Snake) overlapped the SS Range in late winter 2004; GPS data were obtained for all but the Kyklo pack (Figures 4).

2.1.3 Calf Survival, Recruitment, and Adult Mortality

Calf survival surveys were conducted by helicopter in late June and late October 2002 through 2004. Radio-collared females were located and presence/absence of calf-at-heel confirmed. All caribou associated with each collared animal were classified by sex and age (adult female, adult male, calf). Incidental observations of caribou not associated with collared females were also recorded.

Interim results from the 2002 and 2003 spring surveys indicated low calf survival to late June. CE study funding was used to conduct four replicate surveys between May 25 and June 30 2004 to confirm live-birth rates and gain additional insight into neonatal mortality.

Late winter compositional surveys were conducted by helicopter in March 2003 and 2004 to estimate annual juvenile recruitment. Radio-collared females were located and all caribou associated with collared and uncollared groups were classified by sex and age. Recruitment was expressed as ratio of calves per 100 adult females.

Annual adult survival rates were calculated by Culling et al. (2006) using the Kaplan and Meier method staggered entry design, with standard error calculated using Greenwood's formula (Pollock et al. 1989; Krebs 2003). Population rate of increase was calculated as:

$$\frac{\text{Adult survival}}{1-(\text{March calves}/2/100)}$$

2.1.4 Telemetry Data Analysis

A common GPS telemetry data set was developed and used for both the Habitat Use/Ecology and CE study components. Low precision (2D) locations, extreme outliers, and obvious erroneous points were removed, leaving means of 2,013 ± 232 three-dimensional (3D) locations per caribou (range 210 to 6,457), and 4.2 ±1 3D locations per day.

These GPS datasets were subsampled using a multi-stage process to reduce spatial and temporal autocorrelation and potential satellite acquisition bias associated with canopy closure. One of a possible six 3D daily locations was randomly selected from the total sample of 3D points. This one-per-day dataset was systematically subsampled to select 1 location every third day; if gaps occurred in the data, the next available location was selected. These final random data sets were used for caribou home range estimation and resource selection analyses.

GPS data were pooled between years, with the rationale that boreal caribou display similar patterns of habitat selection annually. Influence of differing industrial activity intensity and location could not be evaluated because these data were not available for the first three years of the study. This is considered to be reasonable because cumulative effect management should be based on multi-year, rather than short-term population response.

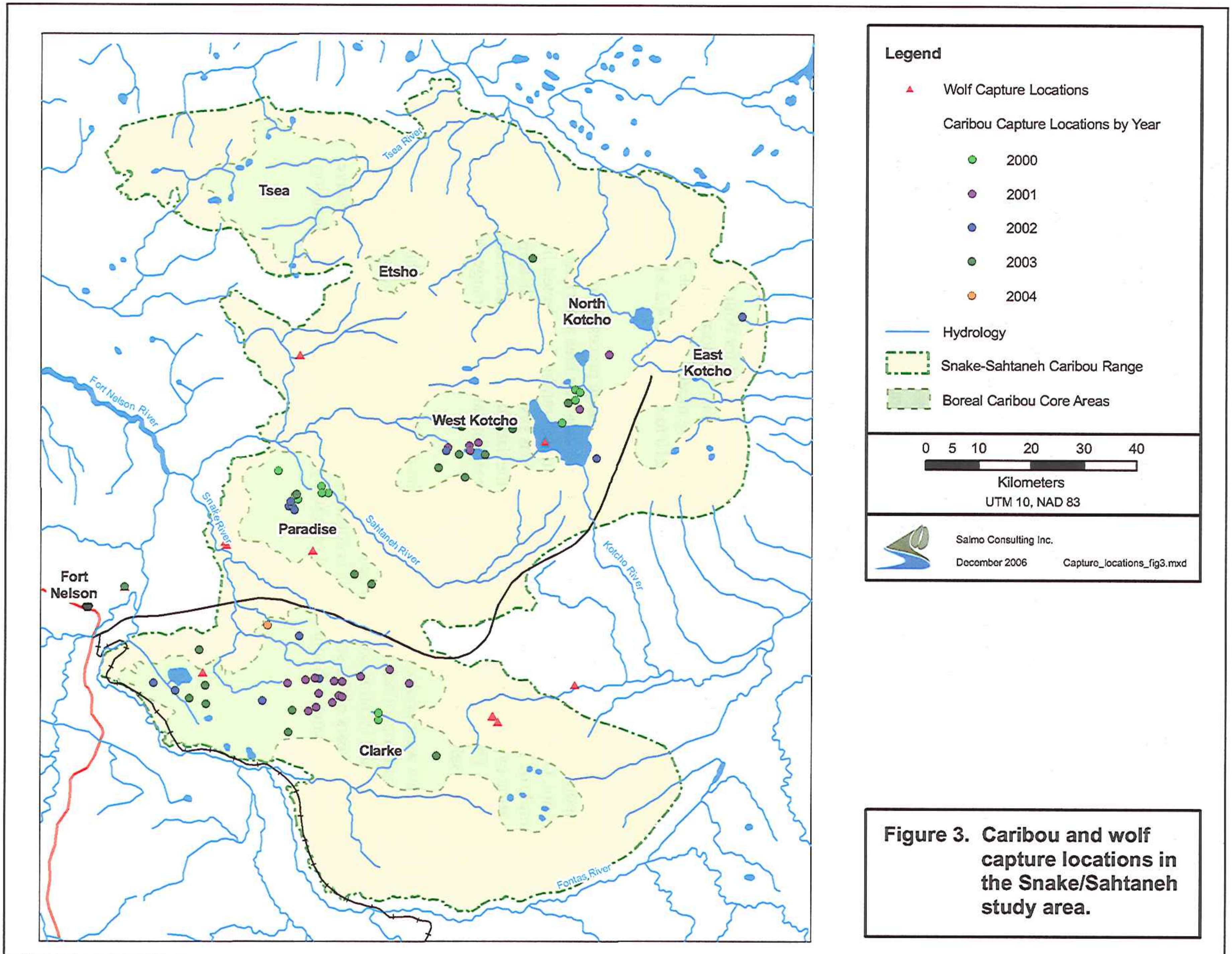

Figure 3. Caribou and wolf capture locations in the Snake/Sahtaneh study area.

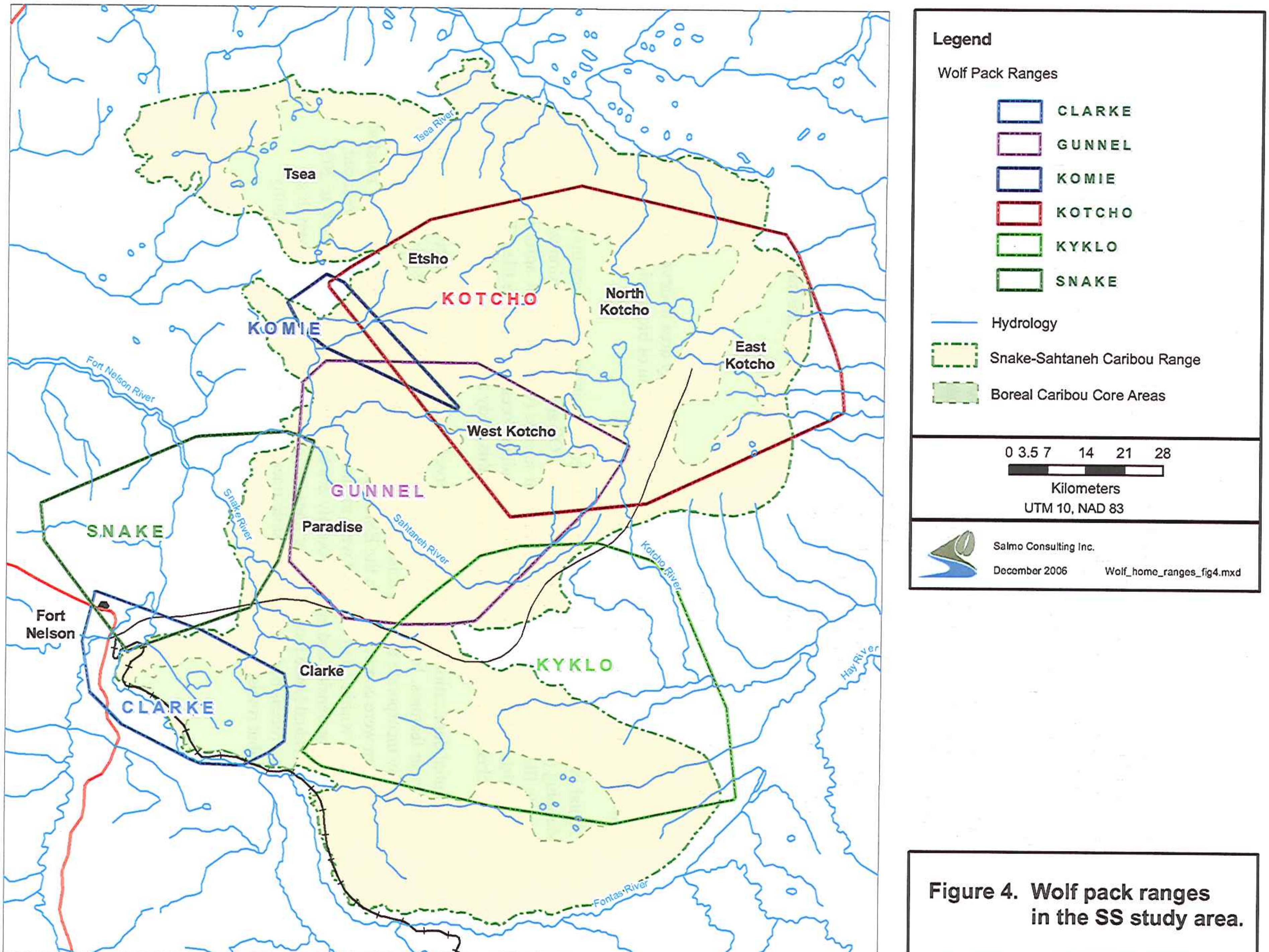

Figure 4. Wolf pack ranges in the SS study area.

A similar process was used to subsample wolf GPS data. Data points representing occasional long distance movements beyond territory boundaries were excluded from the analysis. Mean number of total 3D locations for the 14 wolf GPS datasets used in the analysis was 665 ± 232 (range 237 to 1,059). Telemetry locations were subsampled to a maximum of one location every other day to provide a more robust sample. The final random sample includes a mean of 64 ± 5 locations per wolf, representing 4 to 9 months of monitoring.

GPS locations were entered into an ArcView Geographic Information System (ArcInfo GIS); Version 3.2 and 9.2, Environmental Systems Research Institute Inc., Redlands CA). All GIS analyses were conducted by Teresa Raabis of Boreal Enterprises.

Annual and multi-year home ranges (100% minimum convex polygon (MCP); Mohr 1947) generated for the Habitat Use/Ecology component (Culling et al. 2006) were used. These were calculated for all caribou using the ArcView *Animal Movement* extension (Hooge and Eichenlaub 2000). Multi-year pack territories (100% MCP) were delineated for wolves using the same extension and combined into a composite multi-year wolf home ranges.

2.2 LAND USE FEATURES

Readily-available digital data was obtained for the CE study area to develop the ArcView GIS layers used to delineate land use features. A discussion of biophysical features and habitat conditions is provided in Culling et al. (2006).

Digital information on land use features included: Terrain and Resource Inventory Mapping (TRIM) hydrography and feature files; Oil and Gas Commission well and facility files; annual Oil and Gas Commission seismic (GOAT) files; Canfor road files; and British Columbia Forest Service and Canadian Forest Service fire files. The land use feature classification and assumptions used in this study are provided in Table 2.

Substantial duplication and overlap was observed in the digital files between roads and other linear features. In the CE study area, new road and pipeline rights-of-way commonly incorporate existing seismic lines. Within the SS Range, parallel seismic lines within 10 m were combined with the ESRI Integrate tool based on hierarchy (i.e., parallel seismic lines within 10 m of a road were assumed to be part of the road). This reduced linear corridor density and area by roughly 2% to 5% at the range scale and 0% to 20% within individual home ranges. Power lines and pipelines were excluded from this integration process because unlike seismic lines, these rights-of-way are frequently located to abut roads.

Table 2. Snake-Sahtaneh Boreal Caribou study land use classification scheme.

Feature	Size	Hierarchy[1]	Source
Community	GIS Polygon drawn from TRIM file	1	TRIM, Feb. 2005
Railway	20 m wide	2	TRIM, Feb. 2005
Industrial Facilities	GIS Polygon size or 4 ha default	3	OGC, July 2004; TRIM Feb. 2005
Secondary Roads	20 m wide	4	TRIM, Feb 2005; OGC, July 2004; CanFor
Airstrips	GIS Polygon size	5	TRIM, Feb. 2005
Wellsites	1.2 ha	6	OGC, July 2004
Trails	4 m wide	7	TRIM, Feb. 2005
Borrow Pits	GIS Polygon size	8	TRIM, Feb. 2005
Power Lines	50 m wide	9	TRIM, Feb. 2005
Pipelines	20 m wide	10	TRIM, Feb. 2005
Seismic Lines	8 m wide	11	TRIM, Feb. 2005
Cutblocks	GIS Polygon size	12	CanFor, Jan. 2005; BCTS
Fires	GIS Polygon size	NA	Fort Nelson Forest Service and Canadian Forest Service (Pacific Office), current to end of 2004 fire season

[1] Order in which features were assigned. Overlaps were assigned to feature with lowest hierarchy number.

Factors such as the size, age, and activity level of land use features are thought to influence both caribou and predator response and interactions at home range and within-home range scales. An understanding of the influence of specific land use attributes is a prerequisite to identify appropriate mitigation methods. These attributes include:

- **Feature age and vegetation/snow condition**: caribou, other ungulates, and predators may be attracted to features with desirable vegetation (e.g., clover or early seral vegetation) or conditions that facilitate movement (e.g., packed snow or visible corridors through forest). Older unused features with high shrub or tree cover are thought to have lower predation risk because they are less attractive to both predators and prey;
- **Feature size**: predator response is thought to be directly related to feature size, width, and line-of-sight. Conventional (8 m wide) seismic lines with long line-of-sight are thought to increase wolf efficiency and predation risk more than meandering low impact (<3 m wide) seismic lines;

- **Activity level**: caribou, other ungulate, and predator response is thought to be inversely related to human and vehicle use intensity. High use features such as all weather roads are thought to reduce adjacent use by caribou and wolves more than seismic lines that are used seasonally or infrequently;
- **Feature type**: caribou, other ungulate, and predator response may be related to smells, sounds, or visual stimuli of a feature. Wolves may be attracted to, and caribou may avoid, noise or smells at industrial sites while a gravel pit of equivalent size would have less influence.

Feature attribute information is rarely included with readily available digital files. One of the original objectives of the CE study was to develop an attributed data base for the study area to support more detailed fine-scale analyses. Because linear corridor frequency was extremely high, remote methods of feature classification were considered or tested. In late winter 2004, reconnaissance surveys were flown to document areas of industrial activity, and aerial photographs were taken to see if corridors used by vehicles and snowmachines could be differentiated from unused corridors. Small-scale trials suggested that aerial photographs could be useful in ideal snow and light conditions, but an early thaw prevented this technique from being used for the entire study area.

Ultimately, detailed attribution of land use features within the SS study area was not completed as planned. Digital files were less accurate than anticipated and although there was a substantial increase in industrial activity and land use features during the study, no spatially-explicit files were available for these features. In addition, recent modelling studies suggest that landscape- to range-level conditions such as primary prey abundance exert a greater influence on caribou population dynamics than do local land use attributes such as linear corridor condition (Weclaw and Hudson 2004; McCutchen 2007).

GIS data were used to calculate land use variables thought to influence caribou response (Table 3). Variables were calculated for several hierarchical scales: 'Landscape' (the CE study area, area within the CE study area but outside the SS Range, and combined wolf pack home range); 'Range' (SS Range, combined core area, and individual core areas); and 'Home Range' (individual caribou home ranges). Methods are described below.

Total area of individual and combined land use footprints was calculated for landscape, range, and home range scales using the assumptions summarized in Table 2.

Area within 250 m of land use features and area burned (based on available digital files) was calculated for landscape, range, and home range scales to provide an index of area directly and indirectly affected. These metrics are used in the BCC (BCC 2003; Hubbs pers. comm.) regression equation.

Feature density was calculated for roads, seismic lines, well sites, facility sites, and cutblocks at landscape, range, and home range scales. Total corridor length was calculated for landscape and range scales and average density values were determined based on the associated analysis area. For the home range and within-home range scales, a 1 km X 1 km grid was generated and corridor length and number of well sites, facility sites, and cutblocks was calculated within each grid cell. Each telemetry location was then assigned the density values for the cell it was situated in. Well and facility feature density provides an index of year-round activity.

Distance to the nearest feature was calculated with ArcView GIS for each caribou telemetry and random point to allow comparison of used versus available habitat. Insufficient community, railway, airstrip, trail, power line, and pipeline locations were available and proximity to these land use features was not considered in resource selection analyses. Overlap between features was not accounted for in distance calculations due to the density of land use features within the CE study area.

Table 3. Land use variables used for Snake-Sahtaneh boreal caribou cumulative effect analyses.

Variable	Description
Footprint Variables	
LOSS	Total area within each feature type and within all features combined using assumptions provided in Table 2.
DISTURB	Total area within 250 m of any land use polygon or linear feature.
CUT	Total area within forestry cutblocks.
BURN	Total area burned within last 50 years.
Feature Density Variables	
ROADDENS	Total kilometers of roads per square kilometre.
SEISDENS	Total kilometres of seismic lines per square kilometre.
CORRDENS	Total kilometers of linear corridor (roads, seismic lines, trails, power lines, railways, and pipelines) per square kilometre.
WELLDENS	Number of wells per square kilometre.
FACLDENS	Number of oil/gas facilities per square kilometre.
CUTDENS	Number of cutblocks per square kilometre.
Proximity Variables	
ROADDIST	Distance (m) to edge of nearest road.
SEISDIST	Distance (m) to edge of nearest seismic line.
WELLDIST	Distance (m) to edge of nearest well.
FACLDIST	Distance (m) to edge of nearest facility.
CUTEDIST	Distance (m) to edge of nearest cut block.
WOLFDIST	Distance (m) to centroid of nearest wolf pack home range polygon defined with ArcView Field calculator.

2.3 RESOURCE SELECTION ANALYSES

2.3.1 Range Selection

Land use variables from the SS Range and core areas (used) were compared to metrics for the entire CE study area (available) using the chi-square goodness-of-fit test (Manly et al. 2002). Petroleum land use footprints are randomly distributed on the landscape (Dyer et al. 2001; Salmo et al. 2003), so habitat availability was not controlled for.

2.3.1.1 BCC Equation

The Alberta Boreal Caribou Committee commissioned analyses to develop a habitat planning target for boreal caribou herds. The regression equation developed from this work is an excellent predictor of population trends in northern Alberta herds. It incorporates two range-scale components: 1) an index of the industrial footprint, calculated as the percentage of caribou range within 250 m of a linear feature or man-made clearing; and 2) the percentage of caribou range burned by recent (≤50 years) wildfire (BCC 2003). The most recent equation (A. Hubbs pers. comm.) is:

$$\hat{\lambda}=1.191+(-0.314)x_1+(-0.291)x_2$$

Where,

$\hat{\lambda}$ - represents caribou finite rate of increase given x_i values for x_1 and x_2

x_1 - represents the percentage of caribou range within 250 m of industrial features, and

x_2 - represents the percentage of caribou range burned by recent (≤50 years) wildfire.

2.3.2 Within-Range Selection

Resource selection analyses are undertaken to develop predictive models of animal occurrence. Habitat selection or avoidance depends on habitat availability and accessibility and refers to the use of specific features proportionally more or less than they are available (Manly et al. 2002; Anderson et al. 2005). However, because spatial orientation of habitat elements may affect resource selection model outputs, they are typically restricted spatially and temporally to the landscape in which they were developed (Boyce et al. 2002; Osko et al. 2004).

Habitat selection occurs at multiple scales as individuals seek to access food, shelter, and mates or avoid predators, competitors, or insects (e.g., Rettie and Messier 2000; Johnson et al. 2004; Anderson et al. 2005; Buskirk and Millspaugh 2006). The objective of Snake-Sahtaneh cumulative effects resource selection analyses was to identify landscape to within-home range level selection (2nd to 3rd order [Johnson 1980]) relative to land use features, predators, and habitat. A hierarchical use-availability design was employed (Manly et al. 2002; Keating and Cherry 2004).

Resource selection analyses undertaken for the Snake-Sahtaneh CE study emphasized variables thought to be most practical for cumulative effects assessment and management by all land use sectors. These include variables that are easily obtained or calculated, can be cost-effectively updated as land use changes, and provide effective estimates of long-term boreal caribou population response.

At the range, home range and within-home range level, Resource Selection Function models taking the form

$$w(x) = \exp(\beta_1 x_1 + \beta_2 x_2 + \ldots \beta_i x_i)$$

were constructed to examine caribou resource selection, where $w(x)$ is defined as the relative probability of resource selection, β_i represents the selection coefficients and x_i represent independent variables (Manley et. al. 2002, Nielsen et. al. 2004). Selection coefficients describe the increase or decrease in the dependent variable where there is a single unit increase in the independent variable. For example, a selection coefficient of -0.3 means that the dependent variable would decrease by this amount for each one unit increase in the independent variable.

Land use variables were tested for univariate significance. Correlated land use variables ($r > 0.70$; Hosmer and Lemeshow 2000) were not combined for resource selection analyses. The simplest variable was used in subsequent modeling with the assumption that this would most practical for cumulative effects assessment and management.

Logistic regression conducted in STATA and Statistica Version 7.1 was used to develop resource selection models. Use, adult mortality, neonate mortality (to week 4), and summer calf mortality (to month 5) were considered as dependent variables at the home range scale. Model significance, overall fit and performance were evaluated using Pearson's X^2, Hosmer and Lemeshow goodness-of-fit statistic ($\hat{C}$) and Akaike Information Criterion respectively (Hosmer and Lemeshow 2000; Burnham and Anderson 2002). Reasonable fit was considered to occur where X^2 was significant ($P<0.05$) and $\hat{C}$ was not significant ($P>0.05$).

Akaike's Information Criteria adjusted for small sample sizes (AIC_c) (Burnham and Anderson 2002) was used to identify the most parsimonious model(s) for cumulative effects assessment and management. The model with the smallest AIC_c was considered the best and differences between that model and all other models were used to determine other likely models. Models with differences greater than 2 units were considered to be less plausible and those with differences greater than 10 units were considered to be implausible (Burnham and Anderson 2002).

2.3.2.1 Home Range

Land use variables were calculated as proportion of home range area for the 48 individual caribou datasets. This approach is recommended to minimize potential bias from animals with more locations (Aebischer et al. 1993; Alldredge et al. 1998; Thomas and Taylor 2006).

Relationship between home range size and land use and habitat variables was evaluated using multiple regression conducted in Statistica Version 7.1. Home range variable data were normally distributed (K-S d= 0.9594 p>0.2).

Home range scale resource selection was evaluated by comparing these individual home range datasets (used) to those from random home ranges within the SS Range (available). Hectagonal home ranges equivalent in size to each individual caribou were generated with ArcView and their centres randomly located within the SS Range. Land use variables were then calculated if the home ranges fell outside the equivalent caribou home range had no more than 10% of their area outside the SS Range boundary, or they were randomly placed until this criterion was met.

Habitat variables and seasonal resource selection models are described in Culling et al. (2006). Variables with the greatest explanatory power were used for the CE component; these are summarized in Table 4. Habitat mapping was only available for the SS Range, so combined land use-habitat analyses were restricted to the home range scale.

Table 4. Habitat variables used for Snake-Sahtaneh boreal caribou cumulative effect analyses.

Variable	Description
DU Earth Cover Model Variables[1]	
WOODSPRC	Woodland Needleleaf Habitat Class, incorporating Woodland Needleleaf, Woodland Needleleaf Lichen, and Woodland Needleleaf Moss DU Earth Cover Classes; 10-25% of cover in trees; includes black spruce bogs, transitional sites, mixed pixel areas at edges of needleleaf stands, and patches of burn regeneration; comprises 14% of SS Range.
HABBURN	Burn Regeneration DU Earth Cover Class augmented by fire history polygons derived from other sources; comprises 1.4% of SS Range.
OPENSPRC	Open Needleleaf Habitat Class, incorporating Open Needleleaf and Open Needleleaf Moss DU Earth Cover Classes; 26-60% of cover in trees; includes black spruce bogs and transitional sites; comprises 43% of SS Range.
Terrain and Hydrology Model Variables	
SLOPE1	Level Slope Class 1: 0.00 ° to 0.30°.
LAKE1	Lakes and lake clusters (2 or more lakes >2 ha in size with overlapping 250 m buffers) larger than 5 ha.

[1] More complete description provided in Culling et al. (2006).

Several *a priori* models were tested to evaluate caribou use and mortality in relation to land use, habitat, and combined land use and habitat variables (Table 5). These models reflect available information on boreal caribou response in other ranges (see Section 1.4) and focus on variables for which provisional management targets or thresholds have been developed, or other variables thought to be most useful for cumulative effects management.

2.3.2.2 Within Home Range

Within-home range selection was evaluated using feature density and proximity variables (Table 3) with a used-available design. The probability of available locations being used was very low because point locations were used (Keating and Cherry 2004).

Proximity analyses for most land use features were categorized to be consistent with Dyer (1999) and Oberg (2001) so that results can be directly compared. Categories were: 0-100 m; ≥100-250 m; ≥250-500 m; ≥500-1000 m; ≥1000-2000 m; ≥2000-3000 m, and ≥3000 m. Cutblock occurrence within 3000 m was low, so cutblock buffer categories were: 0-500 m; ≥500-1000 m; ≥1000-2000 m; ≥200-3000 m; ≥3000-5000 m; ≥5000-10,000 m, and ≥10,000 m.

Statistical analyses followed Dyer et al. (2001) using log-ratio analysis of compositions (Aebischer et al. 1993) to analyze caribou selection of different proximity buffers. Where buffers were completed unused, zero proportions were replaced with 0.0001 as described by Aebischer et al. (1993). Log ratios were initially evaluated using the Chi-square goodness-of-fit test to determine if nonrandom use of buffers occurs. The next step was to rank buffer categories in order of preference by comparing pairwise differences between matching log ratios in a ranking matrix. The ratio of the mean:standard error of each pairwise comparison was used to measure departure from random use.

Unlike Dyer et al. (2001) preference or avoidance was determined by comparing buffer use to the 1000-2000 m buffer, rather than the outermost buffer. This modification was adopted because land use intensity within the SS Range is sufficiently high that most caribou locations occur within 2000 m of some type of land use.

Table 5. *A priori* models for the Snake-Sahtaneh boreal caribou cumulative effect analyses.

Model Variables	Description
Land Use Models	
BURN + LOSS	Direct natural and land use habitat loss index.
CORRDENS + LOSS	Access and land use habitat loss index.
ROADDENS + LOSS	Access and land use habitat loss index.
BURN + CORRDENS	Access and natural habitat loss index.
BURN + CUT	Forestry land use index.
ROADDENS + CUT	Access and forestry habitat loss index.
WELLDENS + BURN	Land use and natural habitat loss index.
DISTURB + BURN	BCC equation parameters.
WELLDENS + CORRDENS	Hydrocarbon land use index.
WELLDENS + ROADDENS	Hydrocarbon land use index.
FACLDENS + ROADDENS	Hydrocarbon activity index.
FACLDENS + CORRDENS	Hydrocarbon land use index.
Habitat Models	
HABBURN + WOODSPRC + SLOPE1	Best predictive variables from SS Habitat Use/Ecology component (Culling et al. 2006).
HABBURN + OPENSPRC + SLOPE1	Good predictive variables from SS Habitat Use/Ecology component.
HABBURN + WOODSPRC + LAKE1	Good predictive variables from SS Habitat Use/Ecology component.
HABBURN + OPENSPRC + LAKE1	Good predictive variables from SS Habitat Use/Ecology component.
Combined Land Use and Habitat Models	
DISTURB + BURN + WOODSPRC + OPENSPRC + SLOPE1	Most important variables from SS Habitat Use/Ecology component and literature.
DISTURB + BURN + WOODSPRC + OPENSPRC + LAKE1	Most important variables from SS Habitat Use/Ecology component and literature.
CORRDENS + SLOPE1	Simple habitat-land use model.
LOSS + SLOPE1	Simple habitat-land use model.
WELLDENS + SLOPE1	Simple habitat-land use model.
CUT + SLOPE1	Simple habitat-land use model.
DISTURB + SLOPE1	Key habitat variables combined footprint.
DISTURB + BURN + SLOPE1 +	Simplified habitat plus combined footprint.
DISTURB + BURN + LAKE1	Simplified habitat plus combined footprint.

3. RESULTS

3.1 INDUSTRIAL LAND USE

Hydrocarbon exploration and production activity intensified in the Snake-Sahtaneh area during the study period. The 'tight gas' Jean Marie production play that commenced in 1999 is centred over the study area (Hayes 2006). Seismic exploration activity was variable over the study (Figure 5), but increased dramatically after year 1 and peaked in year 3 (winter 2001/2002). Just over 66,000 km of seismic exploration (>1.2 km/km^2 at CE study area scale) was proposed in the study area between 1999 and 2005, although not all of this was completed. Almost all seismic exploration was conducted during winter, and most involved 3D geophysical programs consisting of reduced width (<6 m wide) or low impact (<3 m) lines in a grid pattern spaced at roughly 400 m intervals.

New road, wellsite, and facility construction activity intensified in study years 4 and 5 in response to provincial policy, external demand, and new pipeline capacity. In latter years, activity levels were highest in the Clarke, West Kotcho, and East Kotcho core areas.

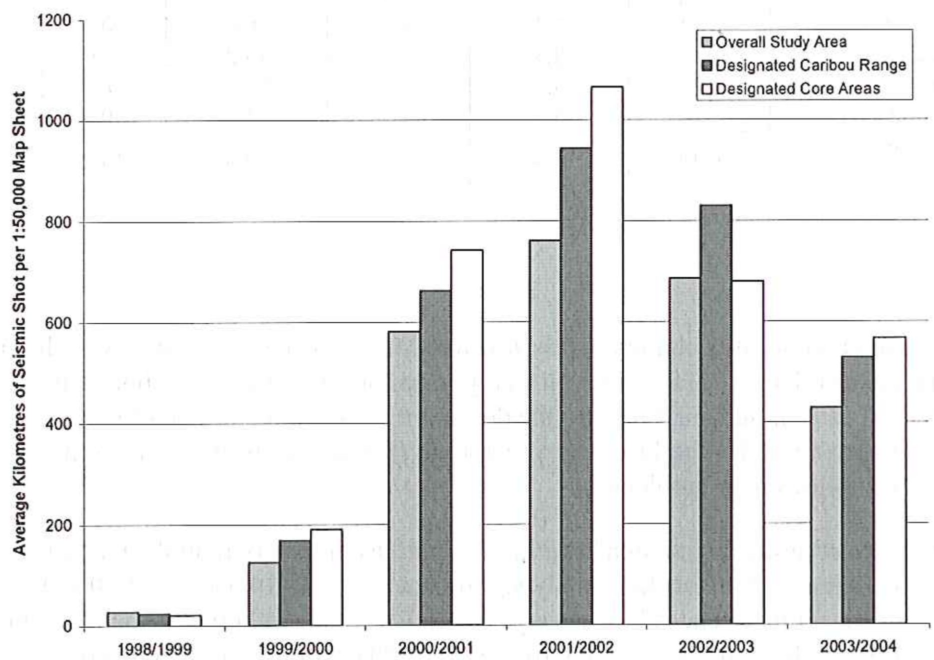

Figure 5. Recent proposed seismic exploration activity in the Snake-Sahtaneh cumulative effect study area.

3.2 LANDSCAPE SCALE RESOURCE SELECTION

The land use footprint at multiple scales within the CE study area is summarized in Table 6.

Table 6. Land use footprint within the Snake-Sahtaneh cumulative effect study area at several scales.

Study Area Component	Area (km^2)	Average total linear corridor density (km/km^2)	Area cleared (%)	Area within 250 m of a land use feature (%)	Area burned (%)
Overall Cumulative Effect Study Area	51,179	2.9	3.3	67.8	13.3
Snake-Sahtaneh Caribou Range	11,980	4.1	4.2	80.3	15.5
Snake-Sahtaneh Caribou Range outside Core Areas	8,234	3.9	4.1	79.3	14.4
Snake-Sahtaneh Combined Core Area	3,746	4.4	4.4	82.6	17.9
Clarke Core	1,381	5.2	5.2	86.7	6.7
East Kotcho Core***	318	3.8	4.3	83.4	64.4
Etsho Core	62.4	2.6	3.0	65.2	0.0
North Kotcho Core***	748	7.4	3.6	70.6	30.4
Paradise Core	403	2.5	2.5	75.2	8.3
Tsea Core***	472	5.2	4.6	90.8	0.0
West Kotcho Core***	362	5.7	5.4	91.7	30.6
Combined wolf pack home ranges	10,142	4.5	4.8	82.5	13.2

*** Significantly different than CE study area at $p<0.001$

Total area cleared and burnt is comparatively low and linear corridor density is very high in the SS study area relative to footprint values reported for other boreal caribou ranges (Dyer 1999; BCC 2003). Seismic lines are the dominant land use feature at all scales, both on basis of density (84%) and total area disturbed (60%). Roads are the next most common feature, followed by cutblocks.

The SS Range and combined core area have higher land use intensity than the CE study area but these differences are not statistically significant ($X^2 < 3.414$, df = 4, $P > 0.19$). Statistically significant differences in landscape metrics are present between the CE study area and the East Kotcho core ($X^2 = 200.5$, df = 4, $P < 0.001$), the North Kotcho core ($X^2 = 29.75$, df = 4, $P < 0.001$), the Tsea core ($X^2 = 23.54$, df = 4, $P < 0.001$), and the West Kotcho core ($X^2 = 34.99$, df = 4, $P < 0.001$).

3.3 HOME RANGE SCALE SELECTION

Summary land use metrics for individual caribou home ranges, random home ranges, and wolf pack ranges are provided in Table 7. Data for individual caribou home ranges are provided in Appendix 1.

Table 7. Land use footprint in Snake-Sahtaneh caribou and wolf pack home ranges (mean ± SD; range in parentheses).

Metric	Caribou Home Ranges	Caribou Random Home Ranges	Wolf Pack Home Ranges
N	48	48	6
Area (km^2)	1,388 ± 898 (117-3,666)	1,427 ± 945 (117-3,975)	1,865[1] ± 1,356 (242-3,860)
Average road density (km/km^2)	0.45 ± 0.17 (0.14-1.14)	0.47 ± 0.17 (0.15-1.05)	0.74 ± 0.44 (0.46 – 1.59)
Average total linear corridor density (km/km^2)	4.2 ± 1.2 (1.4-9.2)	4.3 ± 1.4 (1.8-9.1)	5.1 ± 2.0 (2.5-8.3)
Area cleared (%)	4.4 ± 1.2 (1.5-9.5)	4.5 ± 1.4 (1.8-8.9)	5.7 ± 2.0 (3.8-9.9)
Area cut (%)	0.1 ± 0.1 (0-0.4)	0.06 ± 0.08 (0-0.4)	0.2 ± 0.2 (<0.001-0.6)
Area disturbed (within 250 m of a land use feature; %)	82.4 ± 9.0 (52.9-92.8)	81.6 ± 9.5 (59.4-97.0)	85.1 ± 9.2 (70.2-94.2)
Area burned (%)	12.8 ± 8.5 (0-32.7)	13.7 ± 15.2 (0-85.8)	11.3 ± 0.08 (0-22)

[1] Wolf pack means based on composite home range values.

Wolf pack home ranges had significantly higher overall land use than caribou home ranges ($F_{6,47}=2.77$, df=6, $P<0.03$), primarily due to higher road density and cleared and cut area within wolf pack home ranges.

Pearson correlation coefficients for home range land use and habitat variables are provided in Table 8. Several land use variables were highly correlated ($r > 0.70$; Hosmer and Lemeshow 2000), including coarse land use indicators (disturbed area and total cleared area), and access density metrics (corridor density, seismic line density, road density). In the SS area access density was highly correlated with well density. Corridor density provides the simplest metric of oil and gas land use activity while cleared or disturbed area provides the simplest metrics of cumulative industrial land use.

Level slope was highly correlated with area of lakes and lake complexes and woodland spruce habitat. As suggested in Culling et al. (2006), area with level terrain is the simplest caribou habitat metric for the SS Range.

Table 8. Pearson correlation coefficients for home range land use and habitat variables in the Snake-Sahtaneh boreal caribou range (highly correlated variables bolded).

Variable	BURN	DIST URB	LOSS	CUT	CORR DENS	SEIS DENS	ROAD DENS	WELL DENS	FACL DENS	WOOD SPRC	OPEN SPRC	HAB BURN	LAKE1	SLOPE1
BURN		-0.01	0.09	0.20	0.09	0.06	0.24	0.03	-0.34	-0.40	0.03	0.40	-0.35	-0.19
DISTURB	-0.01		**0.84**	0.46	**0.84**	**0.84**	**0.76**	0.57	0.55	0.12	-0.49	-0.45	-0.67	-0.35
LOSS	0.09	**0.84**		0.63	**0.99**	**0.98**	**0.94**	**0.70**	0.44	0.08	-0.45	-0.26	-0.56	-0.15
CUT	0.20	0.46	0.63		0.58	0.56	0.60	0.23	0.03	0.20	-0.50	-0.35	-0.34	0.16
CORRDENS	0.09	**0.84**	**0.99**	0.58		**1.00**	**0.93**	0.67	0.39	0.07	-0.45	-0.23	-0.58	-0.16
SEISDENS	0.06	**0.84**	**0.98**	0.56	**1.00**		**0.89**	0.68	0.41	0.08	-0.44	-0.20	-0.57	-0.16
ROADDENS	0.24	**0.76**	**0.94**	0.60	**0.93**	**0.89**		0.60	0.30	-0.06	-0.32	-0.27	-0.54	-0.21
WELLDENS	0.03	0.57	**0.70**	0.23	0.67	0.68	0.60		**0.72**	0.14	-0.16	0.01	-0.27	-0.05
FACLDENS	-0.34	0.55	0.44	0.03	0.39	0.41	0.30	**0.72**		0.21	-0.22	-0.19	-0.18	-0.15
WOODSPRC	-0.40	0.12	0.08	0.20	0.07	0.08	-0.06	0.14	0.21		-0.65	-0.48	0.37	**0.76**
OPENSPRC	0.03	-0.49	-0.45	-0.50	-0.45	-0.44	-0.32	-0.16	-0.22	-0.65		0.44	0.26	-0.36
HABBURN	0.40	-0.45	-0.26	-0.35	-0.23	-0.20	-0.27	0.01	-0.19	-0.48	0.44		-0.03	-0.11
LAKE1	-0.35	-0.67	-0.56	-0.34	-0.58	-0.57	-0.54	-0.27	-0.18	0.37	0.26	-0.03		**0.71**
SLOPE1	-0.19	-0.35	-0.15	0.16	-0.16	-0.16	-0.21	-0.05	-0.15	**0.76**	-0.36	-0.11	**0.71**	

3.3.1 Home Range Use

Logistic regression coefficients for the twelve best home range scale caribou use models are summarized in Table 9. Models are presented by rank from best to poorest performing based on AIC_c scores. Best models based on combined Pearson X^2 ($P < 0.05$), Hosmer-Lemeshow $\hat{C}$ ($P > 0.05$), and AIC_c values ($\Delta AIC < 2$) are shaded. Additional model parameters and poorer performing models are provided in Appendix 3.

Only habitat variables were present in the best models of SS caribou use. The most influential habitat variables included relative proportion of burns and woodland spruce habitat. Relative proportion of level terrain was also a significant variable at the home range scale. Caribou use of these habitat types was greater than expected (Table 9).

Area disturbed (<250 m from a land use feature) and well density were the most influential land use variables affecting caribou use at the home range scale (Table 9). Area disturbed was the only land use variable included in plausible resource selection models ($\Delta AIC < 10$), but it had an insignificant influence on use relative to habitat variables and its effect on use was variable (i.e., selection in one model vs. avoidance in another; Table 9). Statistically significant land use variables in unsupported models included facility density and area cut (logged; Appendix 3).

3.3.2 Adult Survival

Logistic regression coefficients for the twelve best home range scale adult survival models are provided in Table 10. Models are presented by rank from best to poorest performing based on AIC_c scores. Best models based on combined Pearson X^2 ($P < 0.05$), Hosmer-Lemeshow $\hat{C}$ ($P > 0.05$), and AIC_c values ($\Delta AIC < 2$) are shaded. Additional model parameters and poorer performing models are provided in Appendix 4.

Both habitat and land use variables are included in reasonable home range scale models of female survival. Adult female survival was significantly higher in home ranges with more burns and open spruce habitat and significantly lower in home ranges with high well density, facility density, and disturbed area (<250 m from a land use feature).

Relative proportion of burnt habitat was the best single descriptor of adult caribou survival. Variants of the BCC equation were the best multivariate models of SS adult caribou survival. Proportion of home range burned combined with proportion disturbed, cleared, and cut or well/facility density were variables in plausible models. Performance of these BCC equation variants was not substantially improved with inclusion of a level terrain or lake variable (Table 10).

3.3.3 Calf Survival

Annual trends in neonate and calf survival for 2002, 2003 and 2004 are depicted in Figure 6. Data are presented relative to May 15, the derived overall peak calving date for the SS herd (Culling et al. 2006). Most mortality occurs during the neonate period.

All home range scale neonatal and calf survival models had poor overall performance and no statistically significant variables (Table 11). Additional model parameters and poorer performing models are provided in Appendix 5 and 6.

Figure 6. Yearly neonate and calf survival in the Snake-Sahtaneh boreal caribou range, 2002-2004.

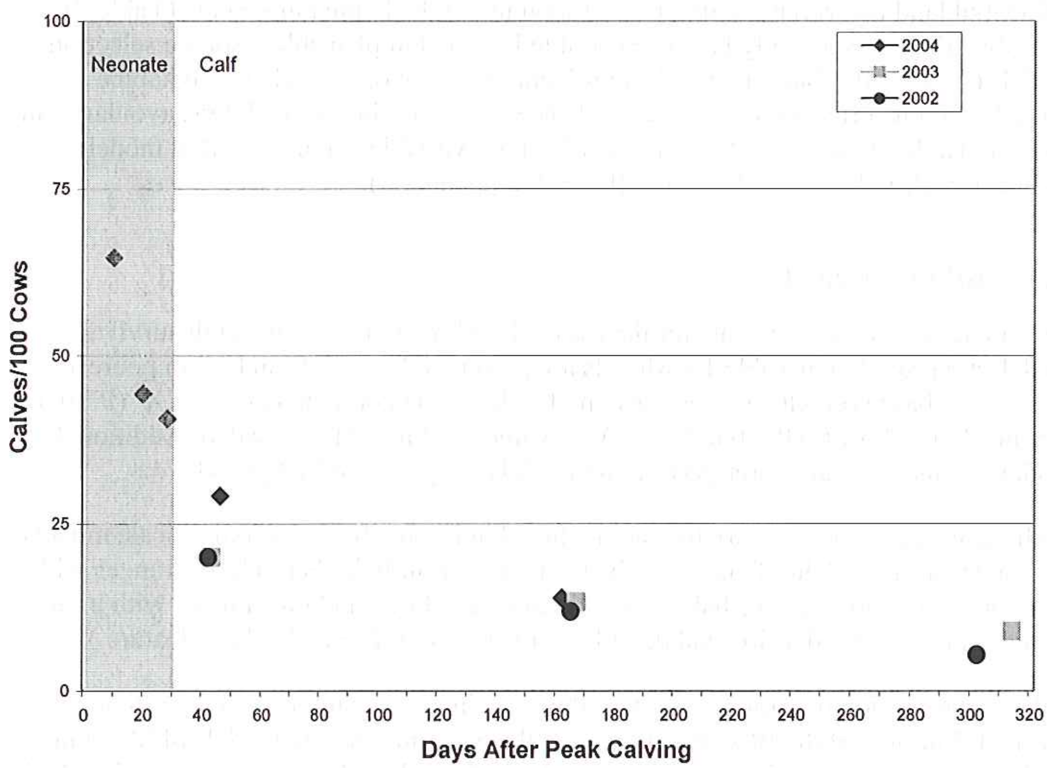

Table 9. Caribou use coefficient estimates (SE), model deviance (Pearson X^2), goodness-of-fit (Hosmer-Lemeshow $\hat{C}$), and ΔAIC_c for best *a priori* models in the Snake-Sahtaneh boreal caribou range (significant values bolded; best models shaded).

Model	β_1 (SE)	β_2 (SE)	β_3 (SE)	β_4 (SE)	β_5 (SE)	X^2, df	$\hat{C}$, df	ΔAIC_c
HABBURN + WOODSPRC + LAKE1	**38.39 (20.18)**	**14.24* (4.72)**	19.95 (61.25)			**17.02, 3*** **	12.14, 8	0.00
HABBURN + WOODSPRC + SLOPE1	41.07 (22.68)	**16.36* (7.29)**	-1.31 (2.85)			**15.75, 3** **	7.24, 8	0.40
HABBURN + OPENSPRC + SLOPE1	14.01 (17.42)	-3.29 (3.37)	**3.98** (1.71)**			**10.91, 3***	8.75, 8	5.30
DISTURB + BURN + WOODSPRC + OPENSPRC + LAKE1	0.25 (3.78)	2.08 (3.14)	**16.25* (6.86)**	7.01 (0.29)	6.11 (88.63)	**14.83, 5***	12.71, 8	6.20
DISTURB + BURN + WOODSPRC + OPENSPRC + SLOPE1	-0.756 (3.43)	2.871 (2.98)	11.203 (7.43)	2.734 (4.61)	0.789 (2.85)	**13.29, 5***	10.70, 8	6.80
WOODSPRC	**10.82*** (3.40)**					**13.01, 1*** **	14.51, 8	7.60
HABBURN + OPENSPRC + LAKE1	18.997 (14.41)	-5.556 (3.37)	144.44 (87.32)			**9.05, 3***	8.75, 8	7.90
WELLDENS + SLOPE1	**-1018.31* (432.72)**	**4.301** (1.61)**				**15.29, 2*** **	13.22, 8	13.1
CUT + SLOPE1	431.45 (255.38)	**4.06* (1.54)**				**12.50, 2** **	11.04, 8	15.9
SLOPE1	**4.434** (1.57)**					**9.25, 1** **	7.11, 8	17.2
OPENSPRC	-4.20 (2.52)					2.88, 1	**28.49, 8** **	17.9
DISTURB + SLOPE1	2.23 (2.61)	**4.756** (1.63)**				**9.98, 2** **	3.54, 8	18.4

* P<0.05; ** P<0.01

Table 10. Caribou adult survival coefficient estimates (SE), model deviance (Pearson X^2), goodness-of-fit (Hosmer-Lemeshow $\hat{C}$), and ΔAIC_c for best *a priori* models in the Snake-Sahtaneh boreal caribou range (significant values bolded; best models shaded).

Model	β_1 (SE)	β_2 (SE)	β_3 (SE)	β_4 (SE)	β_5 (SE)	X^2, df	$\hat{C}$, df	ΔAIC_c
BURN	**20.32*** **(8.13)**					**6.24, 1***	4.90, 8	0.00
DISTURB + BURN	-10.18 (6.48)	**20.87*** **(8.44)**				**8.28, 2***	2.05, 8	0.00
WELLDENS + BURN	**-1843.01*** **(970.20)**	**20.83*** **(8.35)**				**6.86, 2***	6.89, 8	0.20
OPENSPRC	**20.35*** **(9.27)**					**4.81, 1***	7.09, 8	0.40
BURN + LOSS	**23.32*** **(9.82)**	-45.54 (27.77)				**6.12, 2***	4.16, 8	0.50
BURN + CORRDENS	**23.41*** **(9.82)**	-0.48 (0.29)				**6.14, 2***	4.22, 8	0.50
DISTURB + BURN + WOODSPRC + OPENSPRC + LAKE1	-10.62 (8.49)	28.51 (17.42)	21.61 (16.29)	39.86 (26.96)	-253.52 (199.66)	5.49, 5	8.76, 8	0.80
DISTURB + BURN + SLOPE1	**-10.78*** **(5.05)**	**17.32*** **(7.69)**	-3.48 (3.31)			**8.03, 3***	2.77, 8	0.90
DISTURB + BURN + LAKE1	**-15.91*** **(7.40)**	**15.74*** **(6.21)**	-122.83 (89.30)			**10.02, 3***	6.09, 8	1.00
WOODSPRC	-9.89 (5.48)					3.25, 1*	6.18, 8	1.30
BURN + CUT	**21.47*** **(8.93)**	-225.39 (500.51)				**5.79, 2***	1.71, 8	1.70
FACLDENS	**-2976.43**** **(1127.14)**					**6.97, 1****	4.89, 8	1.90

* P<0.05; **P<0.01

Table 11. Caribou 2002 neonatal survival coefficient estimates (SE), model deviance (Pearson X^2), goodness-of-fit (Hosmer-Lemeshow Ĉ), and ΔAIC_c for *a priori* models in the Snake-Sahtaneh boreal caribou range (significant values bolded; best models shaded).

Model	β_1 **(SE)**	β_2 **(SE)**	β_3 **(SE)**	β_4 **(SE)**	β_5 **(SE)**	X^2**, df**	**Ĉ, df**	ΔAIC_c
WELLDENS	-3518.82 (3324.91)					1.13, 1	11.11, 8	0.0
HABBURN	32.21 (26.88)					1.44, 1	6.69, 8	0.2
DISTURB + BURN	-15.62 (14.10)	-18.65 (11.82)				3.63, 2	6.97, 8	0.5
BURN	-14.56 (13.88)					1.10, 1	6.89, 8	0.53
DISTURB + BURN + LAKE1	-29.71 (17.56)	-29.65 (18.59)	-517.82 (454.9)			3.29, 3	8.16, 8	0.7
HOME RANGE AREA	-0.01 (0.011)					0.76, 1	9.37, 8	0.7
WELLDENS + BURN	-3228.48 (3400.64)	-12.63 (16.42)				2.81, 2	8.22, 8	1.0
FACLDENS	-3423.61 (3858.22)					0.79, 1	7.78, 8	1.0
DISTURB	-10.10 (9.36)					1.16, 1	7.96, 8	1.1
SLOPE1	6.28 (6.48)					0.94, 1	9.51, 8	1.1
OPENSPRC	-5.79 (9.48)					0.37, 1	9.98, 8	1.2
ROADDENS	-5.94 (5.62)					1.13, 1	10.44, 8	1.2

* $P<0.05$

3.3.4 Home Range Size

Home range size generally decreased as the relative area of preferred habitat (level slope, woodland spruce, and burns) increased. Home range size generally increased as relative disturbed area (area <250 m of a land use feature) increased.

The best predictive model of caribou home range size combined habitat and land use variables: woodland spruce habitat and area disturbed (R^2 = 49.2%; $F_{2,42}$ = 20.33, $P < 0.0001$). Next best was a three variable habitat model including woodland spruce habitat, burnt habitat and lakes (R^2 = 41.3%; $F_{3,41}$ = 9.63, $P < 0.0001$).

Fair multivariate models included: area burned, area cleared, and level slope(R^2 = 35.0%; $F_{3,40}$ = 7.19, $P < 0.0006$); level slope and area disturbed (R^2 = 33.8%; $F_{2,41}$ = 10.46, $P < 0.0003$); woodland spruce habitat and lakes (R^2 = 32.8%; $F_{2,42}$ = 10.26, $P < 0.0002$); Burn Regeneration habitat and level slope; (R^2 = 30.0%; $F_{2,38}$ = 8.18, $P < 0.002$); woodland spruce habitat and level slope (R^2 = 29.9%; $F_{2,38}$ = 8.12, $P < 0.002$); open spruce habitat and level slope (R^2 = 28.7%; $F_{2,38}$ = 7.66, $P < 0.002$); open spruce habitat and lakes (R^2 = 27.1%; $F_{2,42}$ = 7.79, $P < 0.002$); and the BCC landscape model comprised of area burned and area disturbed (R^2 = 23.2%; $F_{2,45}$ = 6.80, $P < 0.003$).

Proportion of home range with level slope explained 28.2% (R^2) of observed variation in home range area ($F_{1,46}$ = 16.48, $P < 0.001$) while proportion of woodland spruce habitat explained 26.0% (R^2) of observed variation ($F_{1,46}$ = 15.12, $P < 0.001$). Disturbed area explained 14.1% (R^2) of observed variation in home range area ($F_{1,42}$ = 7.565, $P < 0.01$).Other land use and habitat variables were not significantly correlated with home range size.

3.4 WITHIN HOME RANGE RESOURCE SELECTION

3.4.1 Land Use

A summary of land use variables for caribou and random locations within the SS Range is provided in Table 12. Pearson correlation coefficients for all proximity and density variables are provided in Table 13. Within home range resource selection coefficients for caribou use and adult survival are provided respectively in Tables 14 and 15.

Caribou proximity to all land use features within the SS Range was significantly different than random (X^2 >10,345, df = 7400, $P < 0.001$). Road and seismic line density in the 1 km^2 grid around individual caribou locations was significantly different from random (X^2 >100,000, df = 7400, $P < 0.001$), while well and facility density was not (X^2 <775, df = 7400, P=1).

The only land use proximity and density variables that were highly correlated for individual locations within home ranges were distance to wells and facilities (Table 13).

Table 12. Descriptive statistics for caribou and random locations within the Snake-Sahtaneh boreal caribou range.

Metric	Caribou Locations			Random Locations		
	Mean	SD	Range	Mean	SD	Range
Distance to Road (m)	792.8	592.9	<1-3,891	855.8	727.4	<1 – 5,585
Distance to Seismic Line (m)	167.7	172.9	<1-1,615	172.1	215.5	<1-2,898
Distance to Well (m)	2,525	1,807	4-14,691	2,419	2,178	4-13,892
Distance to Facility (m)	4,987	4,691	36-23,120	4,167	4,169	26-26,310
Distance to Cutblock (m)	11,655	7,425	0-44,221	15,387	10,309	0-53,475
Distance to Wolf Pack Centre (m)	20,209	7,565	120-43,697	23,526	11,312	255-27,419
Corridor Density (km/km^2)	4.24	1.21	1.43-9.19	4.28	1.44	1.82-9.10
Seismic Density (km/km^2)	3.64	0.99	1.27-7.60	3.67	1.22	1.42-7.65
Road Density (km/km^2)	0.45	0.17	0.14-1.14	0.47	0.17	0.15-1.05
Well Density ($\#/km^2$)	0.001	0.0004	0.0004-0.002	0.001	0.0007	0.00009-0.003
Facility Density ($\#/km^2$)	0.0007	0.0003	0.0007-0.002	0.0009	0.0004	0.0009-0.002

Table 13. Pearson correlation coefficients for random location land use variables in the Snake-Sahtaneh boreal caribou range (highly correlated variables bolded).

Variable	ROAD DIST	SEIS DIST	WELL DIST	FACL DIST	CUTE DIST	WOLF DIST	SEIS DENS	ROAD DENS	WELL DENS	FACL DENS
ROADDIST		0.23	0.30	0.32	0.05	0.17	-0.27	-0.45	-0.17	-0.14
SEISDIST	0.23		0.17	0.16	-0.03	0.11	-0.45	-0.13	-0.09	-0.06
WELLDIST	0.30	0.17		**0.76**	-0.11	0.12	-0.34	-0.22	-0.28	-0.20
FACLDIST	0.32	0.16	**0.76**		-0.15	0.11	-0.33	-0.20	-0.22	-0.20
CUTEDIST	0.05	-0.03	-0.11	-0.15		0.12	0.01	-0.02	0.07	0.03
WOLFDIST	0.17	0.11	0.12	0.11	0.12		-0.26	-0.14	-0.09	-0.04
SEISDENS	-0.27	-0.45	-0.34	-0.33	0.01	-0.26		0.26	0.18	0.12
ROADDENS	-0.45	-0.13	-0.22	-0.20	-0.02	-0.14	0.26		0.32	0.26
WELLDENS	-0.17	-0.09	-0.28	-0.22	0.07	-0.09	0.18	0.32		0.55
FACLDENS	-0.14	-0.06	-0.20	-0.20	0.03	-0.04	0.12	0.26	0.55	

3.4.2 Within Home Range Use and Survival

Well density provided the most reasonable descriptor of caribou use and also described survival within caribou home ranges. Caribou use was significantly lower where well density was higher (Table 14), although survival probability was higher in these areas (Table 15).

Distance to the nearest seismic line provided a reasonable model of adult mortality risk, with survival probability lower close to seismic lines and in areas with higher well density (Table 15). Although predictive model fit was poor, SS caribou adult mortality risk was inversely related to distance to nearest wolf pack home range centre. A non-linear threshold was observed in the response curve at a distance of approximately 30 km.

Neonate and calf mortality models for 2002, 2003 and 2004 are provided in Tables 16 through 20 (no calves with collared females survived to March 2003). Neonate and calf survival models for the entire study are provided in Tables 21 and 22, respectively.

Table 14. Caribou use coefficient estimates (SE), model deviance (Pearson X^2), goodness-of-fit (Hosmer-Lemeshow $\hat{C}$), and ΔAIC_c for proximity and density variables in the Snake-Sahtaneh boreal caribou range (significant values bolded; best model shaded).

Variable	**β_1 (SE)**	**β_2 (SE)**	**X^2, df**	**$\hat{C}$, df**	**ΔAIC_c**
CUTEDIST	**-0.05*** (0.002)**		**618.09, 1***	**170.36, 8***	0.00
WOLFDIST	**-0.04*** (0.002)**		**461.76, 1***	**1133.11, 8***	196.7
FACLDIST	**0.04*** (0.004)**		**120.04, 1***	**195.35, 8***	504.0
WELLDENS + ROADENS	**-0.21*** (0.04)**	**-0.08*** (0.02)**	**52.94, 2***	**33.79, 4***	577.6
WELLDENS	**-0.25*** (0.04)**		**41.27, 1***	0.66, 1	587.0
ROADDIST	**-0.14*** (0.024)**		**34.79, 1***	**60.02, 8***	596.8
FACLDENS + ROADDENS	**-0.10* (0.05)**	**-0.10*** (0.02)**	**32.01, 2***	**44.23***	600.6
ROADDENS	**-0.12*** (0.023)**		**26.63, 1***	**40.39, 4***	604.0
FACLDENS	**-0.14** (0.05)**		**8.71, 1****	-	619.6
WELLDIST	**0.03** (0.008)**		**9.90, 1***	**207.54, 8***	619.9
SEISDENS	**0.02** (0.006)**		**7.76, 1****	**61.37, 8***	622.4
SEISDIST	-0.12 (0.083)		1.97, 1	**38.23, 8***	628.9

* P<0.05; ** P<0.01; *** P<0.001

Table 15. Adult survival coefficient estimates (SE), model deviance (Pearson X^2), goodness-of-fit (Hosmer-Lemeshow $\hat{C}$), and ΔAIC_c for proximity and density variables in the Snake-Sahtaneh boreal caribou range (significant values bolded; best models shaded).

Variable	β_1 (SE)	β_2 (SE)	X^2, df	$\hat{C}$, df	ΔAIC_c
WOLFDIST	**-0.12*** (0.007)**		**298.70, 1***	**60.49, 8****	0.00
FACLDIST	**0.09*** (0.017)**		**30.26, 1***	**98.10, 8***	224.8
WELLDIST	**0.15*** (0.033)**		**19.86, 1***	**38.13, 8***	251.1
WELLDENS + ROADENS	**0.40* (0.18)**	**0.26** (0.09)**	**16.45, 2***	**44.09, 4***	259.8
FACLDENS + ROADDENS	**-0.23* (0.09)**	**0.31*** (0.09)**	**16.37, 2***	**34.08, 4***	260.5
ROADDENS	**0.29*** (0.09)**		**11.10, 1***	**63.34, 4***	263.1
SEISDIST	**0.98** (0.309)**		**10.03, 1****	15.66, 8	264.7
WELLDENS	**0.49** (0.18)**		**7.39, 1****	-	265.2
ROADDIST	**0.20* (0.081)**		**6.01, 1***	**31.19, 8***	268.9
FACLDENS	-0.20 (0.11)		3.50, 1	-	270.3
SEISDENS	0.02 (0.01)		2.13, 1	**87.21, 8***	272.5
CUTEDIST	0.01 (0.009)		**1.89, 1**	**184.30, 8***	273.0

* P<0.05; ** P<0.01; *** P<0.001

Table 16. Neonatal 2002 survival coefficient estimates (SE), model deviance (Pearson X^2), goodness-of-fit (Hosmer-Lemeshow $\hat{C}$), and ΔAIC_c for proximity and density variables in the Snake-Sahtaneh boreal caribou range (significant values bolded; best models shaded).

Variable	β_1 (SE)	β_2 (SE)	X^2, df	$\hat{C}$, df	ΔAIC_c
WELLDIST	**0.25*** (0.02)**		**139.67, 1*****	**25.33, 8****	0.00
CUTEDIST	**-0.06*** (0.004)**		**177.20, 1*****	**205.81, 8*****	30.7
FACLDIST	**0.05*** (0.006)**		**43.36, 1*****	**225.60, 8*****	131.2
WOLFDIST	**-0.02*** (0.004**		**33.53, 1*****	**256.48, 8*****	140.4
FACLDENS + ROADDENS	**-0.29* (0.13)**	**-0.15* (0.06)**	**11.20, 2****	**9.44, 3***	153.7
FACLDENS	**-0.34* (0.13)**		**6.56, 1***	**-**	156.9
ROADDENS	**-0.17** (0.06)**		**7.13, 1****	**8.88, 3***	157.8
WELLDENS + ROADENS	-0.12 (0.09)	**-0.15* (0.06)**	**8.82, 2***	2.56, 3	158.1
WELLDENS	-0.17 (0.09)		3.62, 1	-	161.5
SEISDENS	-0.03 (0.02)		3.41, 1	11.69, 8	161.7
SEISDIST	-0.09 (0.22)		0.17, 1	**18.53, 8***	164.8
ROADDIST	0.04 (0.06)		0.37,	**6.02, 8**	165.5

* $P<0.05$; ** $P<0.01$; *** $P<0.001$

Table 17. Calf 2002 survival coefficient estimates (SE), model deviance (Pearson X^2), goodness-of-fit (Hosmer-Lemeshow $\hat{C}$), and ΔAIC_c for proximity and density variables in the Snake-Sahtaneh boreal caribou range (significant values bolded; best model shaded).

Variable	**β₁ (SE)**	**β₂ (SE)**	**X^2, df**	**$\hat{C}$, df**	**ΔAIC**
WELLDIST	**0.37*** (0.02)**		**232.98, 1*** **	**26.19, 8*** **	0.00
FACLDIST	**0.07*** (0.006)**		**127.57, 1*** **	**312.90, 8*** **	12.4
CUTEDIST	**-0.04*** (0.004)**		**142.07, 1*** **	**270.50, 8*** **	31.0
FACLDENS + ROADDENS	-0.24 (0.15)	**-0.54*** (0.11)**	**25.47, 2*** **	4.40, 3	259.4
ROADDENS	**-0.56*** (0.11)**		**24.34, 1*** **	**8.09, 3***	260.4
WELLDENS + ROADENS	-0.14 (0.14)	**-0.54*** (0.11)**	**24.79, 2*** **	**14.52, 3** **	261.1
SEISDENS	**-0.10*** (0.01)**		**33.69, 1*** **	**52.41, 8*** **	272.9
ROADDIST	**0.35*** (0.06)**		**27.39, 1*** **	**18.74, 8***	273
FACLDENS	-0.35 (0.17)		**4.10, 1***	-	291.1
WELLDENS	**-0.29* (0.14)**		**4.27, 1***	-	291.7
WOLFDIST	-0.01 (0.05)		3.41, 1	**218.91, 8*** **	295
SEISDIST	0.04 (0.23)		0.03, 1	**26.12, 8*** **	297.4

* P<0.05; ** P<0.01; *** P<0.001

Table 18. Neonatal 2003 survival coefficient estimates (SE), model deviance (Pearson X^2), goodness-of-fit (Hosmer-Lemeshow $\hat{C}$), and ΔAIC_c for proximity and density variables in the Snake-Sahtaneh boreal caribou range (significant values bolded; best models shaded).

Variable	β_1 (SE)	β_2 (SE)	X^2, df	$\hat{C}$, df	ΔAIC_c
WOLFDIST	**-0.04*** (0.007)**		**33.87, 1*** **	**107.41, 8*** **	0.0
SEISDENS	**0.06*** (0.02)**		**10.18, 1*** **	**22.12, 8** **	20.2
WELLDIST	**-0.09*** (0.02)**		**10.87, 1*** **	15.31, 8	23.2
CUTEDIST	**-0.02** (0.007)**		**7.48, 1** **	**45.71, 8*** **	23.5
FACLDENS	**-0.78* (0.38)**		**4.11, 1***	-	24.2
FACLDENS + ROADDENS	**-0.83* (0.41)**	0.09 (0.08)	4.74. 2	2.47, 4	25.1
SEISDIST	-0.66 (0.38)		3.07, 1	4.05, 8	28.2
ROADDIST	0.15 (0.08)		3.08, 1	**16.12, 8***	28.5
WELLDENS	**-0.24 (0.17)**		2.00, 1	-	29.6
WELLDENS + ROADENS	-0.27 (0.17)	0.08 (0.08)	3.33, 2	0.68, 3	30.7
ROADDENS	0.05 (0.08)		0.42, 1	3.52, 4	31.3
FACLDIST	0.004 (0.009)		0.21, 1	**46.01, 8*** **	31.6

* P<0.05; ** P<0.01; *** P<0.001

Table 19. Neonatal 2004 survival coefficient estimates (SE), model deviance (Pearson X^2), goodness-of-fit (Hosmer-Lemeshow $\hat{C}$), and AIC for proximity and density variables in the Snake-Sahtaneh boreal caribou range (significant values bolded; best model shaded).

Variable	β_1 (SE)	β_2 (SE)	X^2, df	$\hat{C}$, df	ΔAIC_c
FACLDIST	**-0.18*** (0.009)**		**356.60, 1*** **	**184.32, 8*** **	4750.5
WELLDIST	**-0.38*** (0.02)**		**320.60, 1*** **	**64.53, 8*** **	4817.5
WOLFDIST	**0.05*** (0.005)**		**105.33, 1*** **	**192.47, 8*** **	5006.5
SEISDENS	**0.05*** (0.01)**		**17.97, 8*** **	**63.23, 8*** **	5123.6
WELLDENS + ROADENS	**0.29*** (0.08)**	**-0.15** (0.05)**	**13.94, 2*** **	**21.11, 3*** **	5128.2
WELLDENS	**0.22** (0.08)**		**7.48, 1** **	-	5134.2
SEISDIST	**0.52** (0.20)**		**7.29, 1** **	**21.44, 8** **	5134.3
ROADDIST	**0.12* (0.05)**		**5.65, 1***	**27.70, 8*** **	5135.9
ROADDENS	-0.10 (0.05)		3.36. 1	**33.94, 3**	5137.5
FACLDENS + ROADDENS	0.06 (0.11)		3.70, 2	**37.39, 4*** **	5139.2
CUTEDIST	0.002 (0.005)		0.19, 1	**412.8, 8*** **	5141.2
FACLDENS	0.03 (0.11)		0.10, 1	-	5142.2

* P<0.05; ** P<0.01; *** P<0.001

Table 20. Calf 2004 survival coefficient estimates (SE), model deviance (Pearson X^2), goodness-of-fit (Hosmer-Lemeshow $\hat{C}$), and AIC for proximity and density variables in the Snake-Sahtaneh boreal caribou range (significant values bolded; best model shaded).

Variable	β_1 (SE)	β_2 (SE)	X^2, df	$\hat{C}$, df	ΔAIC_c
CUTEDIST	**-0.11*** (0.009)**		**130.15, 1*** **	**77.73, 8*** **	3669.5
WOLFDIST	**0.07*** (0.005)**		**150.33, 1*** **	**154.76, 8*** **	3723.5
FACLDIST	**-0.12*** (0.01)**		**150.36, 1*** **	**232.31, 8*** **	3791.3
WELLDIST	**-0.20*** (0.02)**		**87.63, 1*** **	**83.87, 8*** **	3829.3
ROADDIST	**0.13* (0.06)**		**4.88, 1***	12.03, 8	3894.5
ROADDENS	-0.11 (0.06)		2.90, 1	43.03, 1	3896.1
FACLDENS + ROADDENS	-0.11 (0.14)	-0.10 (0.06)	3.41, 2	**44.67, 3*** **	3897.3
WELLDENS + ROADENS	0.01 (0.11)	-0.11 (0.07)	2.87, 2	**54.86, 2*** **	3898.1
FACLDENS	-0.14 (0.15)		0.93, 1	-	3898.3
SEISDENS	-0.01 (0.01)		0.79, 1	104.15, 1***	3898.9
SEISDIST	-0.17 (0.22)		0.63, 1	**20.14, 8** **	3899.1
WELLDENS	-0.03 (0.10)		0.11, 1	-	3899.1

* P<0.05; ** P<0.01; *** P<0.001

Table 21. Neonatal survival coefficient estimates (SE), model deviance (Pearson X^2), goodness-of-fit (Hosmer-Lemeshow Ĉ), and ΔAIC_c for proximity and density variables in the Snake-Sahtaneh boreal caribou range (significant values bolded; best model shaded).

Variable	β_1 (SE)	β_2 (SE)	X^2, df	Ĉ, df	ΔAIC_c
FACLDIST	**-0.04** (0.013)**		**7.45, 1****	**72.6, 8*****	0.0
ROADDIST	**0.30* (0.125)**		**5.88, 1***	10.4, 8	0.3
WOLFDIST	**0.03* (0.012)**		**5.97, 1***	**16.8, 8***	0.5
CUTEDIST	**-0.03* (0.012)**		**5.10, 1***	**58.5, 8*****	0.6
FACLDENS	-1.32 (0.852)		2.39, 1	-	0.6
FACLDENS + ROADDENS	-1.28 (0.840)	-0.05 (0.142)	2.47, 2	**7.16, 2***	2.8
SEISDENS	-0.05 (0.030)		2.80, 1	**30.7, 8*****	3.7
WELLDENS	0.24 (0.212)		1.25, 1	-	4.9
WELLDIST	-0.04 (0.042)		0.78, 1	12.1, 8	5.3
ROADDENS	-0.08 (0.142)		0.36, 1	4.19, 2	5.6
SEISDIST	0.21 (0.399)		0.29, 1	6.4, 8	5.8
WELLDENS + ROADENS	0.26 (0.219)	-0.10 (0.147)	1.53, 2	4.70, 3	6.3

* $P<0.05$; ** $P<0.01$; *** $P<0.001$

Table 22. Calf survival coefficient estimates (SE), model deviance (Pearson X^2), goodness-of-fit (Hosmer-Lemeshow $\hat{C}$), and ΔAIC_c for proximity and density variables in the Snake-Sahtaneh boreal caribou range (significant values bolded; best model shaded).

Variable	**β_1 (SE)**	**β_2 (SE)**	**X^2, df**	**$\hat{C}$, df**	**ΔAIC_c**
CUTEDIST	**-0.11*** (0.013)**		**62.36, 1*** **	**27.8, 8*** **	0.0
FACLDIST	**-0.05*** (0.014)**		**13.33, 1*** **	**122.5, 8*** **	53.8
WOLFDIST	**0.03** (0.009)**		**7.41, 1** **	**63.7, 8*** **	56.2
WELLDIST	**0.08* (0.038)**		**4.67, 1* **	**30.9, 8*** **	58.3
SEISDIST	0.31 (0.437)		0.50, 1	5.8,8	61.8
SEISDENS	0.02 (0.024)		0.48, 1	**35.5, 8*** **	61.8
WELLDENS	-0.10 (0.172)		0.35, 1	-	62.0
FACLDENS	-0.09 (0.227)		0.18, 1	-	62.1
ROADDIST	-0.04 (0.127)		0.09, 1	13.4, 8	62.2
ROADDENS	-0.03 (0.124)		0.07, 1	**35.6, 3*** **	62.2
WELLDENS + ROADENS	-0.09 (0.188)	-0.01 (0.135)	0.35, 2	4.70, 3	64.0
FACLDENS + RODDENS	-0.09 (0.219)	-0.02 (0.123)	0.19, 2	**25.9, 3*** **	64.1

* $P<0.05$; ** $P<0.01$; *** $P<0.001$

3.4.3 Proximity Analysis

3.4.3.1 Roads

The overall frequency of caribou and random locations within road proximity buffers is shown in Figure 7. Mean caribou use of the 500-1,000 m road buffer was greater than expected, and caribou use of the 0-100 m, 2,000-3,000 and >3,000 m road buffers was less than expected.

The 500-1,000 m buffer was preferred relative to all others based on log ratio analysis. Subsequent preference rankings from second highest to lowest were: 1,000-2000 m buffer; 250-500 m buffer; 100-250 m buffer; 0-100 m buffer; 2,000-3,000 m buffer, and >3,000 m buffer.

The 0-100 m road buffer was used significantly less ($t = -2.52$, $P < 0.05$) than the 1,000-2,000 m buffer, as were the 2,000-3,000 m buffer ($t = -4.68$, $P<0.01$) and >3,000 m buffer ($t = -19.04$, $P<0.001$). Use of the 100-250 m, 250-500 m, and 500-1,000 m road buffers was not significantly different from use of the reference 1,000-2,000 m buffer.

Compositional analysis indicates that SS caribou avoided areas within 100 m and more than 2,000 m from roads.

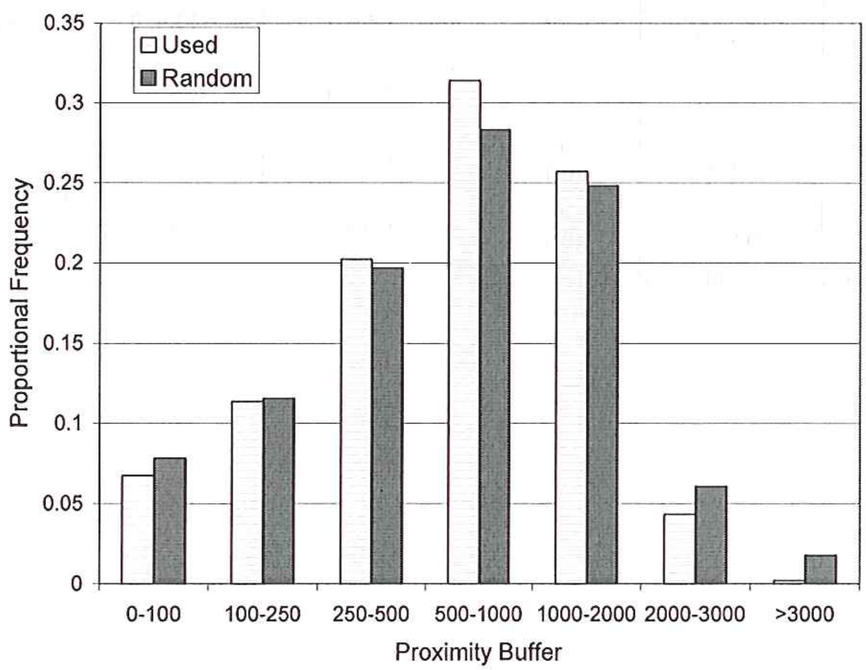

Figure 7. Frequency of caribou and random locations within road proximity buffers.

3.4.3.2 Seismic Lines

The overall frequency of caribou and random locations within seismic proximity buffers is shown in Figure 8. Mean caribou use of the 100-250 m and 250-500 m seismic buffers was greater than expected, while use of all other buffers was less than expected.

The 250-500 m seismic proximity buffer was preferred relative to all others based on log ratio analysis. Subsequent preference rankings from second highest to lowest were: 100-250 m buffer; 0-100 m buffer; 500-1,000 m buffer; 1,000-2,000 m buffer; and 2,000-3,000 m buffer. No caribou or random locations were located more than 3,000 m away from a seismic line.

The 500-1,000 m seismic buffer was used significantly less ($t = -2.69$, $P < 0.05$) than the 250-500 m buffer, as were the 1,000-2,000 m buffer ($t = -11.97$, $P < 0.001$) and 2,000-3,000 m buffer ($t = -62.76$, $P < 0.001$). Use of the 0-100 m and 100-250 m seismic buffers was not significantly different from use of the reference 250-500 m buffer.

Compositional analysis indicates that SS caribou did not avoid areas close to seismic lines, but avoided areas more than 500 m from seismic lines. Reduced use of areas further from seismic lines was likely an artefact of the high seismic line density in the study area.

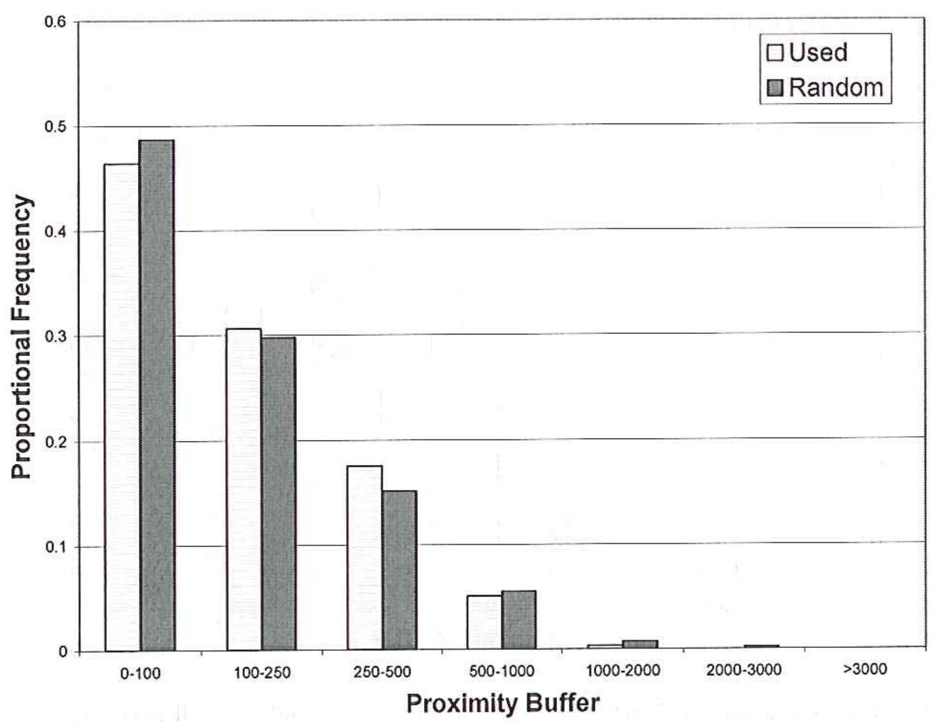

Figure 8. Proportional frequency of caribou and random locations within seismic line proximity buffers.

3.4.3.3 Wells

The overall frequency of caribou and random locations within well proximity buffers is shown in Figure 9. Mean caribou use of the 0-100 m, 2,000-3,000 m, and >3,000 m well buffers was greater than expected, while use of all other buffers was less than expected.

The 2,000-3,000 m well proximity buffer was preferred relative to all others based on log ratio analysis. Subsequent preference rankings from second highest to lowest were: 1,000-2,000 m buffer; >3,000 m buffer; 500-1,000 m buffer; 250-500 m buffer; 100-250 m buffer, and 0-100 m buffer.

The 0-100 m well buffer was used significantly less ($t = -3.56$, $P < 0.05$) than the >3,000 m buffer, as were the 100-250 m buffer ($t = -3.42$, $P<0.05$) and 250-500 m buffer ($t = -2.88$, $P<0.05$). Use of the 500-1,000 m, 1,000-2,000 m, and 2,000-3,000 m well buffers was not significantly different from use of the reference >3,000 m buffer.

Compositional analysis indicates that SS caribou avoided areas within 500 m of wells.

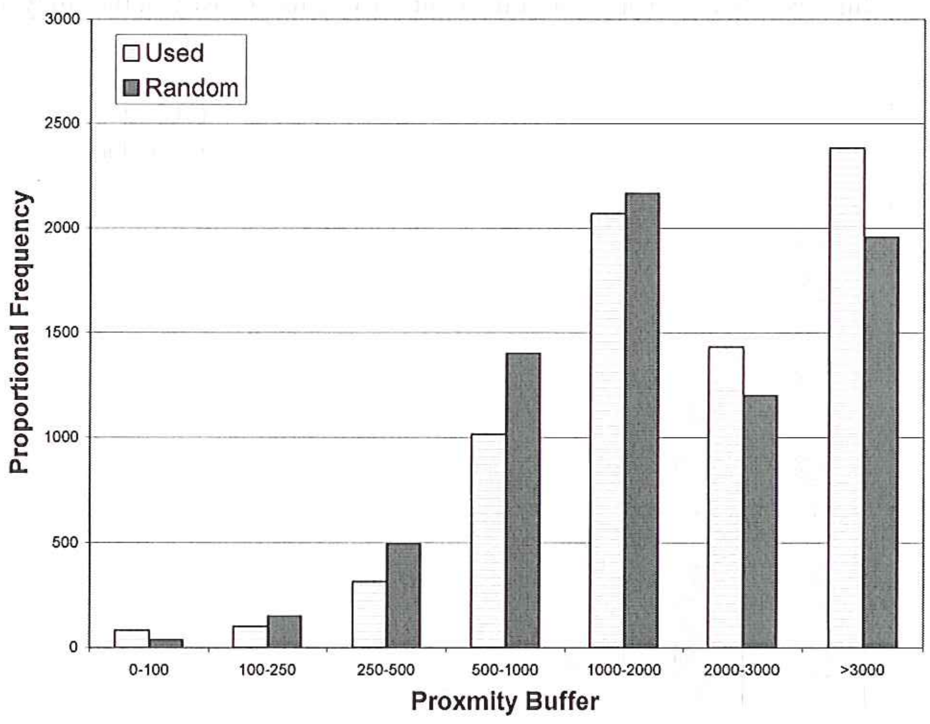

Figure 9. Frequency of caribou and random locations within well proximity buffers.

3.4.3.4 Facilities

The overall frequency of caribou and random locations within facility proximity buffers is shown in Figure 10. Mean caribou use of the 0-100 m, 100-250 m and >3,000 m facility buffers was greater than expected, while use of all other buffers was less than expected.

The 1,000-2,000 m facility proximity buffer was preferred relative to all others based on log ratio analysis. Subsequent preference rankings from second highest to lowest were: 2,000-3,000 m buffer; >3,000 m buffer; 500-1,000 m buffer; 250-500 m buffer; 100-250 m buffer, and 0-100 m buffer.

The 0-100 m well buffer was used significantly less ($t = -10.07$, $P < 0.001$) than the 1,000-2,000 m buffer, as were the 100-250 m buffer ($t = -4.90$, $P < 0.01$) and 500-1,000 m buffer ($t = -3.45$, $P < 0.05$). Use of the 250-500 m, 2,000-3,000 m, and >3,000 m facility buffers was not significantly different from use of the reference 1,000-2,000 m buffer.

Log ratio analysis indicates that SS caribou generally avoided areas within 1,000 m of facilities. Although reduced use of the 250-500 m buffer was not statistically significant relative to the preferred 1,000-2,000 m buffer, all other buffers within 1,000 m of facilities were used less than expected.

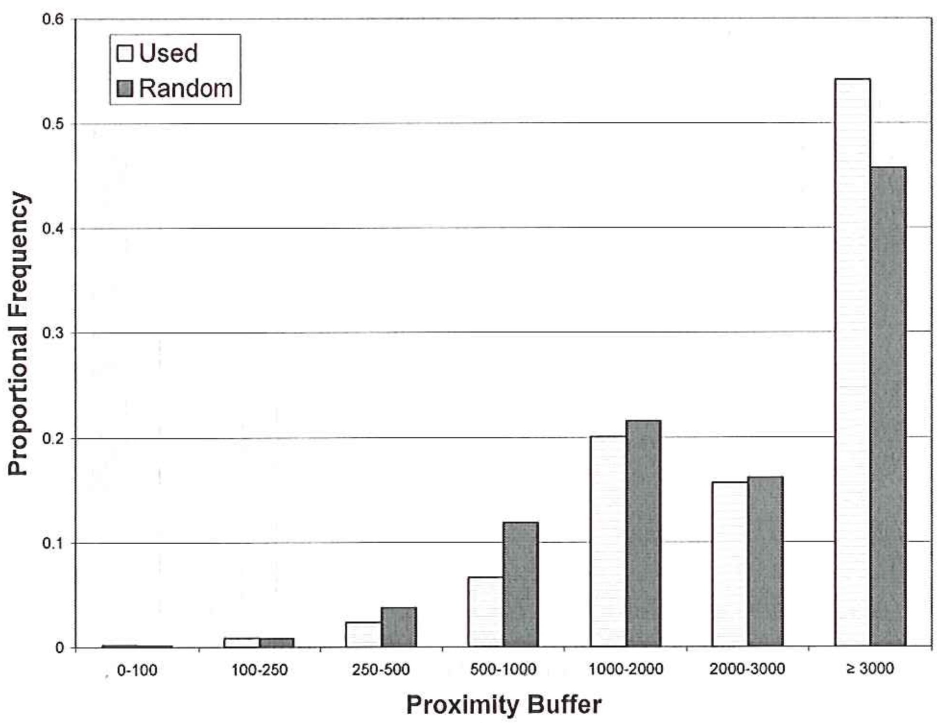

Figure 10. Frequency of caribou and random locations within facility proximity buffers.

3.4.3.5 Cut Blocks

The overall frequency of caribou and random locations within cut block proximity buffers is shown in Figure 11. Mean caribou use of the 1,000-2,000 m, 2,000-3,000 m, 3,000-5,000 m, 5,000-10,000 m, and >10,000 m cut block buffers was greater than expected. Use of the 0-500 m and 500-1,000 m buffers was less than expected.

The >10,000 m cut block proximity buffer was preferred relative to all others based on log ratio analysis. Subsequent preference rankings from second highest to lowest were: 5,000-10,000 m buffer; 3,000-5,000 m buffer; 0-500 m buffer; 1,000-2,000 m buffer; 500-1,000 m buffer, and 2,000-3,000 m buffer.

The 0-500 m cut block buffer was used significantly less ($t = -5.68$, $P < 0.01$) than the >10,000 m buffer, as were the 500-1,000 m buffer ($t = -8.14$, $P<0.001$), 1,000-2,000 m buffer ($t = -6.55$, $P<0.001$), 2,000-3,000 m buffer ($t = -7.11$, $P<0.001$), and 3,000-5,000 m buffer ($t = -4.62$, $P<0.01$). Use of the 5,000-10,000 m cut block buffer was not significantly different from use of the reference >10,000 m buffer.

Log ratio compositional analysis indicates that SS caribou avoided areas within 5,000 m of cut blocks.

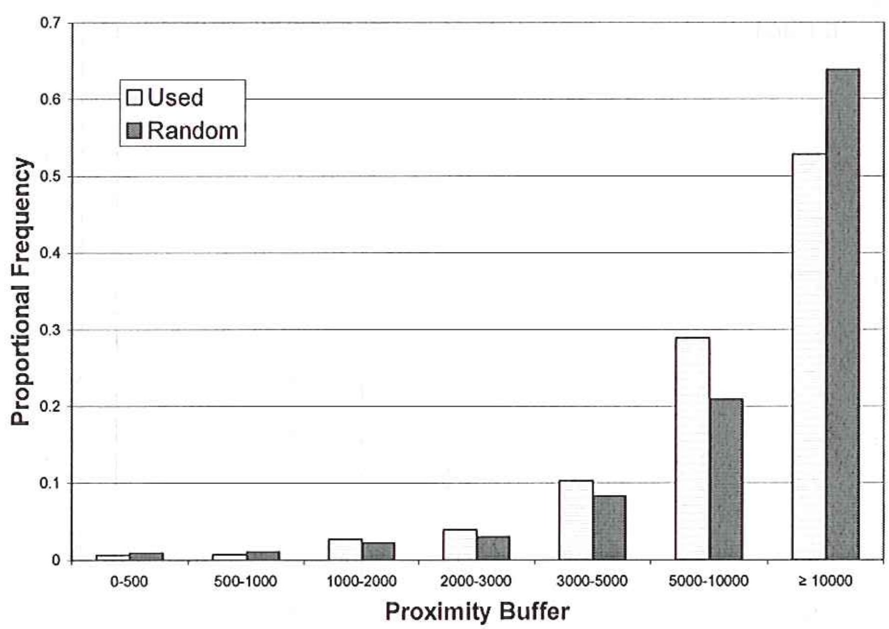

Figure 11. Frequency of caribou and random locations within cutblock proximity buffers.

3.5 POPULATION DYNAMICS

As described more fully in Culling et al. (2006), five of 57 radio-collared caribou were known to have died during the 58 month study period, including 2 cases of confirmed wolf predation, 1 case of suspected black bear predation, and 2 of undetermined cause. Both confirmed cases of wolf predation occurred on seismic lines. Mortalities occurred in April, June, July, August, and October. Standardized annual adult survival for 57 females over 58 months was estimated at 0.94 (95% CI = 0.89 to 0.99). Calf recruitment rates observed during the study were 5 calves:100 cows and 9 calves:100 cows in 2003 and 2004 respectively. Based on these values, the finite range of increase (λ) for the SS herd in 2003-2004 was calculated to be 0.97 (95% CI = 0.92 to 1.02), indicating that the herd was stable to slightly declining.

The Alberta BCC regression equation predicted λ of 0.89 for the SS herd while the regression equation for sedentary herds developed by Bergerud (1996) predicted λ of 0.76. Both equations suggest that the SS population should be declining more rapidly than observed. The difference is due to the comparatively high adult female survival rate found during the SS study.

4. DISCUSSION

Boreal-ecotype caribou such as the Snake-Sahtaneh herd select habitat at a variety of scales and cumulative effect management must recognize and address this if populations in northeastern British Columbia are to be sustained. Throughout much of their range, boreal caribou have been fragmented from a continuous, though patchy, metapopulation into isolated herds with limited interaction (Rettie and Messier 1998, 2000). This has reduced opportunities for immigration to offset local declines and increased the importance of managing each herd or range independently. Most recent western Canadian caribou protection plans have emphasized protection of discrete spatial and temporal attributes (e.g., critical habitat and late winter or calving periods; Culling et al. 2004) for these isolated herds without explicitly considering larger scale or longer-term factors (e.g., predator numbers and burns) that affect habitat supply and predation risk.

In northeast British Columbia, boreal caribou distribution is limited by the presence of suitable habitat. The 4 currently defined boreal caribou ranges consist of sparsely treed, low gradient wetlands separated by areas of upland and riparian habitat that are consistently avoided by caribou (Culling et al. 2004, 2006). As demonstrated here, industrial land use features are concentrated in preferred habitat within the SS Range and – consistent with regional land management plans – recent hydrocarbon exploration activity has also been concentrated in areas that are most frequently used by caribou (Figure 4, Section 3.2). At the landscape scale, this means that cumulative effects risk is elevated for caribou and other wetland-associated biota within the SS Range. Resource selection relationships for SS caribou therefore reflect habitat with a very high land use footprint relative to values reported for other western Canadian ranges.

Two cumulative effects pathways are of primary concern for boreal caribou. The first is reduced habitat effectiveness (and associated loss of carrying capacity) caused by the presence of linear corridors and clearings that caribou avoid. The second is higher mortality resulting from habitat conversion and improved access that leads to increased predator numbers or human/predator hunting efficiency. Both pathways can contribute to short- or long-term population declines. This SS CE study considered both potential pathways by evaluating the influence of habitat and land use features on mortality as well as habitat use. The implications of local to landscape scale results for the SS CE study area are discussed below.

4.1 HABITAT EFFECTIVENESS

Within home-range scale analyses presented in Section 3.4 demonstrate that SS caribou selected areas near most land use features less than expected. This is consistent with documented response in other boreal caribou herds, although buffer width and use intensity relative to specific features commonly differ among herds. These observed differences have implications for cumulative effects modelling and may also be relevant for impact management.

Woodland caribou avoidance of comparatively active or large land use features appears to occur consistently. Both this study and Dyer et al. (2001) documented reduced boreal caribou multi-season use within 100 m of roads and 500 m of wells. Neufeld (2006) also found reduced use near well sites in the Little Smoky range. Reduced use within 5,000 m of cut blocks was found in the SS Range; reduced use was also documented within 1,000 m to 1,200 m of cutblocks in west-central Alberta (Smith et al. 2000; Neufeld 2006). Reduced use within 1,000 m of hydrocarbon facilities occurred in the SS Range, the first time that this land use feature has been specifically considered. Available evidence therefore indicates that for cumulative effects modelling and management, roads, wells, hydrocarbon facilities, and cut blocks should be assumed to reduce boreal caribou habitat effectiveness during all seasons.

In contrast, caribou response to seismic lines appears to be inconsistent. This CE study found no reduced use near seismic lines (Section 3.4.3.2) and visible caribou trails frequently followed seismic lines in the SS Range (T. Antoniuk, pers. obs.). Oberg's (2001) analysis of west-central Alberta mountain ecotype caribou telemetry data also found no seismic line avoidance. Dyer et al.'s (2001) investigations in north-central Alberta documented seasonal avoidance of 100-250 m, while avoidance of up to 500 m was documented for comparatively pristine boreal caribou range in the lower Mackenzie River valley documented (GNWT 2006). Saher's (2005) study of a mountain caribou herd that overlaps the British Columbia-Alberta border showed that resource selection balances competing selection pressures. She found that while caribou selected sites within 250 m of conventional seismic lines, areas within 100 m of the lines were used less than expected. This was attributed to local scale avoidance even though *Cladina mitis*, an important winter food source, was more prevalent near seismic lines. Finally, Neufeld's (2006) study of boreal- and mountain-ecotype herds in west central Alberta found strong evidence that caribou avoided areas closer to seismic lines.

Seismic lines represent a comparatively inactive and narrow land use feature that is inordinately important for cumulative effects management within the Western Canadian Sedimentary Basin (Alberta, Saskatchewan, Northwest Territories, and Yukon). Where present, as in the SS Range, seismic lines generally contribute more anthropogenic edge than any other feature (Schneider et al. 2003; GNWT 2006). Similarly seismic lines often make the largest contribution to the 'disturbed area' variable in the BCC equation (Salmo unpub.data). Because of this, modelling and management assumptions for this land use feature have had, and will continue to have, a profound influence on both predicted impacts and required mitigation.

Habitat effectiveness models used for research and impact assessment purposes emphasize the indirect effects of local-scale avoidance (e.g., UNEP 2001; Weclaw and Hudson 2004). A key question for cumulative effects management is whether documented local behavioural responses are translated into population level effects. There is no evidence that reduced habitat effectiveness has affected boreal caribou pregnancy or parturition rates (Schaefer et al. 1999; Dzus 2001; Thomas and Gray 2002; Culling et al. 2006), so any population-level effects of reduced food carrying capacity should be reflected as home range shifts away from areas of increased activity, compensatory increases in home range size, or increased neonatal mortality associated with lower birth rate (Adams et al. 1995 in Tracz 2005).

At the home range scale, results from the SS Range were consistent with other boreal caribou studies (Section 3.3) where selection was for suitable habitat. In the SS Range, adult female home range selection was best described by habitat variables. Models with both habitat and land use variables were plausible, but area disturbed was less influential than area of woodland spruce and level terrain and its effect on use was inconsistent (Table 9). This indicates that reduced habitat effectiveness in the SS Range was not translated into home range shifts away from areas of increased activity (Section 3.3.1). Tracz (2005) also found that well density did not affect boreal caribou home range location.

Reduced habitat effectiveness may have caused compensatory increases in SS caribou home range size. SS caribou annual to multi-year home range size was best described by a combination of two uncorrelated habitat and land use variables (proportion of preferred woodland spruce habitat and area <250 m of a land use feature; Table 8). Home range size of SS females was weakly correlated with proportion disturbed area (area <250 m of a land use feature), and this could be interpreted as functional habitat loss. However, proportion of preferred woodland habitat explained almost twice as much variation in home range size and the next best model included only habitat variables (Section 3.3.4). This suggests that influence of land use on home range size was secondary and that any compensatory increases were comparatively minor, consistent with conclusions from northeastern Alberta (Stuart-Smith et al. 1997; Tracz 2005).

The SS study confirms that this herd is isolated because individuals select sparsely treed, low gradient wetland habitat, even where this habitat has a comparatively high industrial land use footprint and high predator density. Although individuals do appear to change their habitat use in response to industrial land use, there is no clear evidence of population level effects on home range size and location nor range boundaries. These findings confirm the importance of managing the SS herd and range as a discrete unit.

4.2 MORTALITY RISK

Land use features had a much greater influence on caribou mortality risk than on habitat selection. At the local scale, boreal caribou adult female mortality risk was inversely related to distance to the nearest seismic line and directly related to nearby well density (Section 3.4.2; Table 15). This is consistent with findings from two northeast Alberta ranges where mortality was significantly higher near linear corridors (James and Stuart-Smith 2000) and the southern NWT, where 75% of known boreal caribou mortality occurred within 500 m of linear developments (GNWT 2006).

At the home range scale, adult mortality risk was inversely related to proportion of burns and open spruce habitat and directly related to proportion of disturbed area, well density, and facility density (Section 3.3.2, Table 10). Active land use features such as wells and facilities affected SS caribou mortality over multiple seasons and years. Most of the reasonable survival models for SS home ranges included both natural variables (burned area, open spruce habitat, and level terrain) and land use variables (well density, facility density, corridor density, disturbed area, cleared area, and cut area). These results are consistent with findings for Alberta herds, where the BCC equation predicting population rate of change includes burned area and disturbed area (BCC 2003). Available evidence suggests that it is the combined land use footprint, rather than specific features which has the greatest influence on adult mortality. This is an important distinction because in the past, the research and mitigation emphasis has reflected individual behavioural response rather than mortality risk. Recent findings indicate that adult mortality risk must be managed at the range or landscape scale, regardless of the specific land use features present in the range.

Calf survival trends in the SS Range to 10 months of age were similar between 2002 and 2004 (Figure 6). Most mortality occurred during the neonatal period, consistent with reports on other woodland caribou herds (Bergerud and Elliot 1986; Bergerud and Page 1987; Stuart-Smith et al. 1997; Dunford et al. 2003; Wittmer et al. 2005; YTG 2006, but see Gustine et al. 2006). CE study results do not suggest that birth rates were lower because of reduced carrying capacity, although this hypothesis cannot be ruled out.

Factors that affect calf predation risk are not clear. Bergerud and Page (1987) found that northern-ecotype calf survival was not correlated with changes in the abundance of predators or alternative prey, but was inversely correlated with April snow pack. Lower calf survival has been found in home ranges similar to the SS herd, with smaller wetland patches and a higher proportion of upland (Stuart-Smith et al., 1997).

No reasonable home range scale neonatal mortality models were identified (Section 3.3.3), indicating that neonatal mortality risk is best explained at either the local or landscape scale in the SS Range. Although females displayed calving site fidelity (Culling et al. 2006), between-year variability in neonate mortality was evident, consistent with observations for other woodland caribou herds (Bergerud and Page 1987).

In one or more years, more mortalities than expected occurred closer to wells and in locations with higher facility density and road density; survival was higher than expected in locations with high well density (Tables 16, 18, 19). Overall neonate mortality between 2002 and 2004 was best explained by distance to the nearest road, with neonatal mortality risk increasing near roads (Section 3.4.2, Table 21).

While calf mortality continued at a relatively constant rate following the neonatal period (Figure 6), no combination of habitat and land use variables provided a reasonable explanation of calf mortality at the within-home range or home range scales (Section 3.3.3, Table 22). Locations of calf mortalities were further from roads than expected in 2004, and in areas of lower facility density than expected in 2002 (Tables 17 and 20). The lack of consistent patterns implies that calf mortality in the SS Range occurs randomly following the neonatal period.

Wolf predation appears to be the most likely cause of the high calf mortality observed in the SS Range (Culling et al. 2006) and many other woodland caribou herds (Begerud and Page 1987; Hayes et al. 2003). During the neonate period, wolves selected wetland, stream and lake, low vegetation, tall shrub, and cutblock habitats that were relatively avoided by caribou which selected dense patches of black spruce within open bogs for security cover (Culling et al. 2006). This selection pattern is consistent with that documented for wolves in the Little Smoky boreal caribou range in west central Alberta (Neufeld 2006). Both collared and uncollared wolves were observed alone in peatland habitats during May and June, and it is assumed that these lone wolves were targeting smaller prey such as beaver or ungulate calves (Culling et al. 2006).

4.3 POPULATION EFFECTS

The SS boreal caribou study indicates that mortality, not habitat alteration and loss, was the primary source of population level effects during the five year study period. A key management question is whether mortality is directly related to land use intensity on this range. Land use in the wolf pack composite home range was not significantly different from that of the composite caribou core area (Section 3.2), but wolf pack multi-year home ranges had significantly more land use than caribou home ranges (Section 3.3). This suggests that land use influenced caribou, but not wolf, habitat use at the home range scale. The inclusion of several land use variables in reasonable models of adult survival (Tables 10 and 15) indicates that land use does affect mortality risk on the SS Range.

The high calf mortality but relatively low adult mortality observed in the Snake-Sahtaneh study differs from that documented in Alberta boreal caribou herds. Because population persistence is most sensitive to adult female survival (Smith 2004; Wittmer et al. 2005), the SS herd is declining more slowly in the short-term than predicted by responses of other herds. However, longer term herd decline is inevitable if the calf survival rates calculated for the Snake-Sahtaneh range continue because these are below the level required to replace aging females (Bergerud and Page 1987; YTG nd).

Caribou resource selection at the range and home-range scales appears to be based primarily on habitat, regardless of land use intensity. Individual response to land use is reflected at the home range and within-home range scales, while population-level response is reflected at the landscape and range scale. Industrial development of the SS caribou range appears to have created a situation where caribou continue to select areas with suitable habitat but elevated predation risk. This combination is referred to as an 'ecological trap' or 'attractive sink' because population decline will occur if these conditions persist. A time lag of up to twenty years may occur before land use-related effects are translated into woodland caribou population extirpation (Vors et al. 2007). Ecological traps appear to be relatively common in rapidly changing landscapes like the CE study area (Battin 2004).

4.4 IMPACT MANAGEMENT

In areas such as the SS Range where industrial development is the designated primary land use, the key management issue is how this activity can be planned, mitigated, or coordinated to reduce cumulative effects risk and sustain the SS herd. Two general management approaches have been adopted or proposed in western Canada to avoid or reverse woodland caribou population declines:

1. **Best Practices**: Manage land uses and activities on all caribou primary use areas with caribou protection plans and mitigation 'best practices'.
2. **Range-specific Management**: Manage habitat effectiveness or specific limiting factors identified by research and monitoring of each herd. (e.g., mortality or habitat availability)

4.4.1 Best Practices

The established 'best practices' approach assumes that caribou populations can be protected by minimizing the size of new land use footprints and disturbance during critical life history periods. Examples of mitigation best practices include: low-impact or avoidance techniques to decrease seismic line width and line-of-sight (CAPP 2004); reducing land use in defined core habitats (Culling et al. 2004); minimizing combined disturbance during late winter or calving periods (Pedigree 1991; Bradshaw et al. 1997); and mulching rather than blading seismic lines to encourage shrub and tree revegetation (CAPP 2004).

The best practices approach has been applied to caribou ranges in northeast British Columbia (Culling et al. 2004). For example, although seismic exploration activity in the SS Range increased dramatically during the current study (Section 3.1), the concomitant use of reduced-width seismic lines effectively decreased the incremental land use footprint over this period. This mitigation technique may have also reduced the incremental indirect footprint (i.e., loss of habitat effectiveness), as no avoidance of seismic lines was found in the current study (Section 3.4.3.2). Studies elsewhere have demonstrated the benefits of industrial best practices for caribou ranges (Schneider et al. 2003; Schneider and Dyer 2006).

While best practices will continue to be an essential component of caribou management in northeast British Columbia and elsewhere, there is no evidence that they will be sufficient to maintain the SS herd. Protection of critical habitat and periods on an application-by-application basis has not prevented population declines in other areas where this approach has been applied (McLoughlin et al. 2003; Wittmer et al. 2005). This might be attributed to one or more of the following factors: lag times between landscape disturbance/restoration and subsequent declines/recovery; influence of conditions outside caribou ranges on predator numbers and caribou survival; the continuing increase in direct and indirect footprint that has occurred on most ranges; or the overriding influence of short-term mortality rather than habitat alteration on population dynamics.

CE study results provide no evidence that herds in northeast BC will respond differently. Resource selection modelling indicates that land use intensity and burns have the greatest influence on SS boreal caribou mortality risk. This means that the probability of caribou persistence will decrease as the density of roads, wells, facilities, and seismic lines increases in their range. This highlights the importance of managing the total direct and indirect land use footprint by minimizing incremental land disturbance and encouraging reclamation of existing land use features.

The best practices approach that forms the basis for much of the '*Interim Oil and Gas Industry Guidelines for Boreal Caribou in Northeastern British Columbia*' (Culling et al. 2004) will slow, but not prevent, an increase in mortality risk. To ensure boreal caribou persistence in northeastern British Columbia, land uses that contribute to cumulative effects must be managed over larger landscapes and longer time frames than has occurred to date. The Interim Guidelines does identify the need for range-specific management plans for all identified boreal caribou ranges as well as range disturbance targets that provide an upper cap to land use disturbance. These measures are discussed further below.

4.4.2 Range-specific Management

Results of the CE study confirm the need for range-specific management plans including those elements recommended in the Interim Guidelines (Culling et al. 2004). This is consistent with recommendations for boreal caribou herds in Alberta and the Northwest Territories (BCC 2001; GNWT 2006). This knowledge-based approach focuses on specific factors that affect population persistence, considering both space and time. Predator-prey management and landscape-level targets are two strategies that have been most frequently applied or recommended.

4.4.2.1 Predator-Prey Management

Predator or predator-prey management has been identified as the most practical management option for caribou herds at high risk of extirpation (e.g., Edmonds 1996; Bergerud and Elliott 1998; ASRD 2005; YTG 2006). This approach is used to halt caribou population declines by directly or indirectly reducing predation-related mortality, thereby allowing the population some time to recover. Specific measures include: penning cows and newborn calves (YTG 2006, n.d.; ASRD n.d.); predator lethal control or fertility control (Bergerud and Elliott 1998; Hayes et al. 2003); control of other prey species (ASRD 2005; Weclaw and Hudson 2004); line blocking to reduce predator movement and encounter rates (BCC n.d.); or a combination of these measures (Lessard et al. 2005; Wittmer et al. 2007).

This strategy has been implemented on a range-by-range basis. It requires a good understanding of caribou and alternative prey population dynamics, is very expensive to implement, and can create significant public concern. Although population persistence is most sensitive to adult female survival, management programs that focus on enhancing calf recruitment may be more practical and effective (Gaillard et al. 2000; Smith 2004). Line blocking is an unproven mitigation technique that is currently being evaluated, however modelling and monitoring results suggest that it is unlikely to be a practical range-scale solution (Neufeld 2006; McCutchen 2007).

In many respects, predator-prey management attempts to treat the clearest symptom, rather than the land use-induced cause of caribou decline (Lessard et al. 2005). However, this may be the only effective option to ensure woodland caribou persistence in ranges that have high predator or alternative prey densities, are highly disturbed, or consistently have unsustainable calf and adult mortality rates. In the absence of other range-scale measures, predator and/or alternative prey management should be formally evaluated for the SS Range.

4.4.2.2 Landscape Targets

Landscape management or performance targets are designed to limit the combined land use footprint and avoid adverse cumulative effects on population persistence. This strategy acknowledges that the influence of land use features persists over multiple years and much larger areas than their direct footprint (Dyer et al. 2001; Dzus 2001; Anderson et al. 2002; Adamczewski et al. 2003; Salmo et al. 2003, 2004; AEM 2004; MSRM 2004; MVEIRB 2004; Smith 2004; ASRD 2005). It also concedes that to sustain boreal caribou, industrial and non-commercial users will have to accept further access limitations or employ development techniques that are more expensive, riskier, and less convenient than standard industry practice (ASRD 2005).

The Fort Nelson LRMP (1997) acknowledges the regional and provincial importance of caribou populations and habitats, and suggests that populations will need to be managed in areas such as the Etsho Enhanced Resource Development RMZ which have an overall development management emphasis. Limiting landscape scale disturbance is the least cost approach for relatively undisturbed areas such as the Calendar Range (Culling et al. 2004), where intensive industrial activity has not yet occurred.

Resource selection models from the SS Range suggest that well or facility density and disturbed area (area <250 m from a land use feature) can reasonably be used as land use indices of adult female mortality risk in this area. The utility of the Alberta BCC equation combining burned and disturbed area is supported by the SS CE study as its variables were included in one of the two best caribou survival models for the SS Range. This equation predicts that caribou population decline is likely when more than 66% of the range is burned or more than 61% of the range is <250 m from a land use feature (S. Boutin, pers. comm.). These values are recommended as interim landscape targets for northeast British Columbia until range-specific responses are confirmed through ongoing monitoring of SS herd population dynamics.

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APPENDIX 1.

LAND USE METRICS IN CARIBOU HOME RANGES.

Home Range ID	Area (km^2)	Average total linear corridor density (km/km^2)	Area cleared (%)	Area within 250 m of a land use feature (%)	Area burned (%)
S1	687.6	3.1	3.1	78.1	20.3
S2	1,082.1	5.3	5.8	90.2	11.9
S3	2,839.2	4.9	5.2	89.0	8.6
S4 (mort)	1,875.5	5.1	5.2	91.6	3.9
S5	1,978.8	4.3	4.6	85.7	17.4
S6	3,137.0	4.1	4.3	80.9	24.9
S7	117.2	1.4	1.5	52.9	3.6
S8	862.2	3.3	3.2	74.7	15.9
S9	1,331.1	3.7	3.7	78.1	1.3
S10	593.4	3.6	3.6	82.3	3.1
S11	682.7	3.5	3.5	81.1	5.6
S12	135.9	1.5	1.5	55.3	3.8
S14	650.3	3.6	4.1	79.8	12.5
S15 (mort)	1,118.1	4.0	4.1	84.6	11.0
S16	1,845.0	5.4	5.4	93.5	23.1
S17	1,426.2	2.9	3.5	75.2	32.7
S18	3,591.9	4.2	4.5	85.7	13.3
S19	1,131.5	3.4	3.6	75.9	12.4
S21	1,656.3	3.9	4.0	80.0	10.5
S22 (mort)	276.5	3.3	3.3	79.5	1.3
S24	2,500.9	5.0	5.1	91.1	4..6
S26	118.6	3.6	3.3	85.2	0.0
S28	359.0	4.8	5.4	89.4	0.0
S29	3,975.4	4.5	4.6	89.1	17.5
S30	740.8	3.8	3.7	83.6	6.3
S31	834.5	3.3	3.0	71.1	12.6
S32 (mort)	208.0	5.4	5.7	91.4	0
S33	2,752.9	4.2	4.3	84.3	10.9
S35	2,507.4	3.8	4.0	78.7	11.5
S36	490.9	3.8	3.6	68.9	21.2
S37	1,869.0	4.3	4.3	82.8	6.7
S38	1,679.3	4.5	4.8	85.0	11.8
S39	1,375.7	3.2	3.5	74.3	30.9
S40	1,535.0	6.0	6.2	93.3	23.6
S41	1,181.7	4.9	5.2	84.1	10.2
S42	580.3	3.8	3.8	69.7	21.9
S43	1,553.3	4.0	4.4	87.3	14.4
S44	2,824.3	5.2	5.4	91.7	17.8
S45	1,405.6	4.0	4.3	85.0	18.8
S46	2,521.3	6.1	6.3	96.0	7.2
S47	1,996.7	3.8	3.9	77.4	10.9
S48	1,633.1	4.3	4.2	82.2	14.4
S49	1,418.8	4.3	4.5	85.3	16.3
S50	1,953.0	4.3	4.4	82.6	25.3
S51	1,760.0	5.5	5.6	91.5	23.7
S52	375.0	9.2	9.5	96.8	13.7
S53	781.2	3.6	3.4	75.3	17.9
S54	523.1	5.7	5.9	89.4	8.8
Avg	1,388.3			82.5	12.8

APPENDIX 2.

LAND USE METRICS IN WOLF HOME RANGES.

Area	Area (km^2)	Average total linear corridor density (km/km^2)	Area cleared (%)	Area within 250 m of a land use feature (%)	Area burned (%)
Clarke	772	8.3	9.9	94	12.0
Gunnel	2,201	4.9	5.0	86	9.2
Komie	242	5.9	6.3	94	0.0
Kotcho	3,860	3.9	4.2	79	21.0
Kyklo	2,834	5.0	4.9	87	3.3
Snake	1,283	2.5	3.8	70	22.5
Combined	1,014	4.5	4.8	83	13.2

APPENDIX 3.

CARIBOU USE COEFFICIENT ESTIMATES FOR A PRIORI HOME RANGE SCALE MODELS.

Caribou use coefficient estimates, model deviance, goodness-of-fit, and AIC for *a priori* models in the Snake-Sahtaneh boreal caribou range (significant values at P<0.05 bolded; best models shaded)

Model	β_1 (SE[1])	β_2 (SE)	β_3 (SE)	β_4 (SE)	β_5 (SE)	X^2, df[2]	Ĉ, df[3]	AIC_c[4]
HABBURN + WOODSPRC + LAKE1	**38.39 (20.18)**	**14.24* (4.72)**	19.95 (61.25)			**17.02, 3*** **	12.14, 8	102.3
HABBURN + WOODSPRC + SLOPE1	41.07 (22.68)	**16.36* (7.29)**	-1.31 (2.85)			**15.75, 3** **	7.24, 8	102.7
HABBURN + OPENSPRC + SLOPE1	14.01 (17.42)	-3.29 (3.37)	**3.98** (1.71)**			**10.91, 3***	8.75, 8	107.6
DISTURB + BURN + WOODSPRC + OPENSPRC + LAKE1	0.25 (3.78)	2.08 (3.14)	**16.25* (6.86)**	7.01 (0.29)	6.11 (88.63)	**14.83, 5***	12.71, 8	108.5
DISTURB + BURN + WOODSPRC + OPENSPRC + SLOPE1	-0.756 (3.43)	2.871 (2.98)	11.203 (7.43)	2.734 (4.61)	0.789 (2.85)	**13.29, 5***	10.70, 8	109.1
WOODSPRC	**10.82*** (3.40)**					**13.01, 1*** **	14.51, 8	109.9
HABBURN + OPENSPRC + LAKE1	18.997 (14.41)	-5.556 (3.37)	144.44 (87.32)			**9.05, 3***	8.75, 8	110.2
WELLDENS + SLOPE1	**-1018.31* (432.72)**	**4.301** (1.61)**				**15.29, 2*** **	13.22, 8	115.4
CUT + SLOPE1	431.45 (255.38)	**4.06* (1.54)**				**12.50, 2** **	11.04, 8	118.2
SLOPE1	**4.434** (1.57)**					**9.25, 1** **	7.11, 8	119.5
OPENSPRC	-4.20 (2.52)					2.88, 1	**28.49, 8** **	120.2
DISTURB + SLOPE1	2.23 (2.61)	**4.756** (1.63)**				**9.98, 2** **	3.54, 8	120.7
LOSS + SLOPE1	-6.05 (16.87)	**4.39** (1.58)**				**9.37, 2** **	4.99, 8	121.3

Model	β_1 (SE[1])	β_2 (SE)	β_3 (SE)	β_4 (SE)	β_5 (SE)	X^2, df[2]	Ĉ, df[3]	AIC_c[4]
CORRDENS + SLOPE1	-0.006 (0.18)	**4.43**** **(1.58)**				**9.25, 2****	7.65, 8	121.5
DISTURB + BURN + SLOPE1	1.92 (2.66)	-1.31 (1.86)	**4.89**** **(1.66)**			**10.49. 3***	10.08, 8	122.2
HABBURN	5.602 (13.479)					0.17, 1	7.91, 8	122.9
LAKE1	**134.76** **(78.73)**					**5.07, 1***	7.24, 8	124.8
DISTURB + BURN + LAKE1	3.527 (3.172)	-1.276 (1.959)	186.26 (96.57)			7.34, 3	7.52, 8	126.6
ROADDENS + CUT	-2.90 (1.49)	**780.39**** **(281.35)**				**10.22, 2****	10.31, 8	128.9
WELLDENS	**-1012.82*** **(413.24)**					**6.76, 1****	10.96, 8	130.3
FACLDENS	**-1454.62*** **(608.53)**					**6.59, 1***	5.29, 8	130.5
CUT	**528.71*** **(230.02)**					**6.18, 1***	10.05, 5	130.9
FACLDENS + CORRDENS	**-1785.50*** **(701.93)**	0.21 (0.20)				**7.78, 2***	**18.65, 8***	131.3
WELLDENS + CORRDENS	**-1138.58*** **(461.81)**	0.14 (0.18)				**7.32, 2***	**18.09, 8***	131.8
WELLDENS + SEISDENS	**-1122.77*** **(456.42)**	0.149 (0.22)				**7.25, 2***	13.80, 8	131.8
FACLDENS + ROADDENS	**-1632.94*** **(686.85)**	0.856 (1.47)				**6.94, 2***	6.05, 8	132.1
WELLDENS + ROADDENS	**-1123.08*** **(472.98)**	0.753 (1.44)				**7.04, 2***	9.77, 8	132.1
WELLDENS + BURN	**-1008.71*** **(414.50)**	-0.242 (1.848)				**6.78, 2***	14.51, 8	132.3

Model	β_1 (SE[1])	β_2 (SE)	β_3 (SE)	β_4 (SE)	β_5 (SE)	X^2, df[2]	Ĉ, df[3]	AIC_c[4]
BURN + CUT	-0.303 (1.759)	**526.22*** **(230.53)**				**6.21, 2***	10.61, 8	132.9
CORRDENS + LOSS	1.81 (1.06)	-180.62 (103.01)				3.45, 2	12.74, 8	135.6
ROADDENS	-0.78 (1.21)					0.42, 1	6.68, 8	136.7
DISTURB	0.98 (2.23)					0.19, 1	5.71, 8	136.9
LOSS	-6.74 (15.19)					0.20, 1	12.31, 8	136.9
BURN	-0.62 (1.71)					0.13, 1	**17.16, 8***	136.9
CORRDENS	-0.02 (0.12)					0.02, 1	9.91, 8	137.1
SEISDENS	-0.02 (0.19)					0.02, 1	7.87, 8	137.1
ROADDENS + LOSS	-2.034 (3.27)	17.031 (41.14)				0.59, 2	**13.53, 8***	138.5
BURN + LOSS	-0.727 (1.71)	-7.600 (15.37)				0.38, 2	10.38, 8	138.7
DISTURB + BURN	0.883 (2.25)	-0.523 (1.72)				0.29, 2	14.96, 8	138.8
BURN + CORRDENS	-0.658 (1.72)	-0.030 (0.16)				0.17, 2	4.39, 8	138.9

* P<0.05 ** P<0.01 *** P<0.001

1 SE: caribou use coefficient estimate

2 X^2, df: Pearson correlation coefficient with degrees of freedom

3 Ĉ, df: Hosmer and Lemeshow goodness-of-fit statistic with degrees of freedom

4 AIC_c: Akaike Information Criterion adjusted for small sample sizes

APPENDIX 4.

CARIBOU ADULT MORTALITY COEFFICIENT ESTIMATES FOR A PRIORI HOME RANGE SCALE MODELS.

Caribou adult survival coefficient estimates, model deviance, goodness-of-fit, and AIC for *a priori* models in the Snake-Sahtaneh boreal caribou range (significant values at P<0.05 bolded; best models shaded).

Model	β_1 (SE)	β_2 (SE)	β_3 (SE)	β_4 (SE)	β_5 (SE)	X^2, df	Ĉ, df	AIC_c
BURN	**20.32* (8.13)**					**6.24, 1***	4.90, 8	29.4
DISTURB + BURN	-10.18 (6.48)	**20.87* (8.44)**				**8.28, 2***	2.05, 8	29.4
WELLDENS + BURN	**-1843.01* (970.20)**	**20.83* (8.35)**				**6.86, 2***	6.89, 8	29.6
OPENSPRC	**20.35* (9.27)**					**4.81, 1***	7.09, 8	29.8
BURN + LOSS	**23.32* (9.82)**	-45.54 (27.77)				**6.12, 2***	4.16, 8	29.9
BURN + CORRDENS	**23.41* (9.82)**	-0.48 (0.29)				**6.14, 2***	4.22, 8	29.9
DISTURB + BURN + WOODSPRC + OPENSPRC + LAKE1	-10.62 (8.49)	28.51 (17.42)	21.61 (16.29)	39.86 (26.96)	-253.52 (199.66)	5.49, 5	8.76, 8	30.2
DISTURB + BURN + SLOPE1	**-10.78* (5.05)**	**17.32* (7.69)**	-3.48 (3.31)			**8.03, 3***	2.77, 8	30.3
DISTURB + BURN + LAKE1	**-15.91* (7.40)**	**15.74* (6.21)**	-122.83 (89.30)			**10.02, 3***	6.09, 8	30.4
WOODSPRC	-9.89 (5.48)					3.25, 1*	6.18, 8	30.7
BURN + CUT	**21.47* (8.93)**	-225.39 (500.51)				**5.79, 2***	1.71, 8	31.1
FACLDENS	**-2976.43** (1127.14)**					**6.97, 1****	4.89, 8	31.3
DISTURB + BURN + WOODSPRC +	-2.59 (5.68)	33.36 (26.48)	14.45 (19.63)	36.01 (36.81)	0.12 (13.25)	4.15, 5	8.09, 8	31.3

Model	β_1 (SE)	β_2 (SE)	β_3 (SE)	β_4 (SE)	β_5 (SE)	X^2, df	Ĉ, df	AIC_c
FACLDENS + CORRDENS	**-2865.26*** **(1252.23)**	-0.12 (0.43)				**7.54, 2***	5.43, 8	32.2
HABBURN + OPENSPRC + LAKE1	32.28 (40.38)	17.99 (9.66)	-99.47 (77.81)			4.84, 3	6.34, 8	32.4
DISTURB + SLOPE1	**-10.58*** **(4.95)**	-6.40 (4.03)				**6.02, 2***	4.03, 8	32.5
ROADDENS + LOSS	-16.46 (10.22)	-245.56 (146.19)				2.85, 2	12.39, 8	32.8
HOME RANGE AREA	0.01 (0.007)					2.37, 1	6.02, 8	32.9
FACLDENS + ROADDENS	**-3284.03*** **(1464.11)**	2.40 (4.42)				**6.95, 2***	6.81, 8	32.9
HABBURN	68.47 (40.34)					2.88, 1	4.28, 8	32.9
HABBURN + OPENSPRC + SLOPE1	26.70 (35.23)	18.71 (26.79)	0.54 (10.98)			4.94, 3	7.49, 8	33.2
DISTURB	-9.87 (6.14)					2.59, 1	7.26, 8	33.9
SLOPE1	-4.14 (2.63)					2.15, 1	6.54, 8	33.9
HABBURN + WOODSPRC + SLOPE1	28.09 (33.76)	-9.38 (8.08)	1.28 (4.69)			6.05, 3	5.43, 8	33.9
WELLDENS + SLOPE1	-1260.99 (872.35)	-5.02 (3.37)				2.78, 2	8.75, 8	34.4
HABBURN + WOODSPRC + LAKE1	30.50 (31.26)	-8.24 (6.05)	-1.81 (35.12)			5.79, 3	6.43, 8	34.4
LOSS + SLOPE1	-29.10 (27.23)	-4.84 (3.24)				2.57, 2	5.53, 8	34.9
CORRDENS + SLOPE1	-0.29 (0.28)	-4.84 (3.24)				2.53, 2	5.47, 8	34.9

Model	β_1 (SE)	β_2 (SE)	β_3 (SE)	β_4 (SE)	β_5 (SE)	X^2, df	$\hat{C}$, df	AIC_c
WELLDENS	-1124.47 (851.07)					1.75, 1	4.74, 8	34.9
SEISDENS	-0.39 (0.37)					1.12, 1	7.28, 8	35.2
LOSS	-28.62 (27.86)					1.05, 1	4.46, 8	35.4
CORRDENS	-0.29 (0.29)					1.04, 1	7.81, 8	35.4
LAKE1	-34.68 (35.19)					0.93, 1	10.80, 8	35.7
CUT + SLOPE1	5.30 (384.34)	-4.15 (2.83)				2.15, 2	6.56, 8	35.9
CUT	-36.81 (497.48)					0.01, 1	3.89, 6	36.1
ROADDENS	-0.19 (1.92)					0.01, 1	**13.61, 8***	36.1
WELLDENS + SEISDENS	-914.58 (882.22)	-0.22 (0.37)				1.69, 2	10.12, 8	36.7
WELLDENS + ROADDENS	-1309.27 (938.09)	1.26 (2.24)				1.95, 2	**16.68, 8***	36.7
WELLDENS + CORRDENS	-962.23 (883.78)	-0.14 (0.28)				1.71, 2	9.96, 8	36.8
CORRDENS + LOSS	0.52 (1.75)	-78.18 (174.69)				1.06, 2	8.59, 8	37.3
ROADDENS + CUT	-0.05 (3.49)	-31.99 (724.59)				0.01, 2	5.11, 8	38.1

* $P<0.05$ ** $P<0.01$ *** $P<0.001$

1 SE: adult caribou survival coefficient estimate

2 X^2, df: Pearson correlation coefficient with degrees of freedom

3 $\hat{C}$, df: Hosmer and Lemeshow goodness-of-fit statistic with degrees of freedom

4 AIC_c: Akaike Information Criterion adjusted for small sample sizes

APPENDIX 5.

CARIBOU NEONATE MORTALITY COEFFICIENT ESTIMATES FOR A PRIORI HOME RANGE SCALE MODELS.

Caribou 2002 neonate survival coefficient estimates, model deviance, goodness-of-fit, and AIC for *a priori* models in the Snake-Sahtaneh boreal caribou range (significant values at $P<0.05$ bolded; best models shaded).

Model	β_1 (SE)	β_2 (SE)	β_3 (SE)	β_4 (SE)	β_5 (SE)	X^2, df	$\hat{C}$, df	AIC
WELLDENS	-3518.82 (3324.91)					1.13, 1	11.11, 8	20.0
HABBURN	32.21 (26.88)					1.44, 1	6.69, 8	20.2
DISTURB + BURN	-15.62 (14.10)	-18.65 (11.82)				3.63, 2	6.97, 8	20.5
DISTURB + BURN + LAKE1	-29.71 (17.56)	-29.65 (18.59)	-517.82 (454.9)			3.29, 3	8.16, 8	20.7
HOME RANGE AREA	-0.01 (0.011)					0.76, 1	9.37, 8	20.7
BURN	-14.56 (13.88)					1.10, 1	6.89, 8	20.53
WELLDENS + BURN	-3228.48 (3400.64)	-12.63 (16.42)				2.81, 2	8.22, 8	21.0
FACLDENS	-3423.61 (3858.22)					0.79, 1	7.78, 8	21.0
DISTURB	-10.10 (9.36)					1.16, 1	7.96, 8	21.1
SLOPE1	6.28 (6.48)					0.94, 1	9.51, 8	21.1
OPENSPRC	-5.79 (9.48)					0.37, 1	9.98, 8	21.2
ROADDENS	-5.94 (5.62)					1.13, 1	10.44, 8	21.2
WOODSPRC	-0.005 (13.27)					0.001, 1	7.33, 8	21.4

Model	β_1 (SE)	β_2 (SE)	β_3 (SE)	β_4 (SE)	β_5 (SE)	X^2, df	Ĉ, df	AIC
WELLDENS + SLOPE1	-3036.93 (2948.32)	1.86 (6.47)				1.24, 2	12.11, 8	21.5
LOSS	-80.34 (97.15)					0.68, 1	10.27, 8	21.6
WELLDENS + ROADDENS	-2581.48 (2244.08)	-3.03 (4.59)				1.51, 2	8.89, 8	21.7
BURN + LOSS	-13.51 (13.52)	-79.49 (108.76)				2.79, 2	5.19, 8	21.8
BURN + CORRDENS	-14.35 (12.69)	-0.89 (1.15)				2.35, 2	6.54, 8	21.8
SEISDENS	-0.76 (1.07)					0.51, 1	8.24, 8	21.9
CORRDENS	-0.64 (0.86)					0.57, 1	10.48, 8	21.9
WELLDENS + CORRDENS	-2816.71 (1981.72)	-0.43 (0.79)				2.14, 2	8.37, 8	21.9
WELLDENS + SEISDENS	-2809.13 (1922.44)	-0.54 (1.05)				2.28, 2	8.29, 8	21.9
DISTURB + BURN + SLOPE1	-12.65 (15.04)	-17.21 (11.45)	2.39 (7.31)			3.48, 3	9.49, 8	22.2
CUT	-305.11 (596.71)					0.26, 1	4.03, 8	22.3
FACLDENS + ROADDENS	-2658.63 (3166.37)	-4.19 (4.25)				1.20, 1	10.45, 8	22.3
DISTURB + BURN + WOODSPRC + OPENSPRC + LAKE1	-62.36 (41.24)	-68.45 (43.44)	-7.88 (42.40)	-47.74 (47.94)	-1619.22 (869.38)	3.71, 5	5.36, 8	22.3
BURN + CUT	-13.72 (12.62)	-221.76 (567.27)				1.28, 2	6.92, 8	22.4
DISTURB + SLOPE1	-6.85 (8.81)	4.17 (5.79)				1.14, 2	9.11, 8	22.5

Model	β_1 (SE)	β_2 (SE)	β_3 (SE)	β_4 (SE)	β_5 (SE)	X^2, df	Ĉ, df	AIC
LOSS + SLOPE1	-58.49 (82.00)	5.37 (5.84)				1.12, 2	9.36, 8	22.5
FACLDENS + CORRDENS	-3159.34 (3317.74)	-0.61 (0.80)				0.91, 2	10.69, 8	22.5
LAKE1	5.04 (303.06)					0.01, 1	5.89, 8	22.5
CUT + SLOPE1	-482.46 (688.58)	7.68 (7.13)				1.26, 2	20.03, 8	22.6
CORRDENS + SLOPE1	-0.47 (0.73)	5.80 (5.96)				1.13, 2	11.84, 8	22.7
ROADDENS + LOSS	-10.13 (13.88)	74.60 (252.91)				1.54, 1	11.35, 8	23.0
ROADDENS + CUT	-7.29 (7.57)	316.07 (1004.10)				1.21, 1	11.95, 8	23.1
CORRDENS + LOSS	2.45 (3.06)	-302.06 (333.12)				0.90, 2	9.49, 8	23.1
HABBURN + OPENSPRC + SLOPE1	37.58 (31.59)	-10.88 (23.13)	-1.38 (15.66)			1.92, 3	6.55, 8	23.1
HABBURN + WOODSPRC + SLOPE1	48.40 (161.68)	12.15 (93.55)	-0.67 (38.01)			1.34, 3	8.85, 8	23.2
HABBURN + WOODSPRC + LAKE1	64.25 (46.25)	18.67 (18.35)	-215.53 (245.13)			2.24, 3	6.16, 8	23.3
HABBURN + OPENSPRC + LAKE1	45.97 (31.16)	-14.43 (12.43)	-210.37 (295.12)			2.27, 3	7.48, 8	23.9
DISTURB + BURN + WOODSPRC + OPENSPRC + SLOPE1	-0.23 (23.45)	-21.67 (16.66)	-26.92 (44.02)	-1.28 (22.54)	15.95 (22.04)	3.20, 5	10.91, 8	25.6

** P<0.05 ** P<0.01 *** P<0.001

1 SE: adult caribou survival coefficient estimate

2 X^2, df: Pearson correlation coefficient with degrees of freedom

[3] $\hat{C}$, df: Hosmer and Lemeshow goodness-of-fit statistic with degrees of freedom
[4] AIC_c: Akaike Information Criterion adjusted for small sample sizes

APPENDIX 6.

CARIBOU CALF MORTALITY COEFFICIENT ESTIMATES FOR A PRIORI HOME RANGE SCALE MODELS.

Caribou 2002 calf survival coefficient estimates, model deviance, goodness-of-fit, and AIC for *a priori* models in the Snake-Sahtaneh boreal caribou range (significant values at P<0.05 bolded; best models shaded).

Model	β_1 (SE)	β_2 (SE)	β_3 (SE)	β_4 (SE)	β_5 (SE)	X^2, df	$\hat{C}$, df	AIC
HABBURN	-1366.42 (809.97)					2.85, 1	4.24, 8	11.88
CUT	-1257.24 (878.59)					2.05, 1	6.17, 7	14.9
SLOPE1	-8.43 (5.26)					2.57, 1	9.71, 8	15.4
LAKE1	-555.07 (668.89)					0.69, 1	7.08, 8	15.8
OPENSPRC	3.29 (6.13)					0.29, 1	11.24, 8	16.0
WOODSPRC	-1.81 (11.82)					0.02, 1	11.39, 8	16.1
WELLDENS	-1323.31 (2590.08)					0.26, 1	8.61, 8	16.2
CUT + SLOPE1	-1195.52 (1027.11)	-7.11 (5.85)				3.08, 2	5.93, 8	16.2
DISTURB	6.56 (8.38)					0.61, 1	7.88, 8	16.3
HOME RANGE AREA	-0.002 (0.01)					0.04, 1	12.34, 8	16.4
FACLDENS	1561.31 (3751.42)					0.17, 1	9.71, 8	16.4
WELLDENS + SLOPE1	-2991.42 (3912.36)	-12.72 (7.64)				2.90, 2	5.68, 8	16.4
SEISDENS	0.12 (1.12)					0.01, 1	7.94, 8	16.5

Model	β_1 (SE)	β_2 (SE)	β_3 (SE)	β_4 (SE)	β_5 (SE)	X^2, df	Ĉ, df	AIC
CORRDENS	0.10 (0.83)					0.02, 1	7.95, 8	16.5
ROADDENS	-0.97 (4.02)					0.06, 1	7.85, 8	16.5
LOSS	-4.66 (98.31)					0.01, 1	7.85, 8	16.6
DISTURB + SLOPE1	11.35 (15.76)	-11.23 (10.39)				1.20, 2	10.47, 8	16.9
LOSS + SLOPE1	0.53 (126.51)	-8.44 (6.21)				2.70, 1	9.70, 8	17.4
CORRDENS + SLOPE1	0.23 (1.06)	-8.99 (6.99)				2.28, 1	5.26, 8	17.4
CORRDENS + LOSS	3.75 (3.62)	-348.62 393.06)				1.98, 1	13.11, 8	18.0 n
WELLDENS + CORRDENS	-1606.14 (2694.18)	0.25 (0.54)				1.32, 2	8.85, 8	18.1
WELLDENS + SEISDENS	-1605.14 (2525.32)	0.31 (0.79)				1.55, 1	8.79, 8	18.2
FACLDENS + ROADDENS	1531.09 (3585.20)					1.06, 1	13.67, 8	18.3
FACLDENS + CORRDENS	1782.77 (5189.32)	0.21 (1.23)				0.26, 1	11.19, 8	18.3
ROADDENS + LOSS	-5.68 (17.86)	82.85 (362.54)				0.50, 2	7.65, 8	18.4
ROADDENS + CUT	**12.26* (8.52)**	**-2717.83 (1249.12)**				**5.99, 1***	2.46, 8	18.6

* P<0.05 ** P<0.01 *** P<0.001

1 SE: adult caribou survival coefficient estimate

2 X^2, df: Pearson correlation coefficient with degrees of freedom

3 Ĉ, df: Hosmer and Lemeshow goodness-of-fit statistic with degrees of freedom

4 AIC_c: Akaike Information Criterion adjusted for small sample sizes