University of Alberta

Movement and distribution of woodland caribou (*Rangifer tarandus caribou*) in response to industrial development in northeastern Alberta

by

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Abstract

Rapid encroachment on woodland caribou (*Rangifer tarandus caribou*) habitat by resource extraction industries (oil, gas, forestry and peat) is occurring throughout northern Alberta. The effect of this human development on the movement and distribution of endangered woodland caribou remains poorly understood. Thirty-six woodland caribou were captured and fitted with Global Positioning System (GPS) collars. These yielded 43,415 locations during the 12 month study period. I tested the null hypothesis that woodland caribou use areas adjacent to wellsites, roads and seismic lines as often as they use areas away from these disturbances. Analyses were performed on caribou locations, controlling for vegetation cover classes to remove confounding effects of habitat, and grouped to examine seasonal variation in distribution. Caribou avoided human developments in the study; the level of avoidance appeared to be related to the level of human activity in the study area. Maximum avoidance distances of 1000 m (wells) and 250 m (roads and seismic lines) were recorded. My second null hypothesis was that roads and seismic lines did not act as barriers to caribou movements. I compared the crossing rates of roads and seismic lines to the rate at which caribou crossed lines of a similar density created with an ArcInfo GIS. Seismic lines were not barriers to caribou movements, while roads acted as semi-permeable barriers to caribou movements throughout the study period. Cumulative effects of these anthropogenic disturbances are discussed with respect to functional habitat loss, and I present management strategies to balance caribou conservation with resource extraction in northern Alberta.

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Chapter 1. General Introduction

1.1 Background and Rationale

Woodland caribou (*Rangifer tarandus caribou*) have suffered a large range reduction since European settlement of North America (Edmonds 1991). A combination of human settlement, industrial and agricultural encroachment and overhunting has caused a shrinkage in caribou distribution throughout the United States of America and in Canada along the southern boreal forest fringe (Bergerud 1974). Edmonds (1988) states woodland caribou populations in Alberta have declined during this century, although it has been argued that estimates supporting this decline originated primarily from anecdotal information and misinterpretation (Bradshaw and Hebert 1996).

Concern about woodland caribou numbers resulted in closure of provincial recreational hunting in 1981 and led to their classification as threatened in Alberta (General Wildlife Regulation 1994). This classification has led to government regulations concerning industrial activity in woodland caribou habitat (Alberta Department of Energy 1991). The effect of human developments on the movement and distribution of woodland caribou remains poorly understood, and the biological basis of these regulations is challenged by some industrial companies operating in caribou habitat zones. Woodland caribou populations in northeastern Alberta appear to be stable or slightly declining (Fuller and Keith 1981; Stuart-Smith *et al.* 1997) and there is concern that small changes in population dynamics as a result of industrial development may have significant consequences to the long-term viability of caribou populations in Alberta.

Government guidelines stipulate that "petroleum and natural gas exploration and development activities can occur on caribou range, provided the integrity of the habitat is maintained to support its use by caribou" (Alberta Department of Energy 1991). This thesis examines the movement and distribution of woodland caribou in response to recent petroleum development in northeastern Alberta.

1.2 Thesis Overview

This thesis is organized into five main chapters. This general introduction (Chapter 1) is followed by an extensive review of the literature regarding human activity and its effect on caribou (Chapter 2). Chapter 3 examines the distribution of woodland caribou in response to industrial development, in order to address the following questions:

1. Do caribou avoid roads, wells and seismic lines in the study area?
2. Does avoidance response vary in response to different levels of industrial activity?
3. Do caribou show a waning in avoidance response over time?

Chapter 4 examines whether linear developments act as barriers to caribou movements. I employed a novel GIS technique to address the following questions:

1. Do roads and seismic lines act as barriers to caribou movements?
2. Do barrier effects vary in response to different levels of industrial activity?
3. Do the barrier effects of linear features wane over time?

Data chapters (3 and 4) are written in manuscript style, so there is some redundancy in describing the study area and the methods that I employed. Chapter 5 presents general conclusions and management implications of this study and discusses strategies required to balance caribou conservation with resource extraction in northeastern Alberta.

1.3 Natural History of Woodland Caribou in Alberta

All caribou in Alberta are woodland caribou, *Rangifer tarandus caribou* (Banfield 1961). Two ecotypes of woodland caribou are found in Alberta; the mountain ecotype and the boreal ecotype (Edmonds 1986). The mountain ecotype undergo migrations between their winter range of forested foothills in west-central Alberta and their summer range in the Rocky Mountains. The boreal ecotype, in contrast, remain in forested habitats throughout the year (Edmonds 1986). My study concerns the boreal ecotype. Boreal woodland caribou in Alberta live in small groups in the boreal forest (Fuller and Keith 1981; Edmonds 1988). A number of studies have shown woodland caribou favour lowland habitats across their boreal forest range (Fuller and Keith 1981; Darby and Pruitt 1984; Schaefer and Pruitt 1991; Bradshaw *et al.* 1995). Selection is hierarchical, however (Johnson 1980) and the exact determination may vary at different spatial scales. Bradshaw *et al.* (1995) found woodland caribou feeding sites throughout northeastern Alberta were found more frequently in forested bogs with 85-100% peatland coverage.

Densities of woodland caribou in northeastern Alberta have been reported as 5.5 caribou per 100 km^2 (Stuart-Smith *et al.* 1997). This is comparable with other density measurements in Alberta, such as 3 caribou per 100 km^2 in the Birch Mountains of northeastern Alberta (Fuller and Keith 1981), and 1-8 caribou per 100 km^2 in mountainous western Alberta (Bjorge 1984; Edmonds 1988). Caribou rarely produce more than one calf per cow (McDonald and Martell 1981; Godkin 1986), and this, combined with the fact that females are often 2½ before first breeding (McDonald and Martell 1981; Godkin 1986), accounts for their relatively low reproductive rate. In order to maintain populations at constant levels, low recruitment must be matched by low mortality rates. The low productivity of woodland caribou populations makes them vulnerable to losses from many types of direct mortality such as parasites, diseases, accidents, hunting and predation (Cumming 1992).

Woodland caribou display a number of strategies to reduce predation. Caribou can migrate to alpine areas to reduce exposure to predators (Bergerud *et al.* 1984; Seip 1992), use islands and shorelines as escape habitat for calving (Bergerud 1985, Cumming and Beange 1987; Bergerud *et al.* 1990) and utilize forest wetland habitat (Paré and Huot 1985; Brown *et al.* 1986). Where distinct geographical refuges are not available, woodland caribou reduce predation during calving by dispersing over the landscape (Bergerud 1992). Any process which fragments the landscape, restricts the movement of caribou, and makes them more predictable in space and time has the potential to make caribou more vulnerable to direct mortality losses (Seip 1991).

1.4 Description of the Study Area

The study area consists of approximately 6,000 km^2 of boreal mixedwood and peatland vegetation in northeastern Alberta, Canada (Figure 1-1, centre 56° N, 113° W) (Strong and Leggat 1992), located on the southwest corner of the Athabasca oil sands deposits (Crandall and Prime 1998). There is minimal topographic variation within the study site, with elevation varying between 500 and 700 m above sea level. Lowland vegetation includes black spruce (*Picea mariana*) and black spruce – tamarack (*Larix laricina*) bogs and fens. Upland areas are dominated by trembling aspen (*Populus tremuloides*), white spruce (*Picea glauca*), jack pine (*Pinus banksiana*) and black spruce.

The light bitumen reserves that underlay the study area are attractive to heavy oil producers (Crandall and Prime 1998). Bitumen production in the study area has increased rapidly from 1,300 barrels per day (B/D) during the first half of 1992 to 31,000 B/D during the first half of 1998. There is the potential for production to expand to 100,000 to 120,000 B/D by 2002 (Crandall and Prime 1998).

1.5 The Boreal Caribou Research Program

Concern about the effect of industrial development on woodland caribou escalated until the winter of 1990-91, when the provincial government implemented land-use guidelines for industrial activity occurring on caribou range. These guidelines were designed to minimize the risk of exposure of caribou to industrial disturbance, address concerns regarding public access and minimize caribou habitat loss. The Northeast Region Standing Committee on Woodland Caribou (NERSC) was formed in 1991 to develop a cooperative approach to the integration of caribou conservation and resource development (Edey *et al.* 1998).

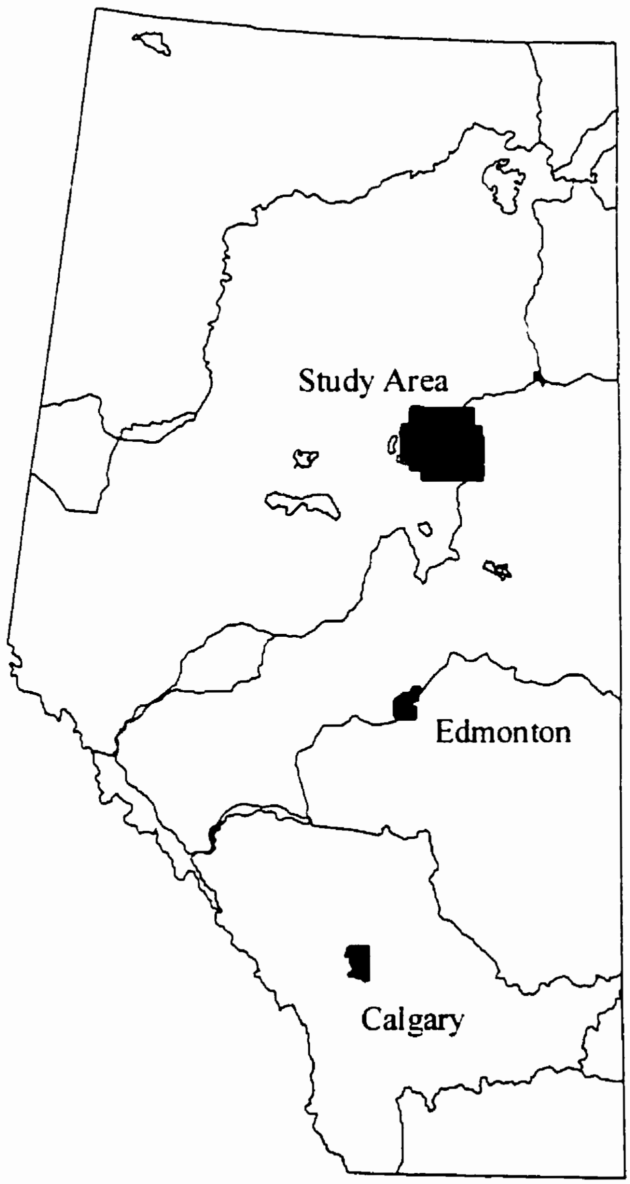

Figure 1-1. Location of the study area in Alberta

The research sub-committees of the Northeast and Northwest Regional Standing Committees on Caribou merged in 1996 to form the Boreal Caribou Research Program (BCRP). Founding NERSC participants included numerous energy and utility companies, a forestry company and representatives from Alberta Environmental Protection, Alberta Energy – Minerals Division and Alberta Energy and Utilities Board. The BCRP now includes many additional resource-based companies and representatives of First Nations and the University of Alberta.

1.6 Introduction to Global Positioning System (GPS) Technology

Very High Frequency (VHF) radio transmitters have been used to track animal movements for over 30 years (Rodgers *et al.* 1996). Use of aircraft for radio tracking is an effective method for tracking animals in inaccessible areas (White and Garrot 1990), but if animals are not visually located, errors in excess of 0.5 km may result (Garrot *et al.* 1987). Numerous factors may be responsible for these errors, including location procedures, altitude above the ground, air speed, observer fatigue or motion sickness (Gilmer *et al.* 1981; Mech 1983). Despite the lack of precision with traditional telemetry, many biologists do not report error estimates in their research (Saltz 1994). Traditional VHF telemetry has been used successfully in the study area to answer many questions about woodland caribou habitat use and demography (Bradshaw *et al.* 1995; Stuart-Smith *et al.* 1997), but a technique capable of collecting many accurate locations in a relatively short time is necessary to effectively record caribou movement trajectories and examine potentially subtle changes in caribou habitat use in response to human developments.

In this study I used Global Postioning System (GPS) collars (Lotek Engineering Systems, Newmarket, Ontario) to monitor caribou locations in response to industrial development in northeastern Alberta. The NAVSTAR Global Positioning System (NAVSTAR GPS) was initiated by the United States Department of Defense in 1973 and consists of a constellation of 24 navigation satellites situated 20,000 km above the Earth (Environment Canada 1993). Differentially corrected GPS locations have an error of less than 10 m (Wells *et al.* 1986), which provides location estimates that are more accurate than any other animal tracking system (Rempel *et al.* 1995; Moen *et al.* 1997; Rempel and Rodgers 1997). GPS telemetry is also capable of yielding many locations over time, and more systematic locations and fixes during night and in poor weather conditions (Rumble and Lindzey 1997).

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Chapter 2. Human activity and caribou: a literature review

2.1 Introduction

A large body of literature exists regarding the influence of human activity on caribou. The majority of these studies have dealt with migratory barren-ground caribou (*Rangifer tarandus granti)* and semi-domesticated reindeer (*Rangifer tarandus tarandus)*. In assessing the consequences of human activity on caribou, it is possible to draw many contradictory conclusions from the literature. These contradictions may result from extrapolating behavioural observations of individuals to effects on populations and from the use of correlational reasoning rather than rigorous hypothesis testing to explain disturbance phenomena (Bergerud *et al.* 1984). Nevertheless, human activity has been shown to affect caribou demography through direct increases in mortality, while developments may cause displacement of caribou, act as barriers to movement and have energetic consequences through harassment and disturbance. I will consider each of these potential effects in turn. Although they are often considered in isolation, the different consequences of human developments on caribou may occur concurrently.

2.2 Potential effects of human developments on caribou

2.2.1 Direct increases in caribou mortality

Woodland caribou mortalities as a result of human developments are well documented. Caribou mortalities due to vehicle collisions can occur when roads intersect caribou range (Brown and Ross 1994; Anonymous 1995; Edmonds and Hobson 1995,). Human access into previously remote areas can cause significant hunting mortality to caribou populations (Bergerud *et al.* 1984; Johnson 1985; Harrington 1996; Seip and Cichowski 1996). The effects of human activity on caribou-predator relationships are more controversial, but may be equally important to woodland caribou demography (Bergerud 1974). Many studies report wolves, *Canis lupus*, as important predators of caribou (Gasaway *et al.* 1983; Fuller and Keith 1980; Bergerud 1978), and wolf predation has been implicated as an important factor in caribou declines throughout North America (Bergerud 1974). Roads (Thurber *et al.* 1994), seismic lines (Horejsi 1979), and snowmobile trails (Edmonds and Bloomfield 1984) may provide easy travel corridors for wolves. Spatially explicit predator models predict that this will increase encounter rates between wolves and caribou (McCauley *et al.* 1993). Increased wolf predation may be related to expansion of moose into caribou habitat (Bergerud 1974; Seip 1990), which provides an alternative prey for wolves and sustains high wolf numbers (Seip 1991). Human habitat modification through forest harvesting may exacerbate the problem by enhancing moose populations (Cumming 1992; Seip 1992).

2.2.2 Displacement and avoidance effects

Barren-ground caribou have been shown to avoid roads with regular traffic around the Prudhoe Bay complex in Alaska (Smith and Cameron 1983, Dau and Cameron 1986, Murphy and Curatolo 1987), while Mercer *et al.* (1985) found that centres of caribou activity were "maximum distances" possible from roads in Newfoundland. They attributed this distribution to a combination of hunting and disturbance associated with transportation corridors. Nelleman and Cameron (1998) demonstrated caribou density in the Kuparuk Development Area in Alaska was inversely related to road density. Road densities of >0.6-0.9 km/km^2 resulted in declines in caribou density of 86% and virtually excluded cow-calf pairs. The authors cautioned that exclusion from preferred rugged areas could result in increased competition for forage, increased risk of predation and lower productivity. A number of authors also argue that caribou displaced from critical areas, such as late-winter foraging zones, may be susceptible to increased predation (Geist 1978, Whitten *et al.* 1992).

Other types of direct habitat loss and disturbance may cause displacement in caribou. Clearcutting in Ontario and Newfoundland resulted in displacement of woodland caribou from cut areas (Darby and Duquette 1986; Chubbs *et al.* 1992), while abandonment of areas frequented by snowmobiles has been documented (Simpson 1987).

It has also been argued that linear developments may enhance caribou habitat (Cronin *et al.* 1994). Incidental sightings of caribou tracks along pipeline right-of-ways indicated that they were used as a spring and summer forage source, and as a movement corridor in winter (Eccles *et al* 1985; Eccles and Duncan 1986). A 'dust shadow' effect (Cronin *et al.* 1994) has been observed in oilfield development areas in Alaska, whereby dust alongside roads causes earlier snowmelt and green-up of vegetation. Caribou feeding in these areas may enhance nutritional intake before calving (Lawhead and Cameron 1988).

Despite concerns, demographic effects have generally not been observed as a result of avoidance and displacement (Smith and Cameron 1983; Mercer *et al.* 1984; Dau and Cameron 1986; Murphy and Curatolo 1987). Migratory herds in Alaska have increased in size despite rapid petroleum development in parts of their traditional range (Cronin *et al.* 1998), emphasizing the importance of confounding factors such as range condition to caribou demographics.

2.2.3 Energetic consequences of disturbance

Thirty years of research into the energetic consequences of human disturbance on caribou has resulted in a voluminous quantity of information that attempts to address the potential impact of disturbance and harassment on caribou. Disturbance from a variety of human activities has been examined, including aircraft (Calef *et al.* 1976; Miller and Gunn 1979; Valkenberg and Davis 1985; Harrington and Veitch 1991;1992), roads and vehicles (Roby 1978; Horejsi 1981; Mercer *et al.* 1985; Dau and Cameron 1986), snowmobiles (Tyler 1991) and simulated petroleum development (Bradshaw *et al.* 1997).

Studies that attempt to identify the energetic costs of disturbance assume that any harassment costs are additive to the energy budget of caribou, and that caribou are unable to compensate for increased energy costs associated with disturbance by increasing forage intake. Although ungulates recovering from nutritional stress may display higher levels of forage consumption (Robbins *et al.* 1981), this assumption appears to be well-founded, since winter weight loss in northern ungulates is well documented (Renecker and Hudson 1993).

Winter weight loss of 10-15% of autumn weight has been recorded in caribou (Steen 1968; Skoog 1968: Dauphine 1976); even reindeer fed lichens *ad libitum* lose weight during winter (Holleman *et al.* 1979). It appears that the dual constraints of rumination time (Robbins 1983) and poor forage quality (Arnold 1985) may prevent compensatory feeding. Bergerud (1974). studying Newfoundland woodland caribou for five years, described winter weight loss of 8-26% in overwintering animals. The 26% weight loss occurred during a winter of extreme snow accumulation. and females produced the smallest calves that year. Jabobsen and Skjenneberg (1975) reported that winter weight loss of 20% in reindeer was not uncommon. Weight loss above 'normal' values could cause embryonic absorption (Zhigunov 1961) or premature birth. although such problems are thought to be uncommon (Cameron *et al.* 1993).

It has been hypothesized that caribou are most vulnerable to disturbance during winter (Bradshaw *et al.* 1997). Many of the physiological and behavioural adaptations to winter displayed by woodland caribou may intensify the potential threat of industrial disturbance. Caribou arrest all growth during the winter months. reducing their metabolic rate by up to 30% (Segal 1962; McEwan 1968: McEwan and Whitehead 1970: Dauphine 1976). Woodland caribou movement rates also decline during late winter (BCRP unpublished data), possibly since increasing snow cover makes movement more energetically costly (Parker *et al.* 1984; Fancy and White 1987). Woodland caribou are well-adapted to locomotion in snow and have large splayed hooves that confer low foot loading values (defined as body weight divided by total foot area contacting the snow) (Kelsall and Telfer 1971). Among ungulates, only the musk deer (*Moschus moschiferus*) has a lower foot loading than the caribou. Despite this adaptation, energetic costs of locomotion for caribou walking in uncrusted snow increase exponentially with increased snow depth (Fancy and White 1987).

Calorific costs of pregnancy also increase exponentially during gestation in ungulates, and reach their highest levels immediately prior to parturition (Robbins 1983). Adamczewski *et al.* (1993) found that gestation costs represented 12-14% of energetic maintenance costs by late winter. Winter also represents the period of peak industrial activity in caribou habitat in Alberta, thus caribou are likely to experience more potentially disturbing encounters at this time.

Animals that have evolved as prey of other animals exhibit predator-avoidance behaviours to prevent being preyed upon (Shalter 1984). Thus, novel objects perceived as predators, such as vehicular traffic, aircraft, roads and oilfield infrastructure may elicit disturbance responses in caribou. This may have consequences to caribou demographics if harassment is severe enough to affect caribou body condition. Energetic demands associated with human disturbance may be addititive, thus winter harassment could reduce an individual's ability to grow and reproduce next spring (Geist 1971).

Caribou generally exhibit signs of anxiety and fear when encountering fast-moving vehicles (Horesji 1981). Horesji (1981) described the behaviour of barren-ground caribou encountering a pick-up truck as a 'limited flight response'. He found female caribou responded to an approaching vehicle by fleeing for a mean of 73 seconds. Bergerud (1974) reported mean flight distances of 81 m and 165 m for females without calves and females with calves respectively, responding to the presence of a man on foot. Miller and Gunn (1979) reported the locomotory response of Peary caribou subjected to helicopter overflights rarely exceeded 500m. A similar displacement was estimated by Bergerud (1963) in response to fixed-wing aircraft overflights. A combination of vehicle traffic and physical barriers elicited increased energy expenditures in caribou (Murphy and Curatolo 1987), while in contrast, Fancy (1983) found caribou near two active drilling sites had similar movement rates and activity budgets to caribou at controlled sites. Low-level jet overflights have been shown to cause disturbance responses in woodland caribou (Harrington and Veitch 1991). Long-term studies on the same population showed it failed to grow between 1972 and 1987, despite a complete hunting ban (Harrington and Veitch 1992), while a neighbouring control population not subjected to overflights more than doubled in size during the same period.

Caribou close to oilfield disturbances in Alaska spent less time lying and increased locomotion relative to control individuals (Murphy and Curatolo 1987). The authors reported that caribou moved faster and spent more time running near a road with moderate traffic (15 vehicles per hour) than at control sites with little traffic (less than one vehicle per hour), although no differences in activity budgets were evident when insect harassment by mosquitoes was high. Murphy and Curatolo (1987) argued that increased activity as a result of disturbance could contribute to energetic stress, but cautioned these energetic costs may be small since calving caribou distance themselves from these reactive zones.

Cow/calf pairs have been shown to respond to lower levels of disturbance than bulls and calfless cows (Calef *et al.* 1976; Kuck *et al.* 1985; Murphy and Curatolo 1987). Bergerud *et al.* (1984) argue that the difference in response by bulls and cows with calves is ultimately due to the differing parental investments associated with a polygynous breeding system. Because of these differences, females should be more likely to select predator-free habitats than males, and be more sensitive to anthropogenic disturbances. Calf locomotion costs may be higher than those of adult caribou (Luick and White 1980), and increased movement rates caused by disturbance may be detrimental to calf growth (Kuck *et al.* 1985).

Cronin *et al.* (1994), in a review of the effects of oil field development on caribou, argue that caribou should readily habituate to the visual presence of sedentary oil field structures, with their associated sounds and odours, and this assertion is supported to a limited extent by other studies in Alaska (Roby 1978; Curatalo and Murphy 1986; Murphy 1988). Motion, however, appears to be a major elicitor of alarm reactions and flight in caribou (Roby 1978), and evidence of habituation is extremely fragmentary. Higher levels of aircraft overflights (Valkenburg and Davis 1985); vehicular traffic (Roby 1978) and snowmobile harassment (Tyler 1991) all caused weaker alarm responses in caribou and reindeer than in populations that had been subjected to lower levels of harassment. Direct approaches by moving objects elicit a greater response in caribou than right-angle or tangential motion (Horejsi 1981; Tyler 1991). In conclusion, it appears that caribou are likely to habituate very slowly and incompletely to vehicular traffic, since vehicles represent potential predators and are highly unpredictable in time and space (Cronin *et al.* 1994).

Although the responses of individual caribou to human developments are well documented, it has been difficult to establish a relationship between human harassment and decreased reproduction in ungulates. Experimental harassment of red deer (*Cervus elaphus*) in New Zealand resulted in slower growth and declines in reproduction (Batcheler 1968), while female mule deer (*Odocoileus hemionus*) harassed with an All-Terrain Vehicle (ATV) displayed lower reproduction than a control group not subjected to harassment (Yarmoloy *et al.* 1988).

There is a direct relationship between pregnancy rate and autumn body condition (Dauphiné 1976; Reimers 1983; Allaye-Chan 1991; Cameron *et al.* 1993) and substantial evidence suggests caribou calf survival is dependent on maternal nutrient uptake and body condition during late pregnancy (Dauphiné 1976; Adamczewski *et al.* 1987 Cameron *et al.* 1993). Numerous studies indicate birth weights of caribou calves are correlated with female forage intake (Varo and Varo 1971; Bergerud 1974; Espmark 1980; Rognmo *et al.* 1983; Skogland 1984; Eloranta and Nieminen 1986). This is important, since small calves have lower survival rates than larger calves (Haukioja and Salovaara 1978; Rognmo *et al.* 1983).

The distinction between conceiving a foetus and early calf survival may be obscured by carryover effects between seasons (Cameron and Ver Hoef 1994). Winter malnutrition may affect the ability of caribou to gain mass in summer, while malnutrition in summer may exacerbate overwinter weight loss. If female caribou are repeatedly unable to compensate for the metabolic costs of gestation and lactation, there may be a cumulative deterioration of body condition that results in a breeding pause (Dauphine 1976; Reimers 1983; Cameron 1994). Periodic infertility is thought to be common in many ungulates (Clutton-Brock et al. 1982; Bowyer 1991; Rachlow and Bowyer 1991), and may have significant adaptive value. A mechanism that prevents ovulation when maternal reserves are low prevents wasted reproductive effort and increases the likelihood of a successful neonate the following year (Cameron 1994).

2.2.4 Human developments as barriers to caribou movement

The majority of studies addressing potential barriers to caribou movements concern short-term responses of migratory barren-ground caribou to human structures. Many anecdotal accounts and descriptive studies have attempted to assess the effects of human developments as barriers to caribou movements (Miller *et al.* 1971; Roby 1978; Johnson and Todd 1977; Klein *et al.* 1980; Whitten and Cameron 1983; Bergerud *et al.* 1984) . Roads and railways have been implicated in causing abandonment of traditional migration routes by reindeer in Eurasia (Klein 1971; 1980), although Bergerud *et al.* (1984) challenges the assertion that these developments are barriers, arguing instead that range reductions due to population decline are responsible for these observations.

Controlled experiments that rigorously test hypotheses are less common. Curatolo and Murphy (1986) reported that caribou in Alaska crossed roads and pipelines as frequently as control sites without these developments. Presence of the Trans-Alaska Pipeline did not appear to affect the traditional migration of the Nelchina caribou herd (Carruthers and Jakimchuk 1987). However, where a pipeline paralleled a road with traffic, crossing frequencies were significantly less than expected (Curatolo and Murphy 1986). The authors postulated that roads and pipelines act in a synergistic fashion.

2.3 Conclusions

To be of significance to wildlife managers, behavioural responses to disturbance must have demonstrable demographic consequences (Shank 1979). However, demographic responses to disturbance are rarely reported. Many authors tend to generalize about demographic effects based on dubious cause-and-effect reasoning which may confound our understanding of caribou behaviour and demography (Bergerud *et al.* 1984).

Despite the controversy, there is ample evidence that human activities cause behavioural changes in caribou, and it seems reasonable to assume that under certain circumstances, human-induced disturbances may adversely affect caribou populations.

Numerous factors may contribute to the degree of response to human activities displayed by caribou, including the type of disturbance, the frequency of disturbance (Roby 1978; Valkenberg & Davis 1985; Tyler 1991), the physical condition (Skogland & Grovan 1988), sex (Horejsi 1981) and reproductive condition (Maier *et al.* 1998) of the disturbed animal, and effects of vegetation and topography (Lyon 1979). Disagreements about the relative importance of human activities to caribou behaviour and demography appear to stem from these differences.

Consequences of these disturbances to caribou populations are still unclear. Undoubtedly, woodland caribou have declined in the face of human encroachment throughout their southern ranges (Bergerud 1974) and arguing over mutually exclusive hypotheses about the causes of these declines may be oversimplistic (Bloomfield 1979). Rigorous hypothesis testing to determine disturbance responses may be scientifically desirable, but there are also major logistical and ethical constraints to research of this type. Geist (1971) argued "Would one wish to compile hard, fast and irrefutable data by testing how far 100 caribou females have to be run in April before they all abort, collapse or die of emphysema?".

Long term population monitoring may provide clues to the importance of industrial development to woodland caribou demographics, but even so, attempts to link changes in woodland caribou populations to disturbance relating from human activity on the landscape will be tenuous. I argue that it is more reasonable to accept uncertainty and focus on quantifying the magnitude of behavioural responses to human activity. All organisms have evolved to deal with a certain level of disturbance (Noss 1996), but when the magnitude of this change exceeds the range of the usual experience of an organism, wildlife managers may be justified in intervening.

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Chapter 3. Distribution of woodland caribou in response to industrial development in northeastern Alberta

3.1 Introduction

Woodland caribou (*Rangifer tarandus caribou*) have suffered a large range reduction since European settlement of North America (Edmonds 1991). A combination of human settlement, industrial and agricultural encroachment and overhunting have caused shrinkage in caribou distribution throughout the United States of America and in Canada along the southern boreal forest fringe, westwards to the Rocky Mountains (Bergerud 1974). Woodland caribou are considered endangered in Alberta (General Wildlife Regulation 1994), and recent rapid petroleum and forestry developments in northern Alberta has raised concern about the effects of industrial activity on woodland caribou.

Many studies have dealt with the impacts of oilfield development on barren-ground caribou (*Rangifer tarandus granti*) in the Arctic (e.g., Cameron *et al.* 1979; Horejsi 1981; Fancy 1983; Smith and Cameron 1983; Curatolo and Murphy 1986; Murphy and Curatolo 1987; Cameron *et al.* 1992, 1995; Nelleman and Cameron 1996, 1998). The response of woodland caribou to infrastructure associated with industrial development has not been reported.

Human encroachment into caribou habitat has many demographic and behavioural consequences, including direct mortality from vehicle collisions and poaching (Johnson 1985; Brown and Ross 1994), changes in predator-prey relationships (Horejsi 1979; Edmonds and Bloomfield 1984), energetic costs associated with disturbance (Murphy and Curatolo 1987; Bradshaw 1998), barrier effects (Curatolo and Murphy 1986) and displacement and avoidance (Whitten and Cameron 1983; Cameron *et al.* 1992; Nelleman and Cameron 1996,1998). Direct loss of habitat occurs when developments such as roads, wells and seismic lines occur in woodland caribou habitat. However, this 'footprint' may be insignificant relative to the functional habitat loss as a result of avoidance (Jalkotzy *et* *al.* 1997). Woodland caribou live in forested habitats quite different to the barren tundra of Alaska, where the shielding effects of vegetation may be expected to mitigate disturbance effects associated with industrial development. Declines in use by elk of habitat adjacent to roads have been reported in a number of studies (Rost and Bailey 1974; Rost and Bailey 1979; Lyon 1979). The area of avoidance has been shown to vary with amount of traffic, road quality and density of cover near the road (Lyon 1979).

I examined whether caribou avoid infrastructure associated with natural resource exploration and industrial development (roads, wellsites and seismic lines). I examined variation in avoidance response over time and quantified avoidance in terms of functional habitat loss. Human-induced changes are not equal, thus each type of disturbance feature must be assessed separately, although an intense array of human activities on the landscape may act in a cumulative fashion and equate to a large area disturbance.

3.2 Description of the Study Area

The study area consists of approximately 6,000 km^2 of boreal mixedwood and peatland vegetation in the northeastern section of Alberta, Canada (Figure 3-1, centre at 56°N, 113°W), (Strong and Leggat 1992) located on the southwest corner of the Athabasca oil sands deposits (Crandall and Prime 1998). There is minimal topographic variation within the study site, with elevation varying between 500 and 700 m above sea level. Lowland vegetation includes black spruce (*Picea mariana*) and black spruce-tamarack (*Larix laricina*) bogs and fens. Upland areas are dominated by trembling aspen (*Populus tremuloides*), white spruce (*Picea glauca*), jack pine (*Pinus banksiana*) and black spruce . Approximately 1% of the study area has been directly altered by surface developments. These developments include roads, wellsites and seismic lines (Figure 3-2).

Figure 3-1. Habitat composition of the study area in northeastern Alberta (centre 56° N, 113° W). The study area is dominated by open coniferous wetland (light grey) and closed coniferous wetland (dark grey). Upland areas (black), water bodies and other habitat types (white) are also shown.

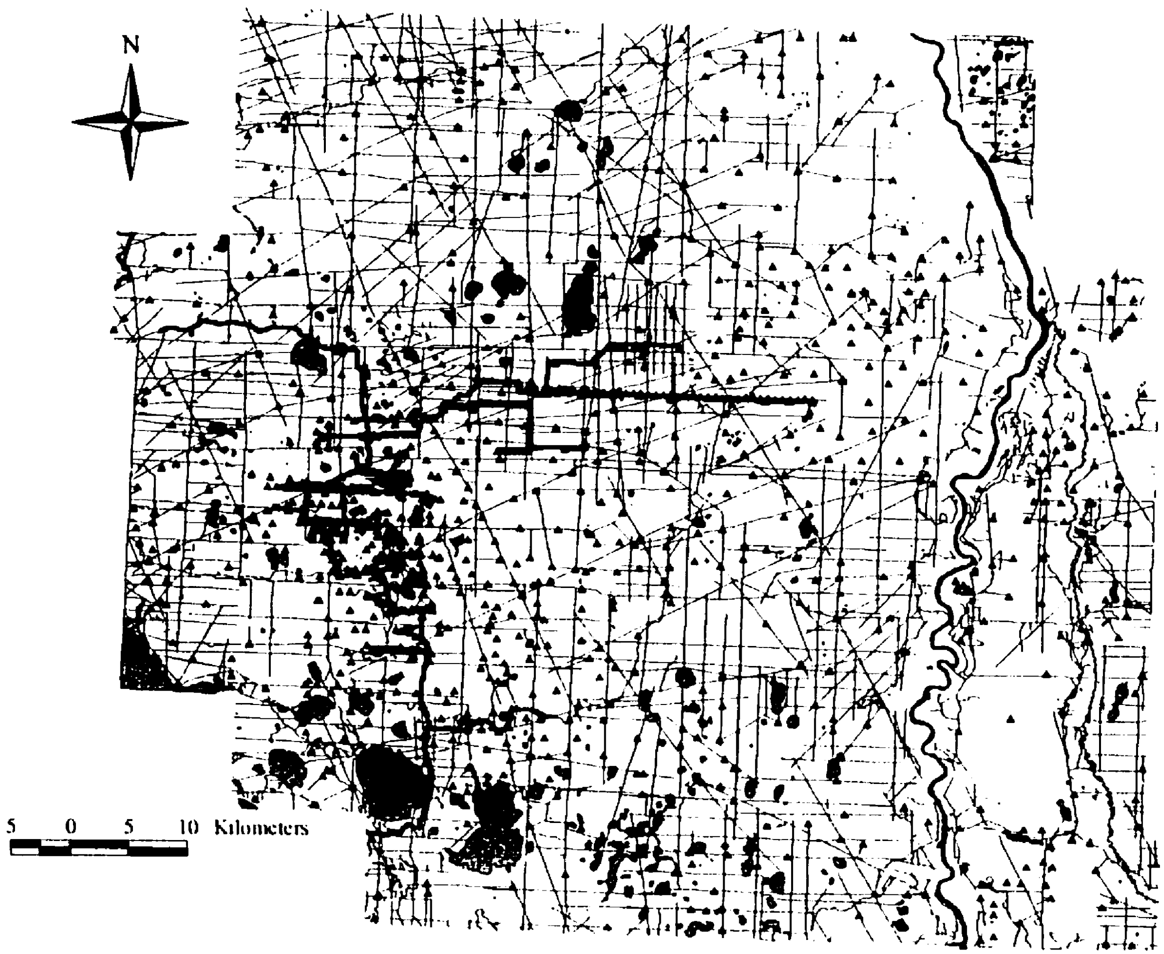

Figure 3-2. Human developments in the study area in northeastern Alberta (centre 56° N, 113° W), showing roads (thick lines), seismic lines (thin lines) and wellsites (triangles).

3.3 Methods

3.3.1 Caribou Location Data Collection

A total of twenty three woodland caribou were captured and collared on February 17-19, 1998. All animal treatment procedures were approved by the Canadian Council on Animal Care Animal Welfare Protocol, University of Alberta Biosciences Animal Care Committee (No. 230901). Animals were captured using a Hughes 500C helicopter and net-gun. Nineteen adult female, 3 young adult female and 1 young adult male caribou were captured. Each caribou was fitted with a Global Positioning System (GPS) collar (Lotek Engineering Systems, Newmarket, Ontario). Caribou were recaptured in January 1999 and refitted with collars with new batteries. Thirteen new caribou (all female) were captured using the same methods, and fitted with new collars in January 1999.

GPSHost software (Lotek Engineering Systems, Newmarket, Ontario) was used to download caribou locations from GPS collars. Due to the selective availability (SA) policy of the U.S. Department of Defence, these uncorrected locations are accurate to 40-65.5 m (Moen *et al.* 1997). The caribou locations were corrected using N3Win Version 2.40, a differential correction program which reduces the locational error created by SA to 4-5 m (Rempel *et al.* 1997). The N3Win program uses a base station as a reference point for the satellite signals (Alberta-Pacific Mill Site, latitude 54° 55" 17.60387 North, longitude 112° 51" 44.99926 West, elevation 654.837 m). The corrected GPS locations were entered into an ArcInfo Geographic Information System (ArcInfo GIS); (Version 7.1.1, Environmental Systems Research Institute Inc, Redlands CA).

3.3.2 Human Development and Activity Data Collection

Digital geographic data for the study area were obtained from Alberta-Pacific Forest Industries, Lormel Consultants, Veritas Consultants, Focus Consultants and individual oil companies active in the study area (Projection: UTM, Zone 12, Datum: NAD 27). These data were compiled in an ArcInfo GIS.

Vehicle traffic data on roads in the study area were collected using Unicorn Traffic Classifiers (Diamond Traffic Products, Oakridge, OR). These consisted of two electromagnetic loops placed under the road surface attached to a monitoring device which recorded the length and velocity of passing vehicles and the date and time of each record. Three traffic classifiers were placed throughout the study area road network to obtain an index of vehicle traffic levels in the study area. These data were augmented with two human traffic surveys at three locations during February 1998 (Late Winter) and August 1998 (Summer) (Appendix 4-1). No attempt was made to monitor the level of activity on seismic lines or wellsites during this study.

3.3.3 Data Analysis

Analysis was performed for five distinct time periods (Table 3-1). The time periods closely approximate published accounts of woodland caribou biology (Bergerud 1975). The distinction between Early and Late Winter is arbitrary and is related to the initial capture dates of caribou. Spatial analysis was performed using the Arc Macro Language (AML) programming functionality in ArcInfo GIS.

I generated a series of distance from development buffers for each type of human infrastructure (Table 3-2). Because the action of drilling a new wellsite has a greater disturbance potential than an older, producing well, I distinguished between 'old wells', with a drilling completion date older than November 1, 1996, and 'new wells' with a drilling completion date more recent than this. I generated minimum convex polygon (MCP) home ranges (Mohr 1947) for each caribou, for each time period, and calculated the total area of each development buffer in each MCP home range, and the proportion of caribou locations that fell within each development buffer. All caribou with home ranges that contained a large enough proportion of each development buffer to expect caribou locations if selection of buffers was random were included in the analysis.

Vegetation data for the study area were obtained using classified LANDSAT satellite imagery, acquired by Alberta-Pacific Forest Industries (J. O'Neill, pers. comm.).

Table 3-1. Analysis Time Periods

Time Period	**Analysis Period**
February 22 1998 – April 30 1998	LATE WINTER
May 1 1998 – June 30 1998	CALVING
July 1 1998 – September 15 1998	SUMMER
September 16 1998 – November 15 1998	RUT
November 16 1998 – February 21 1999	EARLY WINTER*

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

Table 3-2. Development buffers created using ArcInfo GIS

Buffer	Roads	Buffer	Wells	Buffer	Seismic lines
A	< 100 m from road	-------	----------------------------------	A	< 100 m from seismic line
B	≥ 100 m < 250 m from road	B	< 250 m from well	B	≥ 100 m < 250 m seismic line
C	≥ 250 m < 500 m from road	C	≥ 250 m < 500 m well	C	≥ 250 m < 500 m seismic line
D	≥ 500 m < 1000 m from road	D	≥ 500 m < 1000 m from well	D	≥ 500 m seismic line
E	≥ 1000 m < 2000 m from road	E	≥ 1000 m from well		
F	≥ 2000 m < 3000 m from road				
G	≥ 3000 m from road				

Selection of wetlands and avoidance of upland habitats by caribou has been documented in northeastern Alberta (Bradshaw *et al.* 1995; Stuart-Smith *et al.* 1997). Thus, results may be biased if human developments are concentrated on upland habitat. To ensure that caribou use of road development buffers were not confounded by differences in habitat composition between road development buffer types, separate use-availability analyses were performed for each road development buffer type found in open coniferous wetland and closed coniferous wetland, which were the two most common habitat classes in the study area. Wells and seismic lines were ubiquitous throughout the study area, and not thought to be associated with any particular habitat type. To test this, the habitat composition of all development buffers within each caribou home range was calculated for the Late Winter time period.

3.4 Statistical Analysis

3.4.1 Analysis of Habitat Composition of Development Buffers

I tested for normality of data using Kolmogorov-Smirnov tests. Log and arc-sine transformations were used where appropriate (Zar 1984). Habitat composition of different development buffers was compared using single factor ANOVA (Zar 1984).

3.4.2 Compositional Analysis of Development Buffer Selection

I used the log-ratio analysis of compositions (Aebischer *et al.* 1993) to analyze selection by caribou of different development buffers. Habitat use is described as selective (i.e., non-random) if habitat types are used disproportionately to their availability. I performed all analyses using a Microsoft EXCEL® spreadsheet program. To determine whether buffer use differs significantly from random with the log-ratio analysis of compositions, buffer use and availability proportions must be expressed in relation to another habitat type. First, I tested simultaneously across all habitat types for random habitat use, by testing the hypothesis $d = 0$, when $d = y - y_0$. I expressed the log-ratios of used habitat (y) as:

$y = \ln (U_{a,n} / U_{b,n})$, (Appendix 3-2)

where $U_{a,n}$ is the proportion of habitat *a* used by an animal *n*, and $U_{b,n}$ is the proportion of habitat *b* used by animal *n*. Compositional analysis requires that all values are greater than zero (Aebischer *et al.* 1993). Where buffers were completely unused, I replaced zero proportions with 0.0001, as described by Aebischer *et al.* 1993, which was an order of magnitude smaller than the smallest non-zero use proportions in this study. I expressed the log-ratios of available habitat (y_0) as:

$y_0 = \ln (A_{a,n} / A_{b,n})$, (Appendix 3-3)

where $A_{a,n}$ is the proportion of habitat *a* available to an animal *n*, and $A_{b,n}$ is the proportion of habitat *b* available to animal *n*.

I calculated the residual matrix, R_2 from the raw sums of squares and cross-products of d (Zar 1984), and the matrix R_1 from the mean-corrected sums of squares and cross-products of d. I tested the hypothesis that $d = 0$, by calculating chi-squared values using the formula:

$$\chi^2 = -n \ln \Lambda$$

where n = the number of caribou and $\Lambda = |R_1| / |R_2|$

The hypothesis $d = 0$ (habitat use does not differ from random) can be rejected when χ^2 is greater than $\chi^2_{(\alpha\,:\,(\text{no. of buffers} - 1))}$. If significantly non-random use of different habitat types is found, the next step is to find where there is deviation from random and rank habitat types in order of use, from habitats which are preferred to those which are avoided. I examined pairwise differences between matching log-ratios in a ranking matrix (Aebischer *et al.* 1993), using the formula:

$d_{a.b} = \ln (X_{u.a} / X_{u.b}) - (X_{A.a} / X_{A.b})$ (Appendix 3-4)

where $d_{a.b}$ is the pairwise difference between habitats *a* and *b*, $X_{u.a}$ and $X_{u.b}$ are the proportions of habitats *a* and *b* utilized, and $X_{A.a}$ and $X_{A.b}$ are the proportions of habitats *a* and *b* that are available. When $d_{a.b}$ is positive, habitat *b* is preferred to habitat *a*; the opposite is true when $d_{a.b}$ is negative.

I averaged the values of $d_{a.b}$ over *n* caribou individuals. For each pairwise comparison, the ratio of the mean/standard error provides a t value that measures departure from random use. I determined the means and standard errors of each cell in the ranking matrix and compared this to a theoretical distribution. Where the ratio is significant at $\alpha = 0.05$, then there is significantly different use between habitats *a* and *b*. The log-ratio analysis of compositions thus gives a habitat selection ranking relative to all other habitats (Appendix 3-5). To denote preference or avoidance, I compared use of all development buffers to use of the outer buffer or matrix, which represents the remaining area in each home range. If a development buffer was used significantly less than the outer development buffer, I described this as avoidance.

3.4.3 Cumulative Area Affected by Avoidance Behaviour Calculation

Using the avoidance distances demonstrated in this analysis, I calculated the potential area affected by avoidance behaviour using ArcInfo GIS, by combining avoidance effects of roads, wellsites and seismic lines for each time period in the study area.

3.5 Results

3.5.1. Vehicle Traffic Monitoring

Even with a dense network of traffic classifiers, it is difficult to obtain detailed information about traffic levels on all roads in the study area at all times. Problems with severed recording loops and classifier battery failure meant results from the traffic classifier sites were incomplete. Locations of vehicle checkpoints and traffic classifers in the study area are presented in Appendix 4-1. Traffic data recorded in the study area are summarized in Appendix 4-2. Nevertheless, a combination of the fragmentary classifier data and human sampling indicated a number of trends in vehicle traffic on roads in the study area.

Highest traffic levels (generally 600-800 vehicles per day) were recorded during the late winter time period. Lowest vehicle traffic levels (generally less than 100 vehicles per day) were recorded during the summer time period. Traffic levels during the second winter period (early winter) were lower than the previous winter (generally 40-400 vehicles per day, depending on classifier location). This corresponded with low oil prices and lower levels of industrial activity in the study area. Traffic levels during Calving and Rut were not recorded. It is assumed that traffic levels at these times were intermediate between winter and summer values.

3.5.2. Habitat Composition of Development Buffers

Road development buffers contained slightly different amounts of closed mixedwood upland, although these differences were not significant (ANOVA, $F = 1.924$, $df = 6$, $p = 0.091$). There were no significant differences in amounts of open coniferous wetland (ANOVA, $F = 1.375$, $df = 6$, $p = 0.238$) or closed coniferous wetland (ANOVA, $F = 1.058$, $df = 6$, $p = 0.397$) between development buffers. Habitat composition of different road development buffers is presented in Figure 3-4.

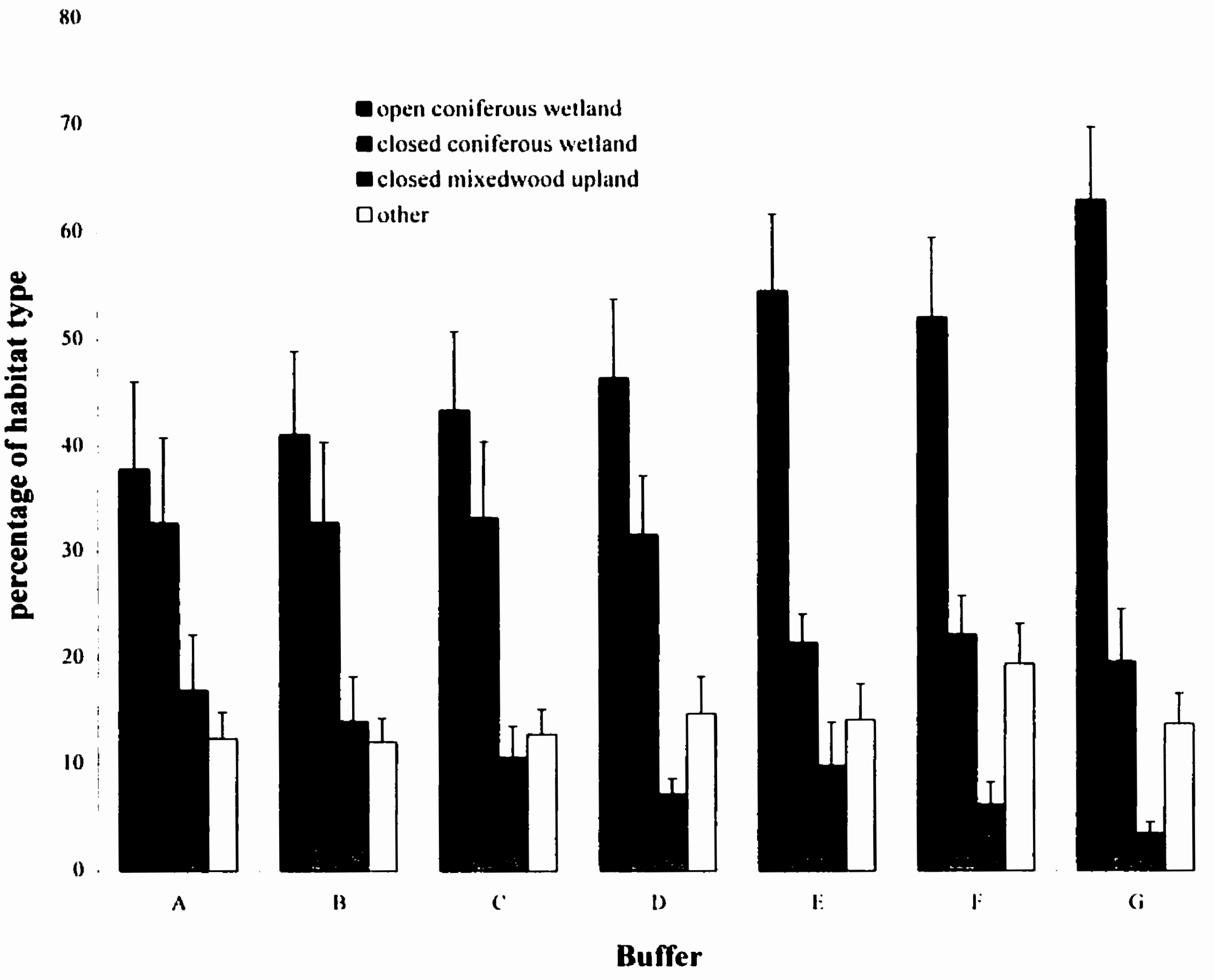

Figure 3-4. Mean(+SE) habitat composition of road development buffers. Note the trend that buffers close to roads contain slightly more closed mixedwood upland and slightly less open coniferous wetland than outer buffers. These differences were not significant at $p < 0.05$.

All wellsite buffers contained a similar percentage of open coniferous wetland (ANOVA, $F = 0.271$, $df = 3$, $p = 0.846$), closed coniferous wetland (ANOVA, $F = 0.377$, $df = 3$, $p = 0.770$) and closed mixedwood upland (ANOVA, $F = 0.359$, $df = 3$, $p = 0.783$). Habitat composition of wellsite development buffers is presented in Figure 3-5.

All seismic line development buffers contained a similar percentage of open coniferous wetland (ANOVA, $F = 0.852$, $df = 3$, $p = 0.469$), closed coniferous wetland (ANOVA, $F = 0.206$, $df = 3$, $p = 0.892$) and closed mixedwood upland (ANOVA, $F = 0.033$, $df = 3$, $p = 0.992$). Habitat composition of different seismic line development buffers is presented in Figure 3-6.

3.5.3 Caribou GPS Locations

The 36 collared caribou yielded a total of 43,415 locations over the data collection period. Mean (±SD) number of locations per caribou varied with time period: Late Winter (686.70 ± 149.41, n = 23), Calving (641.37 ± 114.07, n = 19), Summer (484.58 ± 76.46, n = 11), Rut (270.00 ± 60.25, n = 10) Early Winter (435.59 ± 128.56, n = 17). Mean (± SD) percentage use and percentage availability of the development buffers for each human development type are presented in Tables 3-3 to 3-7.

3.5.4 Selection of Road Development Buffers in Open Coniferous Wetland

Caribou selection of road development buffers in open coniferous wetland was significantly different from random during all time periods (Late Winter: $\chi^2 = 36.26$, $df = 6$, $p < 0.001$; Calving: $\chi^2 = 17.84$, $df = 6$, $p < 0.01$; Summer: $\chi^2 = 219.82$, $df = 6$, $p < 0.001$; Rut: $\chi^2 = 201.18$, $df = 6$, $p < 0.001$).

The log-ratio analysis of compositions indicated caribou in open coniferous wetland used buffers within 250 m of roads (A+B) significantly less than the outer matrix (G) during Late winter, Summer and Rut, and the 100 m – 250 m buffer (B) significantly less than the outer matrix (G) during Calving. Ranking matrices with t-values for road development buffers in open coniferous wetland are presented in Appendix 3-6.

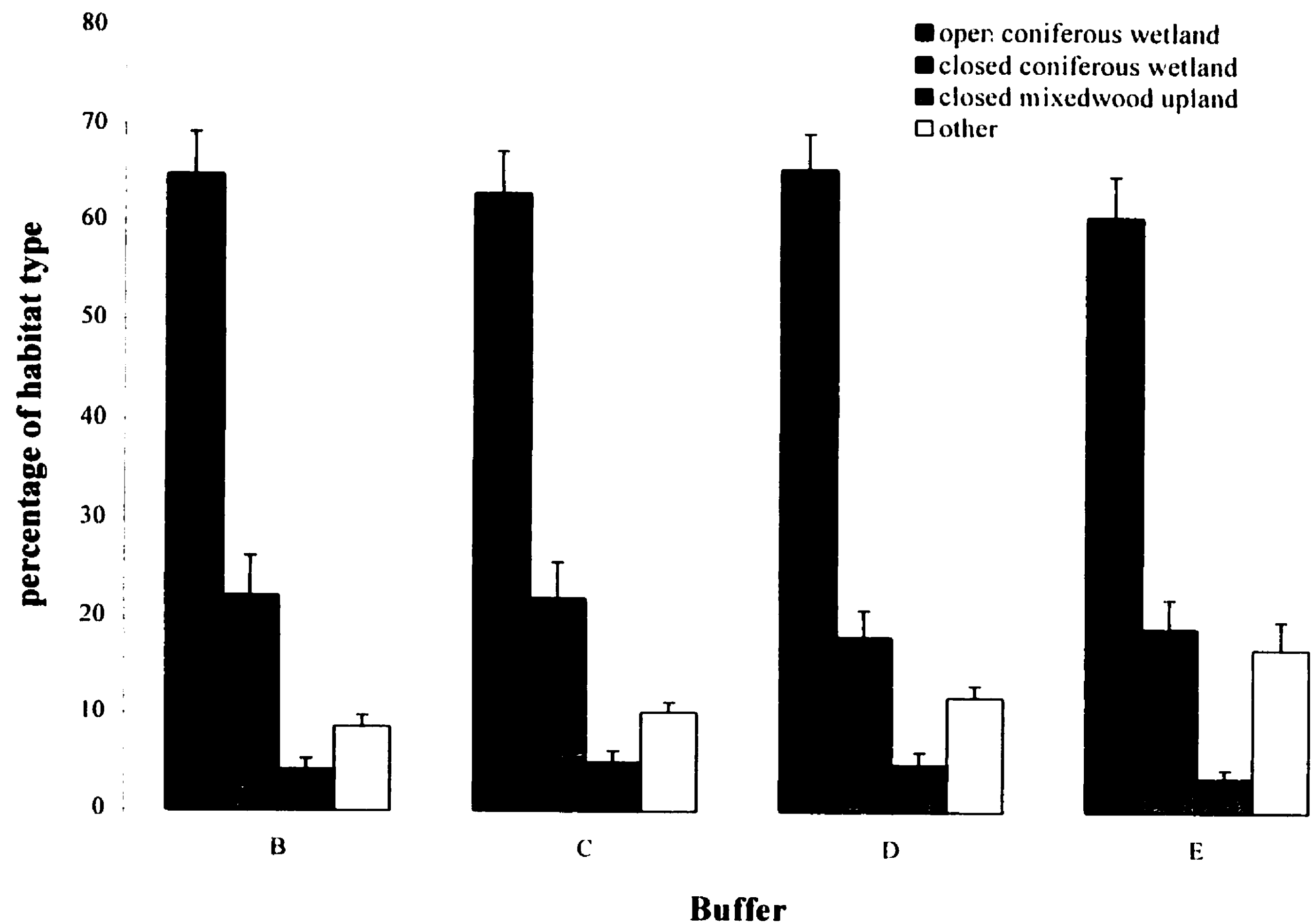

Figure 3-5. Mean (+ SE) composition of wellsite development buffers. Note the similarity in habitat composition between different development buffers.

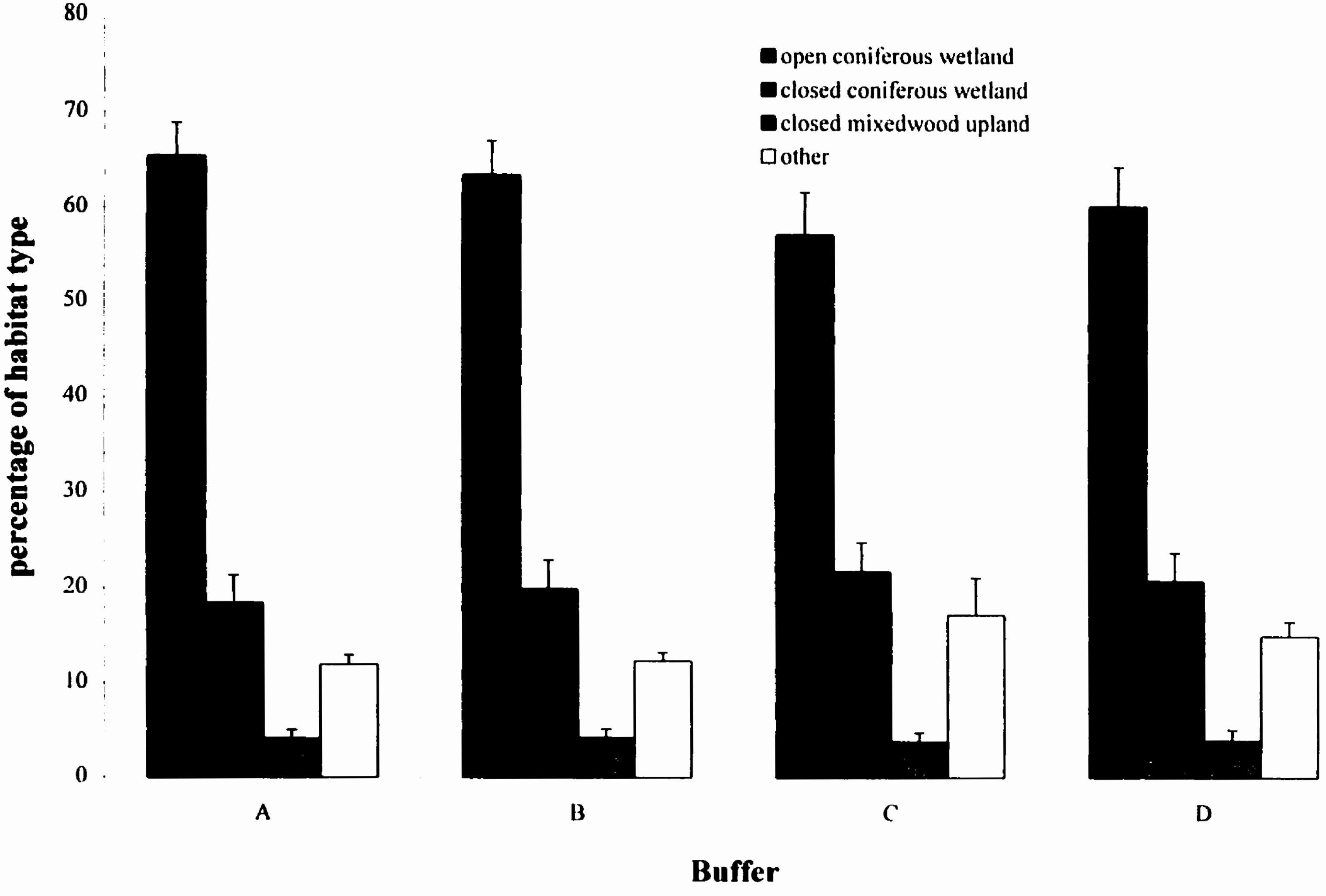

Figure 3-6. Mean (+SE) habitat composition of seismic line development buffers. Note the similarity in habitat composition between different development buffers.

Table 3-3. Mean (and standard deviation) of percentage of caribou locations (used) and percentage of available buffer types (available) for road development buffers in open coniferous wetland habitat.

	A used	A avail.	B used	B avail.	C used	C avail.	D used	D avail.	E used	E avail.	F used	F avail.	G used	G avail.
Late Winter	0.04 (0.06)	2.24 (3.25)	0.70 (0.70)	3.58 (4.77)	3.47 (6.36)	5.82 (6.40)	13.33 (16.76)	9.74 (6.27)	18.48 (15.01)	17.63 (8.06)	9.82 (9.43)	9.97 (4.70)	54.16 (33.42)	51.03 (24.02)
Calv.	0.31 (0.45)	2.91 (2.04)	0.90 (1.65)	3.54 (3.09)	2.76 (4.68)	5.65 (4.03)	11.31 (14.15)	8.73 (3.46)	23.78 (22.28)	20.88 (17.67)	19.10 (12.45)	10.61 (3.79)	41.85 (35.13)	47.70 (25.81)
Summ.	2.14 (4.63)	5.07 (4.11)	2.01 (4.18)	7.73 (6.12)	5.42 (6.95)	11.42 (8.07)	23.25 (25.63)	15.07 (9.64)	17.01 (19.18)	21.16 (12.71)	4.48 (5.44)	8.51 (4.23)	45.72 (48.84)	31.04 (33.93)
Rut	0.08 (0.17)	3.37 (2.26)	1.54 (1.50)	5.17 (3.41)	5.80 (5.95)	7.89 (4.67)	14.00 (15.27)	12.65 (5.72)	19.81 (15.80)	21.95 (8.64)	15.21 (5.51)	14.51 (4.16)	43.57 (36.17)	34.46 (28.41)

Table 3-4. Mean (and standard deviation) of percentage of caribou locations (used) and percentage of available buffer types (available) for road development buffers in closed coniferous wetland habitat.

	A used	A avail.	B used	B avail.	C used	C avail.	D used	D avail.	E used	E avail.	F used	F avail.	G used	G avail.
Late Winter	0.00 (0.00)	3.31 (1.62)	0.16 (0.34)	5.18 (2.30)	5.79 (6.54)	9.54 (4.59)	16.07 (19.91)	18.21 (8.43)	13.10 (13.83)	21.31 (7.35)	5.53 (17.54)	11.76 (6.14)	48.48 (39.94)	31.56 (22.48)
Calv.	0.14 (0.29)	4.48 (2.30)	1.74 (1.76)	6.06 (2.65)	9.36 (8.40)	11.09 (4.93)	28.21 (31.60)	22.56 (11.84)	20.91 (30.59)	22.26 (12.42)	1.42 (2.13)	8.52 (5.15)	38.24 (50.65)	25.02 (34.07)
Summ.	0.27 (0.28)	5.08 (3.16)	2.33 (3.92)	7.58 (4.12)	12.92 (7.67)	13.27 (7.22)	33.26 (28.83)	21.09 (10.96)	15.32 (14.19)	20.61 (11.86)	1.63 (1.94)	6.33 (2.54)	34.29 (46.68)	26.04 (34.97)
Rut	0.66 (0.93)	5.56 (2.68)	0.78 (0.82)	7.97 (3.67)	7.23 (7.33)	12.96 (6.11)	29.26 (19.15)	21.26 (6.37)	29.59 (23.01)	25.94 (13.45)	12.48 (10.02)	11.68 (4.26)	20.02 (42.26)	14.63 (24.37)

Table 3-5. Mean (and standard deviation) of percentage of caribou locations (used) and percentage of available buffer types (available) for old well development buffers

	B used	B available	C used	C available	D used	D available	E used	E available
Late Winter	1.59 (3.11)	2.81 (4.42)	4.43 (8.28)	6.58 (8.00)	15.57 (16.11)	17.73 (10.18)	78.41 (26.61)	72.88 (21.75)
Calving	1.86 (3.05)	4.22 (6.87)	6.37 (11.32)	8.53 (11.04)	26.78 (17.47)	18.51 (9.00)	65.00 (26.74)	68.74 (26.35)
Summer	2.13 (3.28)	6.00 (7.69)	9.06 (14.67)	9.79 (10.79)	20.20 (17.28)	20.66 (12.97)	68.61 (33.79)	63.56 (29.30)
Rut	3.78 (4.78)	5.20 (5.82)	10.58 (12.93)	10.30 (9.78)	21.69 (17.41)	21.70 (12.28)	63.95 (34.74)	62.81 (27.73)
Early Winter	3.61 (6.14)	3.73 (5.03)	7.91 (10.96)	7.88 (8.08)	20.55 (12.93)	21.03 (9.34)	67.93 (28.32)	67.47 (21.89)

Table 3-6. Mean (and standard deviation) of percentage of caribou locations (used) and percentage of available buffer types (available) for new well development buffers

	B used	B available	C used	C available	D used	D available	E used	E available
Late Winter	1.09 (1.01)	4.48 (7.21)	7.40 (6.82)	7.25 (6.25)	22.97 (16.52)	20.02 (11.33)	68.04 (23.09)	68.76 (20.04)
Calving	2.74 (5.35)	4.25 (5.36)	8.84 (11.45)	9.90 (10.73)	20.32 (18.53)	22.80 (11.34)	68.17 (29.74)	62.97 (25.93)
Summer	3.81 (5.75)	3.82 (3.05)	8.10 (9.90)	9.11 (7.00)	29.47 (19.02)	22.79 (13.22)	58.62 (27.94)	64.28 (23.03)
Rut	2.46 (2.64)	4.20 (2.71)	9.43 (9.90)	9.94 (6.20)	22.15 (11.09)	25.19 (10.81)	65.97 (22.01)	60.67 (19.61)
Early Winter	1.80 (1.85)	3.26 (2.95)	7.31 (5.90)	8.57 (6.48)	27.65 (14.84)	24.44 (10.28)	63.24 (20.86)	63.73 (19.16)

Table 3-7. Mean (and standard deviation) of percentage of caribou locations (used) and percentage of available buffer types (available) for seismic line disturbance buffers

	A used	A available	B used	B available	C used	C available	D used	D available
Late Winter	12.60 (6.91)	22.44 (4.56)	22.20 (8.69)	25.80 (4.19)	31.40 (8.36)	26.35 (2.21)	33.80 (20.08)	25.41 (10.72)
Calving	11.25 (8.45)	23.69 (6.68)	30.42 (12.25)	26.85 (5.76)	33.37 (11.11)	26.07 (3.44)	24.97 (20.09)	23.39 (13.55)
Summer	13.68 (10.93)	20.10 (5.88)	22.47 (10.53)	23.94 (5.09)	29.68 (7.27)	26.47 (3.76)	34.16 (16.13)	29.49 (12.29)
Rut	16.06 (3.46)	22.03 (5.16)	24.19 (5.94)	24.85 (4.76)	27.83 (7.52)	25.16 (2.11)	31.92 (13.07)	27.96 (11.74)
Early Winter	11.97 (6.14)	20.32 (3.44)	22.68 (6.47)	24.51 (2.69)	30.76 (5.99)	27.48 (2.32)	34.58 (10.94)	27.68 (6.47)

Buffers that were avoided were still used by caribou. A simple examination of mean use of development buffers as a percentage of expected use based on the available buffer area is presented in Figure 3-7. Mean caribou use of the 0 – 100 m buffer (A) was 3.65% of expected during Late Winter. During Calving, Summer and Rut mean use of the 0 – 100 m buffer was 17.52%, 33.93% and 6.86% of expected use, respectively.

Mean caribou use of the 100 – 250 m buffer (B) was greater than the use of the 0 – 100 m buffer during all time periods, and ranged from 22.7% of expected use during Summer to 25.18% of expected use during Calving. The strength of the avoidance response waned in the 250 – 500 m buffer (C), ranging from 31.55% of expected use during Summer to 57.52% of expected use during Calving.

3.5.5 Selection of Road Development Buffers in Closed Coniferous Wetland

Caribou selection of road development buffers in closed coniferous wetland was significantly different from random during all time periods (Late Winter: $\chi^2 = 34.82$, df = 6, $p < 0.001$; Calving: $\chi^2 = 174.87$, df = 6, $p < 0.001$; Summer: $\chi^2 = 183.02$, df = 6, $p < 0.001$; Rut: $\chi^2 = 174.88$, df = 6, $p < 0.001$).

The log-ratio analysis of compositions indicated caribou in closed coniferous wetland used buffers within 250 m of roads (A+B) significantly less than the outer matrix (G) during Late Winter and the buffer within 100 m of roads (A) significantly less than the outer matrix (G) during Summer. Ranking matrices of road development buffers in closed coniferous wetland are presented in Appendix 3-7.

Figure 3-8 shows that mean caribou use of the 0 – 100 m buffer (A) was 0.00% of expected during Late Winter. During Calving, Summer and Rut mean use of the 0 – 100 m buffer was 1.86%, 3.92% and 8.67% of expected use, respectively.

Mean caribou use of the 100 – 250 m buffer (B) was generally greater than use of the 0 – 100 m buffer during all time periods, and ranged from 3.46% of expected use during Late Winter to 75.75% of expected use during Summer. The strength of the avoidance response waned in the 250 – 500 m buffer (C), ranging from 41.15% of expected use during Rut to 137.74% of expected use during Summer.

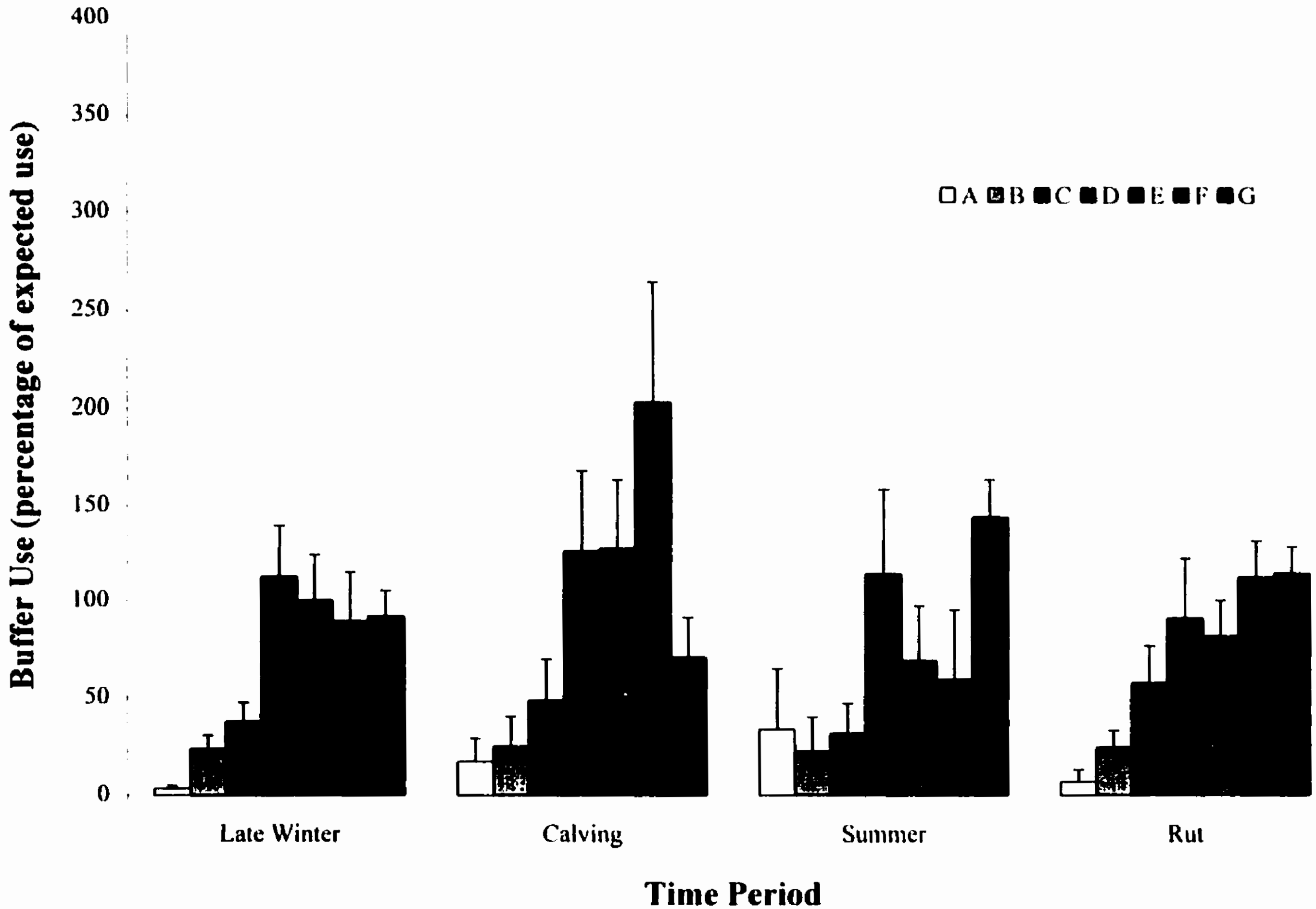

Figure 3-7. Proportional use of road development buffers by caribou in open coniferous wetland. Note the strong avoidance of buffers A and B during all time periods.

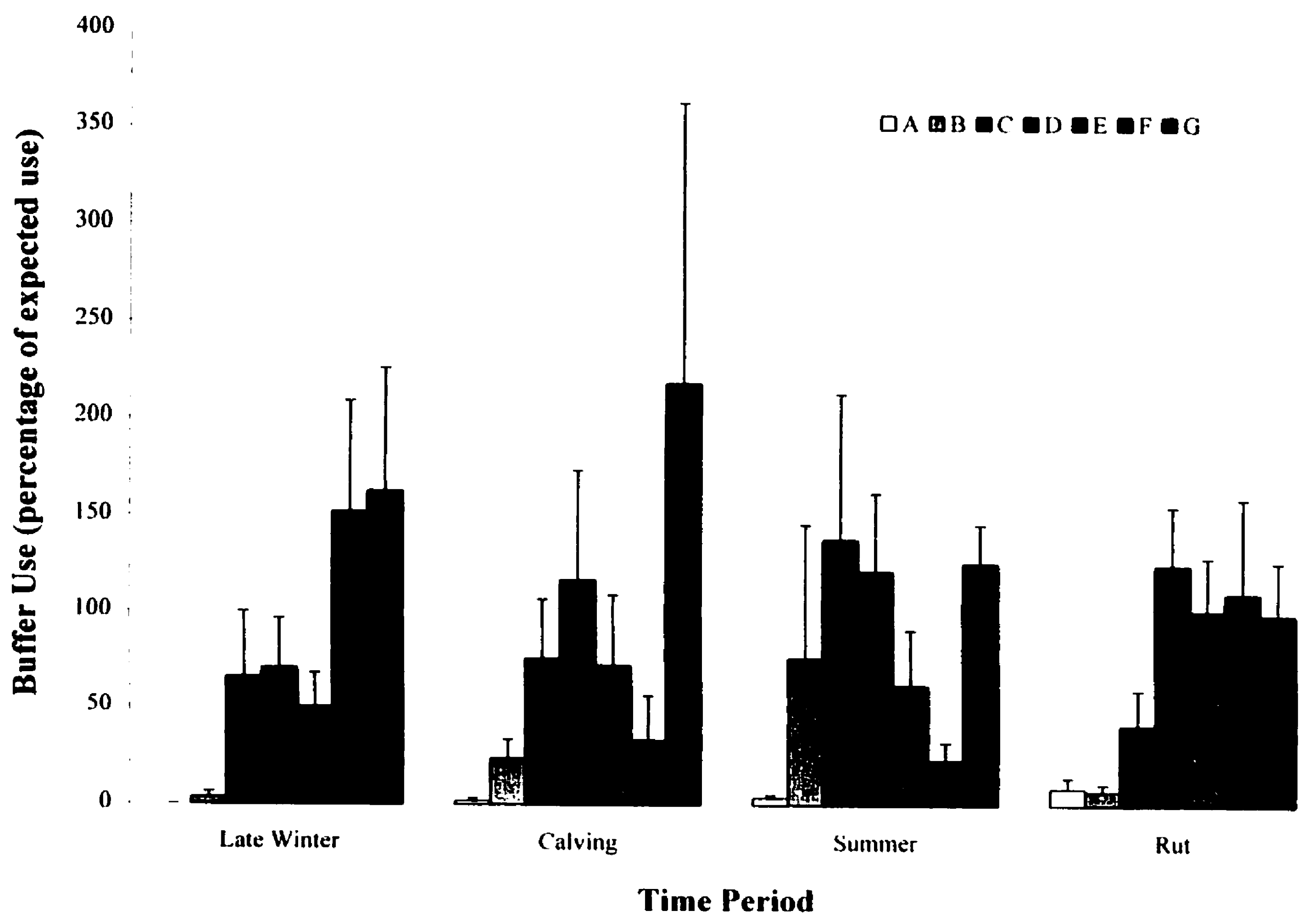

Figure 3-8. Proportional use of road development buffers by caribou in closed coniferous wetland. Note the strong avoidance of buffer A during all time periods.

3.5.6 Selection of New Wellsite Development Buffers

Caribou response to new wellsite development buffers was significantly different from random during Late Winter ($\chi^2 = 15.09$, df = 3, $p < 0.005$), Calving ($\chi^2 = 12.26$, df = 3, $p < 0.01$) and Early Winter ($\chi^2 = 15.25$, df = 3, $p < 0.005$). Caribou selection of new wellsite buffers was not significantly different from random during Summer ($\chi^2 = 4.25$, df = 3, $p > 0.05$) and Rut ($\chi^2 = 5.55$, df = 3, $p > 0.05$).

The log-ratio analysis of compositions indicated caribou used the buffer within 250 m of new wells (B) significantly less than the outer matrix (E) during Late Winter, Rut and Early Winter and buffers within 1000 m of new wells (B+C+D) significantly less than the outer matrix (E) during Calving. Ranking matrices with t-values for new well development buffers are presented in Appendix 3-8.

Figure 3-9 shows that mean caribou use of the 0 – 250 m buffer (B) was 45.31% of expected during Late Winter. During Calving, Summer, Rut and Early Winter mean use of the 0 – 250 m buffer was 65.55%, 117.84%, 49.35% and 54.78% of expected use, respectively.

Mean caribou use of the 250 – 500 m buffer (C) was greater than use of the 0 – 250 m buffer during all time periods, and ranged from 70.57% of expected use during Calving to 108.15% of expected use during Late Winter. Mean use of the 500 – 1000 m buffer ranged from 76.20% of expected during Calving to 136.22% of expected use during Summer.

3.5.7 Selection of Old Wellsite Development Buffers

Caribou selection of old wellsite development buffers was significantly different from random during Late Winter ($\chi^2 = 19.14$, df = 3, $p < 0.001$), and Summer ($\chi^2 = 19.26$, df = 3, $p < 0.001$). Caribou selection of old wellsite buffers was not significantly different from random during Calving ($\chi^2 = 7.30$, df = 3, $p > 0.05$), Rut ($\chi^2 = 6.23$, df = 3, $p > 0.05$) and Early Winter ($\chi^2 = 3.98$, df = 3, $p > 0.05$).

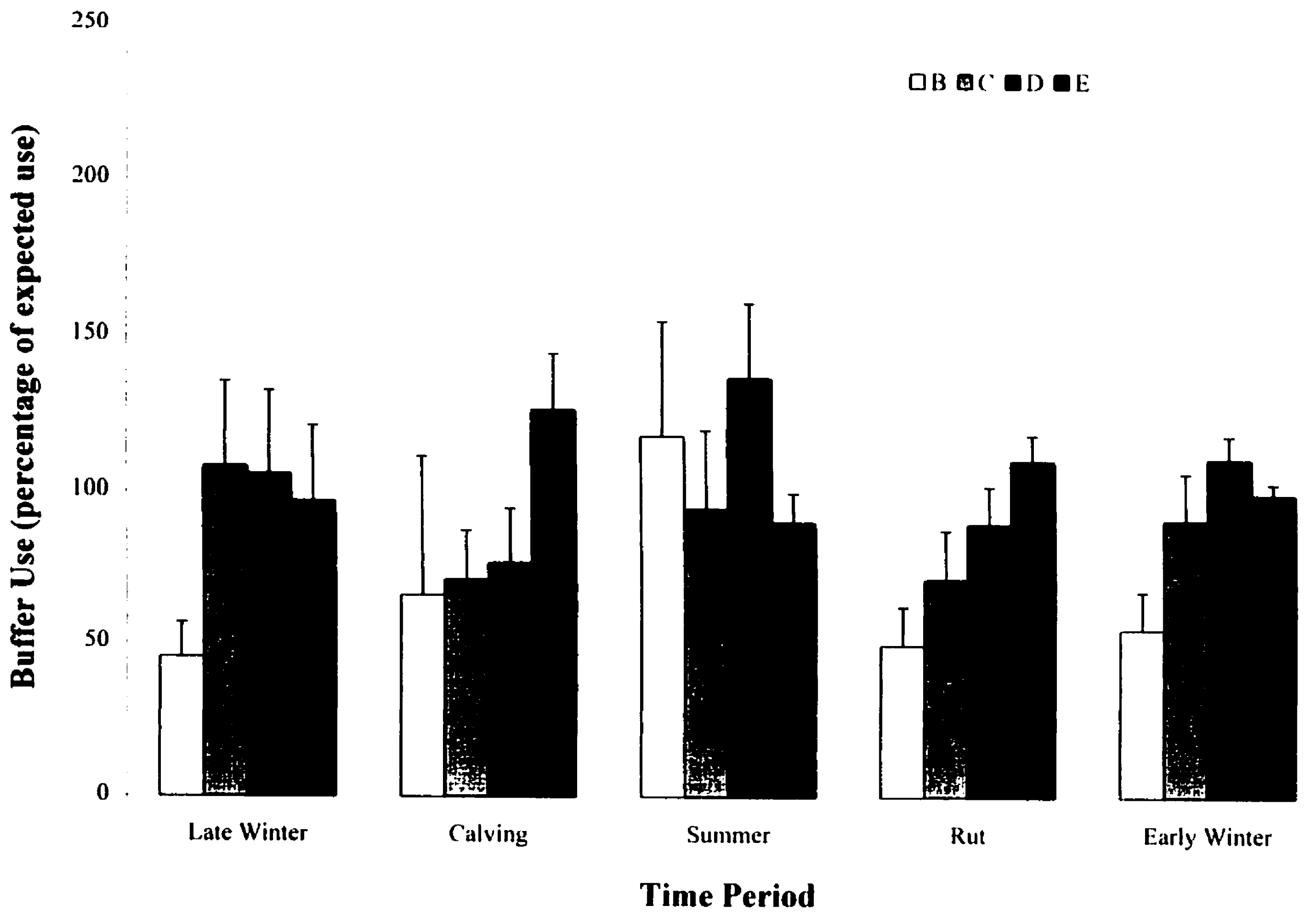

Figure 3-9. Proportional use of new wellsite development buffers by caribou. Note the lower than expected use of buffer B during all periods except Summer.

The log-ratio analysis of compositions indicated caribou used buffers within 500 m of old wells (B+C) significantly less than the outer matrix (E) during Late Winter and Calving and buffers within 250 m of old wells (B) significantly less than the outer matrix (E) during Summer. Ranking matrices with t-values for old well development buffers are presented in Appendix 3-9.

Figure 3-10 shows that mean caribou use of the 0 – 250 m buffer (B) was 84.42% of expected during Late Winter. During Calving, Summer, Rut and Early Winter mean use of the 0 – 250 m buffer was 67.74%, 35.93%, 56.49% and 80.21% of expected use, respectively.

Mean caribou use of the 250 – 500 m buffer (C) was generally greater than use of the 0 – 250 m buffer during all time periods, and ranged from 50.01% of expected use during Late Winter to 84.59% of expected use during Summer. Mean use of the 500 – 1000 m buffer ranged from 79.09% of expected use during Late Winter to 146.41% of expected use during Summer.

3.5.8 Selection of Seismic Line Development Buffers

Caribou selection of seismic line development buffers was significantly different from random during all time periods (Late Winter: $\chi^2 = 19.38$, $df = 3$, $p < 0.001$; Calving: $\chi^2 = 21.68$, $df = 3$, $p < 0.001$; Summer: $\chi^2 = 8.95$, $df = 3$, $p < 0.05$; Rut: $\chi^2 = 13.64$, $df = 3$, $p < 0.005$; Early Winter: $\chi^2 = 21.68$, $df = 3$, $p < 0.001$).

The log-ratio analysis of compositions indicated caribou used buffers within 250 m of seismic lines (A+B) significantly less than the outer matrix (D) during Late Winter, and the 100 m buffer (A) significantly less than the outer matrix (D) during all other time periods. Ranking matrices with t-values for seismic line development buffers are presented in Appendix 3-10.

Figure 3-11 shows that mean caribou use of the 0 – 100 m buffer (A) was 55.28% of expected use during Late Winter. During Calving, Summer, Rut and Early Winter mean use of the 0 – 100 m buffer was 47.64%, 64.81%, 74.66% and 57.70% of expected use, respectively.

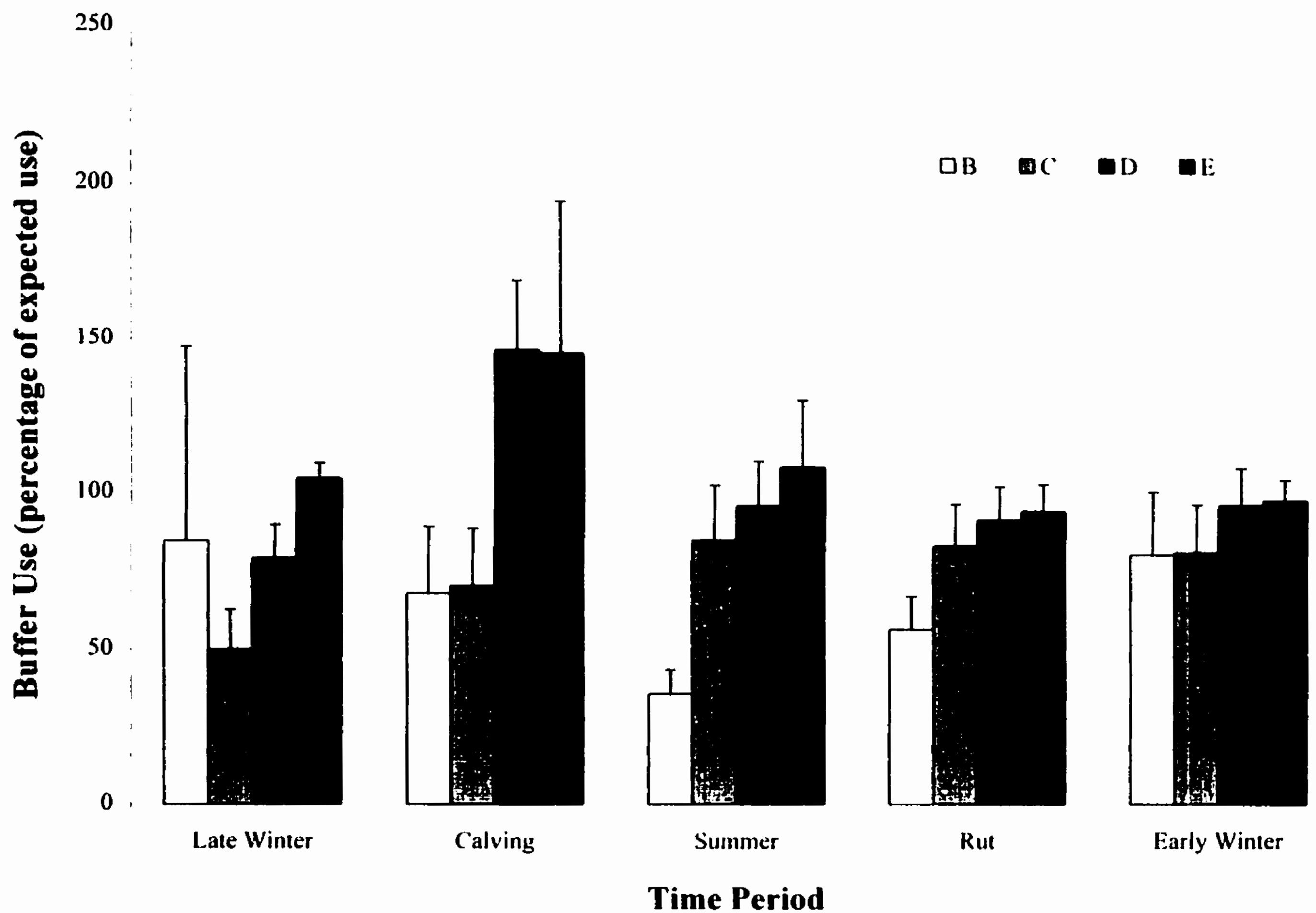

Figure 3-10. Proportional use of old wellsite development buffers by caribou.

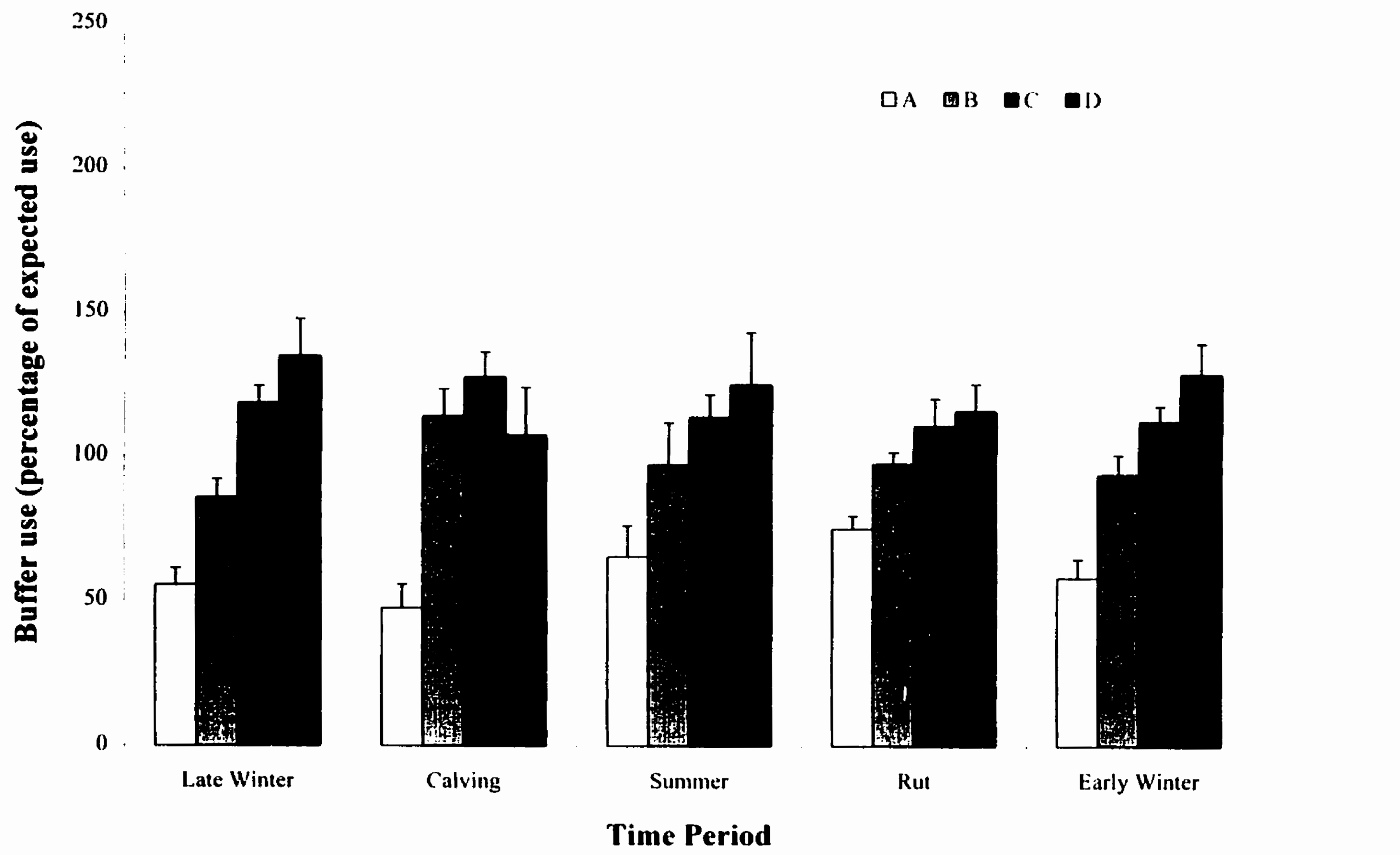

Figure 3-11. Proportional use of seismic line disturbance buffers by caribou. Note the lower than expected use, although not total exclusion of buffer A.

Mean caribou use of the 100 – 250 m buffer (B) was greater than use of the 0 – 100 m buffer during all time periods, and ranged from 85.45% of expected use during Late Winter to 113.78% of expected use during Calving. Mean use of the 250 – 500 m buffer (C) ranged from 110.76% of expected use during Rut to 127.49% of expected use during Calving.

3.5.9 Cumulative Area Avoided

The potential area avoided as a result of avoidance of each type of development feature was calculated by creating an ArcInfo coverage of the maximum significant avoidance distance demonstrated for each development type, for each time period using the log-ratio analysis of compositions (Aebischer *et al.* 1993). The cumulative effect of this avoidance was calculated by combining the ArcInfo coverages for each time period (Table 3-8). The potential area affected by the avoidance response of caribou is also presented as a percentage of the total study area (Table 3-9)

To determine the potential area affected by avoidance of roads, the avoidance distances calculated for open coniferous wetland were used, since this represents the dominant habitat type in the study area (Figure 3-4).

Using the avoidance distances determined by this study, the greatest effects of industrial development on woodland caribou distribution occurred during Late Winter, when 48.0% of the study area would potentially be avoided by caribou.

3.6 Discussion

Assessments which only take into account the physical disturbance associated with industrial development greatly underestimate the cumulative impact of development on caribou. My study is the first attempt to rigorously quantify avoidance responses of woodland caribou in terms of functional habitat degradation. In extreme cases this avoidance can be considered to cause total functional habitat loss. Habitat loss is implicated as the leading cause of species extinctions (Groombridge 1992).

Table 3-8. Potential area affected (ha) by extrapolating area avoided around developments to total study area. The total area of the study area is 617,204 ha. Total area avoided is less than the sum of avoidance of different development features due to overlap of avoidance effects.

Time Period	Road Avoidance (ha)	Old Well Avoidance (ha)	New Well Avoidance (ha)	Seismic Line Avoidance (ha)	Total Avoidance (ha)
Late Winter	11,357	40,347	8,299	276,472	295,991
Calving	11,357	40,347	91,066	128,880	221,180
Summer	11,357	11,132	0	128,880	142,363
Rut	11,357	0	8,299	128,880	141,009
Early Winter	N/A	0	8,299	128,880	134,503

Table 3-9. Potential percentage of study area affected by extrapolating area avoided around human developments to total study area. Total percentage of area avoided is less than the sum of avoidance of different development features due to overlap of avoidance effects.

Time Period	Percentage Road Avoidance	Percentage Old Well Avoidance	Percentage New Well Avoidance	Percentage Seismic Line Avoidance	Total Avoidance Percentage Study Area
Late Winter	1.8	6.5	1.4	44.8	48.0
Calving	1.8	6.5	14.8	20.9	35.8
Summer	1.8	1.8	0.0	20.9	23.1
Rut	1.8	0.0	1.4	20.9	22.9
Early Winter	N/A	0.0	1.4	20.9	21.8

Caribou in open coniferous wetland avoided roads during all time periods. The maximum avoidance distance of roads that was statistically significant (250 m) was undoubtedly conservative and a function of the small sample size, since many caribou did not have roads within their home ranges. Road avoidance distances were generally lower in closed coniferous wetland. This corroborates findings with elk (*Cervus elaphus*), where the avoidance effects of roads were ameliorated by the shielding effects of denser vegetation (Lyon 1979). Maximum avoidance effects of roads for caribou in closed coniferous wetland were demonstrated during Late Winter. This corresponds to the time of highest recorded traffic levels on roads in the study area.

Avoidance of wellsites was generally greatest during Late Winter and Calving. Based on vehicle traffic levels recorded in this study, human activity in the study area was highest during Late Winter, and numerous studies have indicated that female caribou are most sensitive to disturbances when accompanied by calves (Calef *et al.* 1976; Murphy and Curatolo 1987; Maier *et al.* 1998).

My study represents the first empirical evidence of avoidance of seismic lines by caribou. Seismic lines are a common component of petroleum exploration operations in northern regions, and represent one of the most pervasive human features in the boreal forest (Alberta Environmental Protection 1998). Avoidance was greatest during Late Winter, when seismic lines may act as *de facto* winter roads on frozen ground. The wetland terrain should prevent vehicular access on seismic lines at other times of the year. Caribou may be disturbed by traffic on seismic lines in winter and learn to avoid lines at other times, or if predators use these lines as travel corridors (Jalkotzy *et al.* 1997; James 1999), avoidance may be a learned anti-predator response.

All species have evolved under a range of natural disturbance processes. Fire is the most important cause of non-anthropogenic disturbance in the boreal forest (Johnson 1992) and it plays a crucial role in maintaining the boreal forest as a complex mosaic (Rowe and Scotter 1973; Johnson and Rowe 1975; Schaeffer and Pruitt 1991). Traditionally, fire was thought to have purely deleterious effects on caribou habitat supply (Edwards 1954) since it destroys the lichen forage important to the winter diet of caribou (Cumming 1992). In the short-term this is probably true (Klein 1982), although more recently it has been reported that burnt areas produce large amounts of lichen in the long-term (Euler *et al.* 1976; Miller 1979; Klein 1982). It is generally perceived that caribou are not limited by lichen supply (Bergerud *et al.* 1984: Seip 1991) provided that adequate areas are available to enable herds to cope with stochastic events such as severe snow conditions or forest fires (Schaefer and Pruitt 1991).

Prior to fire suppression in Alberta, around 0.5 – 2% of Alberta's forests burned each year (Armstrong *et al.* 1998). The rate at which lichen regrowth permits burned areas to return as useful caribou habitat is unknown. Human developments differ from burned areas in the rate at which these areas return to natural successional trajectories. Improved roads can be considered almost permanent deletions from the natural succession pathway, while tree regeneration and growth on seismic lines is very slow (Revel *et al.* 1984). The persistence of these developments on the landscape must thus also be considered in any analysis of disturbance at a landscape level.

Functional habitat loss as a result of avoidance behaviour may have a number of potential consequences for woodland caribou. Avoidance behaviour associated with linear developments and wells may impede the ability of caribou to avoid harsh microclimatic events and deep snows. Woodland caribou in Manitoba were shown to avoid open and semi-open bogs during deep snow (Darby and Pruitt 1984), and numerous reports indicate caribou move to more favourable locations when snow hardness and depth thresholds are exceeded (Pruitt 1959; Stardom 1975; LaPerriere and Lent 1977).

Functional habitat loss through avoidance may displace caribou into less suitable habitat which may have demographic consequences (Darby and Duquette 1986). A study with red deer and chamois indicated that avoidance of good habitat (in this case induced by intensive hunting), resulted in a decline in productivity (Batcheler 1968). The demographic consequences of poor range conditions have been reported for *Rangifer*, where reindeer on heavily grazed range were significantly smaller, and had lower pregnancy rates as yearlings than reindeer on good range (Reimers *et al.* 1983).

The hypothesis that habitat loss has contributed to declines in woodland caribou populations remains controversial (Darby and Duquette 1986), however, and the effects of industrial activity on predator-prey relationships may be equally important to woodland caribou demography (Bergerud 1974; Bergerud *et al.* 1984; James 1999). Many studies report wolves, *Canis lupus*, as important predators of caribou (Gasaway *et al.* 1983; Fuller and Keith 1980; Bergerud 1978). In northeastern Alberta, wolf predation accounted for 56% of caribou mortalities (Stuart-Smith *et al.* 1997). Spatial distribution data from northeastern Alberta suggests caribou may be distancing themselves from conspecifics in summer. This 'isolation' strategy has been hypothesized to reduce predation risk by lowering the probability of detection by predators (Stuart-Smith *et al.* 1997). It has been suggested that caribou are also sparsely distributed in peatlands to reduce predation, since an overall low biomass of ungulate prey make these areas less attractive to wolves than surrounding upland habitat (Cumming *et al.* 1996). Avoidance of industrial infrastructure may result in crowding of caribou into areas not subject to development. Such behaviour may make caribou more predictable in space and time, and thus more vulnerable to predation and human hunting. Recreational hunting of woodland caribou in Alberta was halted in 1981, yet human hunting is still an important source of mortality to caribou in northeastern Alberta. Stuart-Smith *et al.* (1997) found human hunting was responsible for at least 19% of caribou mortalities in northeastern Alberta: the proportion of mortalities attributable to legal native harvest and illegal poaching is unknown.

Linear corridors provide increased access for hunters into caribou range (Johnson 1985) and persist long after the active life of an oilfield. Wolves avoid areas with high densities of roads (Thiel 1985; Jensen *et al.* 1986; Mech *et al.* 1988), although linear corridors with little traffic may be utilized by wolves as travel routes (Horejsi 1979; Edmonds and Bloomfield; Eccles and Duncan 1986; Thurber *et al.* 1994). Spatially-explicit predator models predict that this will increase encounter rates between wolves and caribou (McCauley *et al.* 1993). Linear corridors may also enhance the ability of wolves to access traditional caribou wetland refuges.

Habitat selection is hierarchical (Johnson 1980), and caribou may select or avoid habitats at a number of spatial scales (Fuller and Keith 1981; Bradshaw *et al.* 1995; Stuart-Smith *et al.* 1997). The level of selection addressed in this study corresponds to Johnson's (1980) *third order selection*, that is the selection of habitats within an animal's home range. No attempt was made to evaluate if avoidance effects associated with human infrastructure are compounded by caribou selecting home ranges in areas of low development (*second order selection*) (Johnson 1980). This is potentially a far more serious challenge to the maintenance of woodland caribou populations in northeastern Alberta.

3.7 Management Implications

There may be limits to industrial development in caribou habitat, beyond which demographic effects will become apparent. Defining these thresholds, as I outlined in Chapter 2, is likely to be very challenging. I have demonstrated that the 'footprint' of industrial development has the potential to exceed the degree of natural perturbation in the boreal forest. However, the avoidance demonstrated in this study rarely represents total habitat alienation (with the exception of heavily used roads), and the demographic consequences of this partial avoidance remain unknown. Nevertheless, the cumulative magnitude of this avoidance response suggests it would be prudent to limit industrial operations in caribou habitat until 'acceptable' levels of development are determined.

Development of new corridors should be minimized through cooperation between industrial companies and by using low-impact and heli-portable seismic operations. Disturbance effects can be mitigated by complete roll-back of trees and debris onto seismic and pipeline right-of-ways and prompt revegetation of linear corridors with native species. The waning of response to anthropogenic features on the landscape corresponds to periods of low activity in an evolving oilfield (Appendix 4-2). This suggests that caribou are not responding to sedentary industrial developments *per se*, but to the vehicular traffic associated with them. Further research is necessary to address whether caribou can tolerate low levels of human use of corridors without displaying avoidance responses, although studies in Alaska and Newfoundland have shown traffic levels as low as 15 vehicles per hour elicit behavioral changes in caribou (Mercer *et al.* 1985; Murphy and Curatolo 1987). Research should also examine if all seismic lines elicit the observed avoidance response, or if lines actively used by humans are avoided by caribou, while those with little vehicular traffic are not avoided.

The large home range requirements and lack of distinct wintering or calving areas for woodland caribou in northeastern Alberta mean that protecting small areas from development will not be a useful strategy for caribou conservation (Stuart-Smith *et al.* 1997). Bergerud *et al.* (1984) concluded that "the major environmental variable that permits caribou to co-exist with predators is space". That 'space' may be shrinking in northeastern Alberta as industrial development encroaches on woodland caribou habitat.

Woodland caribou populations in northeastern Alberta appear to be stable or slightly declining (Fuller and Keith 1981; Stuart-Smith *et al.* 1997). Small changes in population dynamics as a result of industrial development may have significant consequences to the long term viability of caribou populations in Alberta. Further research is necessary to identify acceptable thresholds of development to caribou. Until more is known about the demographic responses of woodland caribou to development, a very conservative approach to resource extraction in caribou habitat is warranted.

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Chapter 4. Linear corridors as barriers to woodland caribou movement in northeastern Alberta

4.1 Introduction

Linear developments such as roads, seismic lines and pipeline right-of-ways are the dominant anthropogenic features in the boreal forest of Alberta (Alberta Environmental Protection 1998). In addition to the direct mortality associated with linear corridors (Johnson 1985), there is increasing concern that these features may act as barriers to the movement of woodland caribou (*Rangifer tarandus caribou*). Roads may act as considerable barriers to movement for many species (Oxley *et al.* 1974; Mader 1984; Clarke *et al.* 1998). Fragmentation of populations in this way may reduce local population sizes and cause local extinctions (Fahrig and Merriam 1985, 1994; Lande 1988; Saunders *et al.* 1991). If linear developments do act as barriers to caribou movements, this may exacerbate the functional habitat degradation through avoidance demonstrated in Chapter 3, and may have consequences in fragmenting endangered caribou populations in northeastern Alberta.

The majority of studies addressing potential barriers to caribou movements concern short-term responses of migratory barren-ground caribou, *Rangifer tarandus granti*, to human structures. Many anecdotal accounts and descriptive studies have attempted to assess the effects of human developments as barriers to caribou movements (Miller *et al.* 1971; Roby 1978; Johnson and Todd 1977; Klein *et al.* 1980; Whitten and Cameron 1983; Bergerud *et al.* 1984). Roads and railways have been implicated in causing abandonment of traditional migration routes by reindeer in Eurasia (Klein 1971; 1980), although Bergerud *et al.* (1984) challenged the assertion that these developments are barriers, arguing instead that range reductions due to population declines caused by overhunting are responsible for these observations. Controlled experiments that rigorously test hypotheses are less common, and tend to be labour intensive and limited to small areas (Curatolo and Murphy 1986; Eide *et al.* 1986).

Methodologies that exist to examine crossing success of small animals are well defined and generally involve the capture and recapture of organisms on opposite sides of local obstacles (Oxley 1974; Mader 1984). Studies with larger mammals have examined the importance of culverts and other non-wildlife passages (Yanes *et al.* 1995; Rodriguez *et al.* 1996) and specialized crossing structures (Reed 1981; Singer and Doherty 1985) to animal crossing success, but no technique presently exists to rigorously quantify crossing success over larger areas. In this chapter, I present a novel technique that utilizes GIS technology to examine if linear developments are barriers to caribou movements.

4.2 Description of Study Area

The study area consists of approximately 6,000 km^2 of boreal mixedwood and peatland vegetation (Strong and Leggat 1992) in the northeastern section of Alberta, Canada (centre at 56°N, 113°W), located on the southwest corner of the Athabasca oil sands deposits (Crandall and Prime 1998). There is minimal topographic variation within the study site, with elevation varying between 500 and 700 m above sea level. Lowland vegetation includes black spruce (*Picea mariana*) and black spruce-tamarack (*Larix laricina*) bogs and fens. Upland areas are dominated by trembling aspen (*Populus tremuloides*), white spruce (*Picea glauca*), jack pine (*Pinus banksiana*) and black spruce. The study area contains 236 km of improved gravel roads, accessible by two-wheel drive vehicles, and 7,111 km of seismic lines.

4.3 Methods

A total of twenty three woodland caribou were captured and collared on February 17-19, 1998. All animal treatment procedures were approved by the Canadian Council on Animal Care Animal Welfare Protocol, University of Alberta Biosciences Animal Care Committee (No. 230901). Animals were captured using a Hughes 500C helicopter and net-gun. Nineteen adult female, 3 young adult female and 1 young adult male caribou were captured. Each caribou was fitted with a Global Positioning System (GPS) collar

(Lotek Engineering Systems, Newmarket, ON). Caribou were recaptured in January 1999 and refitted with collars with new batteries. Thirteen new caribou (all female) were captured using the same methods, and fitted with new collars in January 1999.

GPSHost software (Lotek Engineering Systems, Newmarket, ON) was used to download caribou locations from GPS collars. Due to the selective availability (SA) policy of the U.S. Department of Defence, these uncorrected locations are accurate to 40-65.5 m (Moen *et al.* 1997). The caribou locations were corrected using N3Win Version 2.40, a differential correction program which reduces the locational error created by SA to 4-5 m (Rempel and Rodgers 1997). The N3Win program uses a base station as a reference point for the satellite signals (Alberta-Pacific Mill Site, latitude 54° 55" 17.60387 North, longitude 112° 51" 44.99926 West, elevation 654.837 m). The corrected GPS locations were entered into an ArcInfo Geographic Information System (GIS) (Version 7.1.1, Environmental Systems Research Institute Inc., Redlands CA).

4.3.2 Human Development and Activity Data Collection

Digital geographic data for the study area were obtained from Alberta-Pacific Forest Industries, Lormel Consultants, Veritas Consultants, Focus Consultants and individual oil companies active in the study area (Projection: UTM, Zone 12, Datum: NAD 27). These data were compiled in an ArcInfo GIS.

Vehicle traffic data on roads in the study area were collected using Unicorn Traffic Classifiers (Diamond Traffic Products, Oakridge, OR). These consisted of two electromagnetic loops placed under the road surface attached to a monitoring device which recorded the length and velocity of passing vehicles and the date and time of each record. Three traffic classifers were placed throughout the study area road network to obtain an index of vehicle traffic levels in the study area. These data were augmented with two human traffic surveys at three locations during February 1998 (Late Winter) and August 1998 (Summer) (Appendix 4-2). No attempt was made to monitor the level of activity on seismic lines.

4.3.3 GIS Analysis

Analyses were performed for five distinct time periods (Table 3-1). Spatial analysis was performed using the Arc Macro Language (AML) programming functionality of ArcInfo Version 7.1.1 Geographic Information System (GIS). I generated minimum convex polygon (MCP) home ranges (Mohr 1947) for each caribou for each time period and calculated the total length and density of roads and seismic lines in each home range. Any caribou home range that was completely included in the study area and contained at least 2 km of either linear feature was included in the analysis. Consecutive caribou locations were linked in a join-the-dot trajectory and each time this trajectory crossed either linear feature was recorded. To generate a linear control category I used the following GIS strategy. One hundred pairs of random points were generated within a defined box which encompassed each home range. Each pair of randomly generated points was used to generate a line. This resulted in 100 random lines of varying lengths which within the defined area. The home range was then used to clip out all of the randomly generated lines so that all of the lines were completely contained within the home range. The lines were randomly selected one by one until a density of linear features +/- 10% of the actual density of roads or seismic lines in the home range was achieved. In the previous chapter I demonstrated that there were no significant differences in habitat composition of disturbance buffers different distances from roads and seismic lines (Figures 3-4 and 3-6). Since these linear features are not associated with any particular habitat type, it is reasonable to distribute the control roads and seismic lines randomly throughout each caribou home range.

The same caribou trajectory was laid over this control linear feature network and the number of 'crosses' recorded. This analysis was repeated 200 times for each caribou for each time period for each linear disturbance, to provide a mean number of 'control crossings' to compare to the actual crossing rate.

4.4 Statistical Analysis

Statistical analyses was performed using the SPSS statistical program (SPSS Inc., Chicago, IL). I tested for normality of data using Kolmogorov-Smirnov tests (Zar 1984). Log and arc-sine transformations were used where appropriate (Narusis 1994). Actual number of crossings per time period were compared to the mean number of control crossings using paired sample T-tests (Zar 1984). In all cases, p-values < 0.05 were considered to be statistically significant.

4.5 Results

4.5.1 Home Range Size and Development Density

Mean caribou home range sizes, densities of roads and seismic lines and number of crossing events per time period are presented in Tables 4-1 and 4-2.

4.5.2 Road Crossing Analysis

Caribou crossed roads significantly less than controls during Late Winter ($t = 3.876$, $df = 7$, $p = 0.006$), Summer ($t = 2.710$, $df = 5$, $p = 0.042$), and Rut ($t = 3.982$, $df = 4$, $p = 0.016$). Caribou crossed roads less than controls during Calving, although this difference was not statistically significant ($t = 2.143$, $df = 5$, $p = 0.085$). Insufficient caribou (3) had roads within their home ranges in early winter to be included in the analysis. Crossing success, as a percentage of expected number of crossings (generated by controls) is presented in Figure 4-1.

4.5.3 Seismic Line Crossing Analysis

Caribou crossed seismic lines at a similar frequency to controls during all five time periods (Late Winter: $t = 0.012$, $df = 22$, $p = 0.912$; Calving: $t = 0.472$, $df = 15$,

Table 4-1. Mean (and standard deviation) of home range size, density of roads within home ranges and number of road crosses recorded for each time period .

	Late Winter n = 8	**Calving** n = 6	**Summer** n = 6	**Rut** n = 5
Home range area (km^2)	289.4 (200.5)	198.2 (181.2)	269.5 (244.2)	242.1 (114.8)
Density of roads in home range (km/km^2)	0.1 (0.1)	0.2 (0.2)	0.2 (0.1)	0.3 (0.2)
Number of crosses	4.1 (4.8)	6.8 (7.1)	15.8 (17.1)	14.4 (6.5)

Table 4-2. Mean (and standard deviation) of home range size, density of seismic lines within home ranges and number of seismic line crosses recorded for each time period.

	Late Winter $n = 23$	**Calving** $n = 16$	**Summer** $n = 11$	**Rut** $n = 9$	**Early Winter** $n = 17$
Home Range Area (km^2)	222.7 (165.6)	99.6 (132.9)	108.5 (102.5)	203.5 (104.9)	192.5 (87.5)
Density of seismic lines in home range (km/km^2)	1.2 (0.3)	1.3 (0.4)	1.1 (0.4)	1.2 (0.3)	1.0 (0.6)
Number of crosses	153.1 (74.9)	114.8 (71.3)	134.0 (76.4)	195.6 (78.5)	119.5 (92.3)

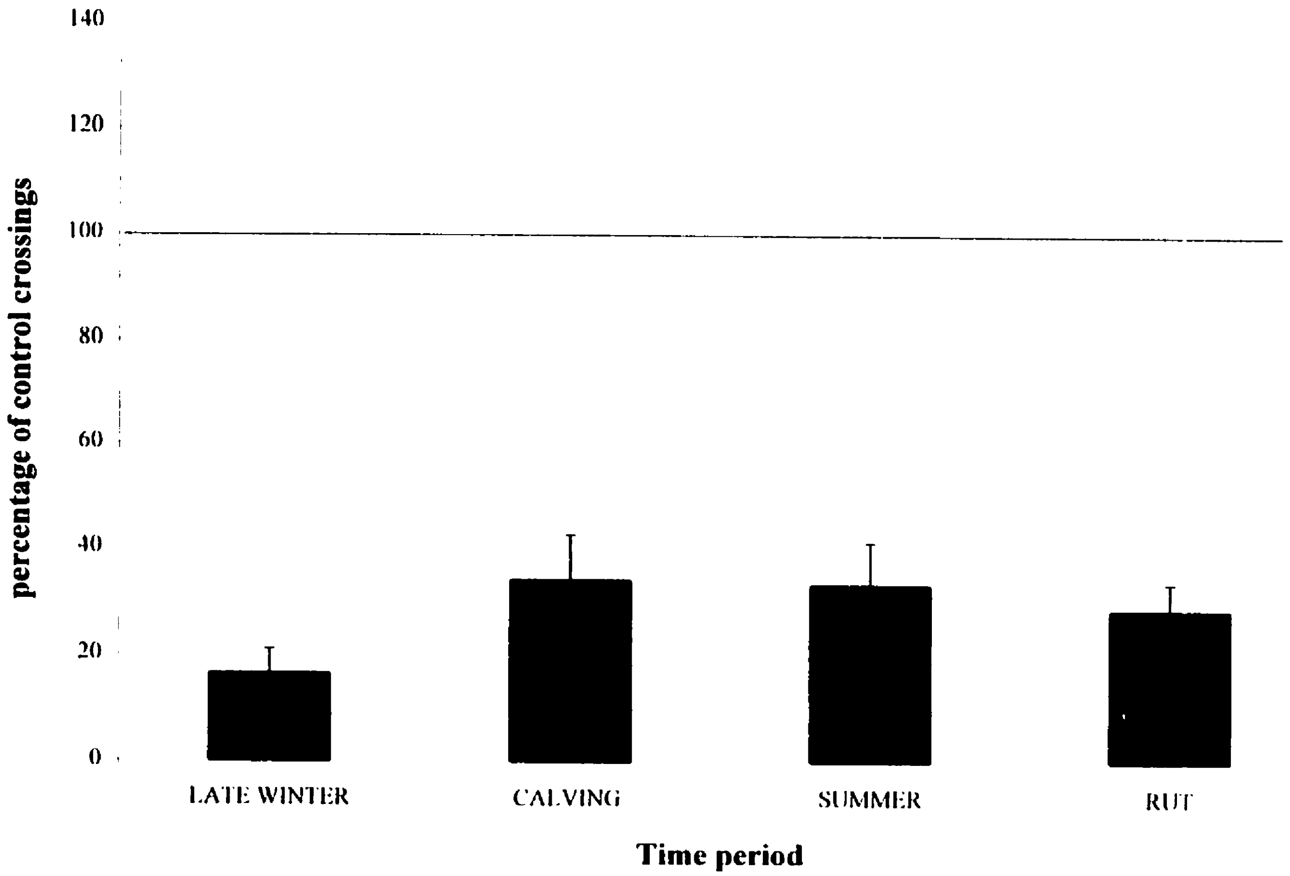

Figure 4-1. Road crossing frequency per time period, presented as percentage of control crossings. Caribou crossed roads significantly less than controls during all time periods.

$p = 0.644$; Summer: $t = 0.249$, $df = 10$, $p = 0.809$; Rut: $t = -0.709$, $df = 7$, $p = 0.501$; Early Winter: $t = -1.071$, $df = 16$, $p = 0.300$). Seismic lines do not appear to be barriers to caribou movement. Crossing success, as a percentage of expected number of crossings (generated by controls) is presented in Figure 4-2.

4.5.4 Traffic Monitoring Results

Even with a dense network of traffic classifiers, it is difficult to obtain detailed information about traffic levels on all roads in the study area at all times. Problems with severed recording loops and classifier battery failure meant results from the traffic classifier sites were disappointing. Traffic data recorded in the study area are summarized in Appendix 4-2. Nevertheless, a combination of the fragmentary classifier data and human sampling indicated a number of trends in vehicle traffic on roads in the study area.

Highest traffic levels (generally 600-800 vehicles per day) were recorded during the late winter time period. Lowest vehicle traffic levels (generally less than 100 vehicles per day) were recorded during the summer time period. Traffic levels during the second winter period (early winter) were lower than the previous winter (generally 40-400 vehicles per day, depending on classifier location). This corresponded with low oil prices and lower levels of industrial activity in the study area. Traffic levels for calving and rut were not recorded. It is assumed that traffic levels at these times were intermediate between winter and summer values.

4.6 Discussion

The avoidance behaviour of caribou to roads demonstrated in Chapter 3 could be partially responsible for the lower than expected road crossing rate, but caribou also avoided seismic lines during all time periods, yet seismic lines did not appear to act as barriers to caribou movements. It should be cautioned, however, that this study consisted of two mild winters with below average snowfall in the study area. In deep snow winters,

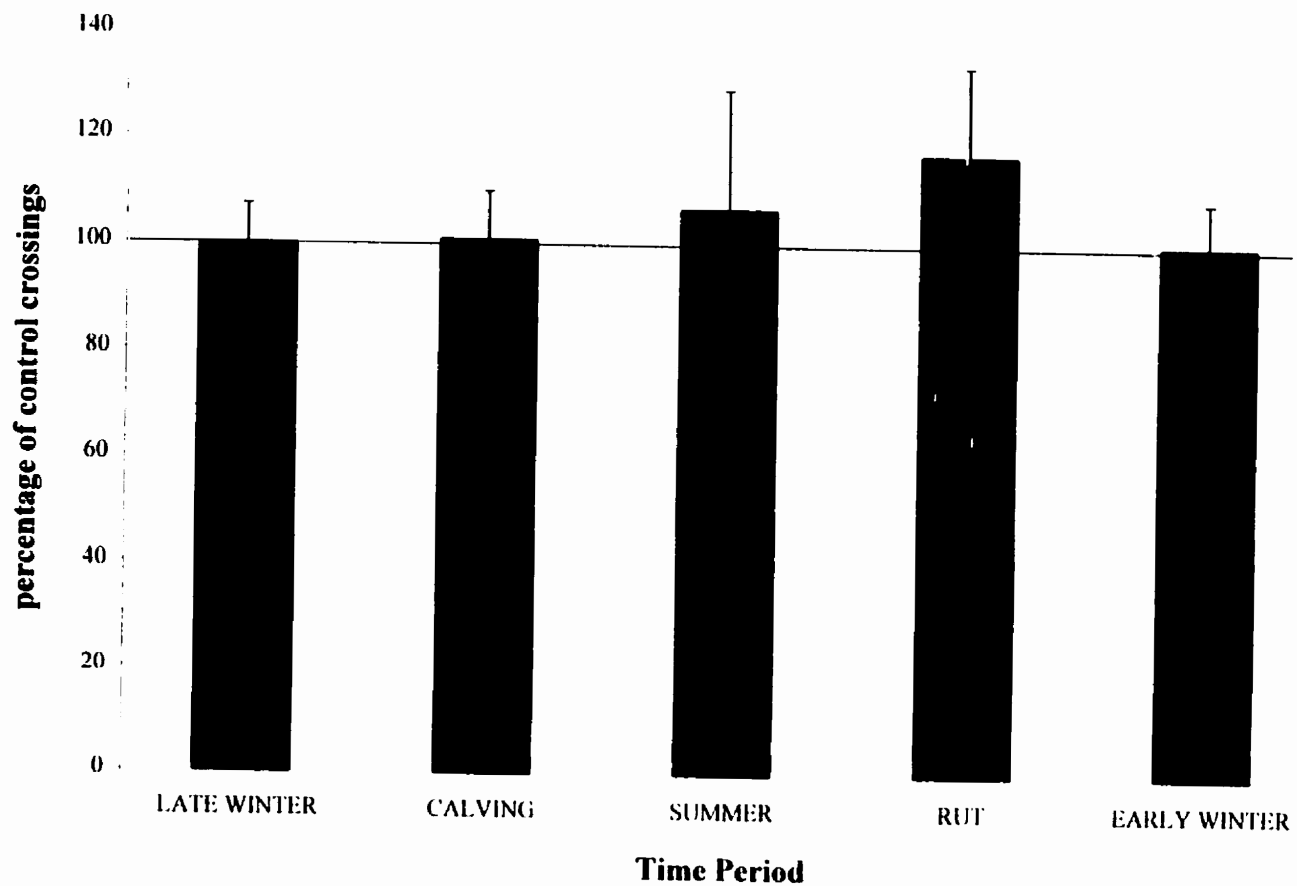

Figure 4-2. Seismic line crossing frequency per time period, presented as percentage of control crossings. There was no difference in crossing frequency of actual and control features during any time period.

grading of seismic lines to allow vehicle access could result in berms of snow which may act as barriers to caribou movement.

Caribou crossed roads significantly less than expected during all time periods except calving. No studies have specifically tested the effects of different levels of vehicle traffic on caribou crossing success to see if thresholds to levels of vehicle traffic do exist. However, these results suggest that even lightly used roads are barriers to caribou movements. Habituation is defined as 'the waning of an animal's response with repeated exposure to a stimulus' (Shalter 1984). There was no evidence of waning of the barrier effect of roads over time. There are numerous examples of ungulates habituating to the presence of humans in National Parks (Geist 1971), but at present there is no evidence of caribou habituating to developments in the study area. Continued research in the study area will examine the potential of habituation to human developments.

Klein (1980) states that caribou resident in the area of human developments should more readily habituate to human associated disturbances than migratory caribou which may encounter such disturbances only seasonally. However, the barrier consequences of development in woodland caribou habitat may be more severe, since sedentary animals may be less strongly motivated to cross developments (Klein 1980). Woodland caribou in northeastern Alberta are relatively sedentary, displaying no seasonal migrations (Stuart-Smith *et al.* 1997). As such, woodland caribou may be less inclined to cross disturbance corridors than migratory barren-ground or mountain caribou, and barrier effects of these developments may be more pronounced.

Curatolo and Murphy (1986) reported that caribou in Alaska crossed roads and pipelines equally to controls. Presence of the Trans-Alaska Pipeline did not appear to affect the traditional migration of the Nelchina caribou herd (Carruthers and Jakimchuk 1987). However, where a pipeline paralleled a road with traffic, crossing frequencies were significantly less than expected (Curatolo and Murphy 1986). The authors postulated that roads and pipelines act in a synergistic fashion. A number of roads in the study area have low (<50 cm) pipelines associated with them. Further research is necessary to examine if these contribute to the demonstrated barrier effects.

Animal movement models have become popular with the advent of GIS. Schippers *et al.* (1996) distinguish three main approaches to modeling animal movements in response to landscape characteristics: distance-based models, diffusion models and random walk models. Distance based models used to predict the connectivity between populations (Buchner 1987; Miller and Carrol 1989) and random walk models (Johnson *et al.* 1992) ignore underlying differences in the landscape, while diffusion models fail to properly represent the complex decisions of individuals (Schippers *et al.* 1996).

Although this modeling approach can provide many insights into the movement of animals through a landscape, many assumptions are made about animal decisions. Schippers *et al.* (1996) argue that more effort should be put into quantifying these parameters. The GIS approach I have outlined in this chapter is a useful method to quantify the effects of human developments as semi-permeable barriers to animal movements and should be considered in the development of caribou movement models.

4.7 Management Implications

Woodland caribou in northeastern Alberta tend to be restricted to peatland complexes (Bradshaw *et al.* 1995; Stuart-Smith *et al.* 1997). These populations contain relatively few individuals (BCRP unpublished data), thus the probability of local extinction is high (Richter-Dyn and Goel 1972). Metapopulation theory (Levins 1970) defines dispersal as a key process in estimating the survival of local populations connected by inter-patch dispersal. Metapopulations are defined as "systems of such local populations connected by dispersing individuals" (Hanski and Gilpin 1991). Movement between peatland complexes by caribou has been reported in northeastern Alberta (Bradshaw 1994; Stuart-Smith *et al.* 1997). Any process which affects the connectivity of a landscape will affect dispersal (Fahrig and Merriam 1985; Apeldoorn *et al.* 1992). Habitat fragmentation through habitat loss, avoidance, and the barrier effects of roads may have significant implications for strategies to maintain woodland caribou populations in Alberta. Barrier effects associated with roads could be more severe at the edges of these peatland complexes, whereby a combination of inhospitable habitat and man-made barriers could potentially arrest dispersal. It is important to note, however, this study addressed primarily female movements. Continued research is necessary to quantify the frequency of both male and female caribou movements between peatland complexes.

Until more is known about the consequences of semi-permeable barriers, such as roads on woodland caribou demographics, it is prudent to adopt a cautious approach to resource extraction in caribou habitat.

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Chapter 5. General Conclusions

5.1 Thesis Conclusions

In this study I have shown that the functional habitat loss associated with industrial development far surpasses the physical footprint of industrial operations in northeastern Alberta. Although I demonstrated significant changes in caribou distribution and behaviour in response to human activity, no attempt was made to measure the demographic consequences of this avoidance.

In this study caribou avoided roads during all time periods, although the extent of avoidance varied seasonally and with habitat type. Vegetation type and level of activity on roads affected the magnitude of this avoidance response, which corroborates similar findings with elk (Lyon 1979). Caribou also avoided old and new wellsites, although no avoidance effects were visible during Summer (new wellsites) and Rut and Early Winter (old wellsites). Caribou avoided seismic lines during all time periods, and displayed the greatest avoidance response during the Late Winter time period when industrial activity was highest in the study area. Roads were barriers to caribou movements throughout the year, which may exacerbate functional habitat loss through avoidance. Suitable habitat that is isolated may in effect become lost to caribou because of the low permeability of roads on the landscape. Seismic lines were not barriers to caribou movement during the course of this study.

The low rate of caribou encountering roads, coupled with the avoidance response to developments displayed by caribou in this and other studies (Nelleman and Cameron 1996; 1998) indicates that the focus on the energetic consequences of harassment (Bradshaw *et al.* 1997; 1998) may be misplaced. Of course, if surface development continues at its predicted rate (Crandall and Prime 1998), and caribou are no longer able to avoid potentially disturbing encounters, the energetic consequences of disturbance may be more significant. Meanwhile, a more pressing problem may be that of functional habitat degradation through avoidance and barrier effects of human developments.

There is a definite requirement for more reliable information on the effects of industrial activity on woodland caribou demography. By proper hypothesis testing it will be possible to avoid the type of correlational reasoning described by Bergerud *et al.* (1984), but it remains difficult to design and conduct non-intrusive research on a large, cryptic and endangered animal such as the woodland caribou. GPS telemetry provides a cost-effective way to accurately and intensively monitor caribou locations. However, there are a number of potential problems in using GPS telemetry to monitor animal movements. Satellite visibility, and hence fix frequency and precision may be affected by physical obstructions caused by animal activity, vegetation and topography (Rempel *et al.* 1995; Moen *et al.* 1996; Rumble and Lindzey 1997). The effects of shielding vegetation can be significant. Rumble and Lindzey (1997) found nearly 50% of attempted GPS locations failed in stands with > 70% overstory canopy cover. GPS telemetry is a new and burgeoning field, and these biases may be corrected by techniques similar to the sightability models that correct population counts based on vegetation and animal behaviour. Despite these challenges, GPS technology, along with cumulative effects modeling and advances in spatial analysis using geographic information systems provide powerful mechanisms to assess the effect of industrial developments on wildlife.

5.2 Management Implications

There are logically two strategies to mitigating the large functional habitat degradation through avoidance demonstrated in this study. Firstly, attempts must be made to reduce the level of disturbance in caribou habitat, in order to reduce the avoidance effects of human infrastructure, and secondly, the human footprint on the landscape should be minimized.

In order to assess the management implications of this research it is useful to review the current guidelines that exist regarding industrial development in caribou habitat. Information Letter 91-17 is a procedural guide for oil and natural gas activity on caribou range. It states that "Petroleum and natural gas exploration and development activities can occur on caribou range provided that the integrity of the habitat is maintained to support its use by caribou" (Department of Energy 1991). The large functional habitat degradation that results from caribou avoidance of industrial infrastructure in the study area (and by extrapolation, throughout northern Alberta) indicates IL 91-17 has been contravened. Although population changes as a result of this behavioural response have not been addressed by this study, the potential magnitude of functional habitat loss suggest it would be prudent to place limits on the amount, intensity and duration of development in caribou habitat.

Parcels of land that are located in caribou range, and are advertised in the Public Offerings of Crown Petroleum and Natural Gas Rights are already accompanied by the addendum that "access is subject to specific restrictions" (Department of Energy 1991). In practice, in the northeastern boreal region, these restrictions are limited to a March 1 deadline to exploration and development. Current industry guidelines call for a shut-down of industrial activity in key caribou zones by 1 March each year to reduce stress on female caribou during late pregnancy (Northeast Regional Standing Committee on Woodland Caribou (NERSC) 1997). Current guidelines in the northeast boreal region for timing of industrial activity are as follows:

1. Between March 1 and June 15, no activity other than production operations (pumping, loading and hauling product, road maintenance and drilling on existing pads), will be permitted in the infield zone.

2. Prior to March 1, a meeting with the local regulatory persons and a program proponent would be convened, at which time a geographic boundary around a Heavy Oil development would be established that would identify infield and outfield zones. These zones would be marked on the Operations Plan map.

3. The "Infield" zone would be the current main core of high intensity activity where drilling and construction operations would be allowed.

4. The "Outfield" zone would be those outside the main core area where all activity would continue to be prohibited between March 1 and June 15.

Oil and gas exploration over much of northern Alberta can only take place over frozen ground. In most years, this means that exploration activity cannot begin until December. With the March 1 deadline in place, the drilling season is limited to two months versus up to three months without restriction. For producers with aggressive drilling programs, the March 1 deadline represents a substantial impediment to development. For producers with only modest drilling programs, the opportunity to connect these wells with pipelines in the same winter season is doubtful. From a biological perspective, the March 1 deadline represents a crude but important mechanism for protecting caribou from disturbance and harassment when they are likely to be most vulnerable. However, the March 1 deadline can logically only be considered as an interim measure, since as the oilfield develops and the "Infield" zone expands, the area protected by the strong "Outfield" timing restriction will continue to dwindle.

The study area fell under the jurisdiction of the northeast boreal region guidelines until 1997, when an addendum to operating guidelines in caribou zones (Northwest Regional Standing Committee on Woodland Caribou 1997b) described the adoption of northwest boreal region guidelines (Northwest Regional Standing Committee on Woodland Caribou 1997a) for the study area. Northwest boreal region caribou guidelines lack a definite timing restriction, instead following the principle of planning winter work for as early in the season as possible, to minimize disturbance to caribou. Nevertheless, this more flexible approach could be construed as as a weakening of caribou protection measures in the study area.

More disturbingly, the addendum to the Northwest guidelines (Northwest Regional Standing Committee on Woodland Caribou 1997b) stated that "the high intensity development area (which corresponds to this study area) *should not be managed to protect caribou* until the majority of oil production was completed. At this time, reclamation would restore the area to usable habitat". This directly contradicts the spirit of IL 91-17 and seriously questions the commitment to realistically balance caribou conservation with resource extraction in Alberta.

IL 91-17 recognizes the importance of considering the cumulative effects of development activities, rather than considering each development application on a well-by-well basis (Department of Energy 1991). However, with the exception of the March 1 deadline, no attempts have yet been made to co-ordinate, concentrate or reduce development activities in the study area, or any other caribou management zone in Alberta. IL 91-17 mandates the Alberta Department of Forests, Lands and Wildlife with the task of monitoring and assessing the risk of development to caribou, and "if justified request that operators modify their activities" (Department of Energy 1991). Given the magnitude of behavioural effects noted in this study, it is reasonable to assume that there is justification for action.

Human infrastructure *per se* is not the most important factor determining the disturbance effects of linear corridors. Human activity associated with roads and other corridors is probably the major source of disturbance for wildlife. One of the most important tools in reducing the effect of linear corridors on woodland caribou may be *access management*, the control of human use of the disturbance corridor. Access management has traditionally meant controlling public access to caribou habitat areas, but this view should be expanded to management of all human use of caribou habitat areas. Community support is necessary for an access management plan to succeed, since recreational users may argue they have a right to use new roads developed on public land (Jalkotzy *et al.* 1997).

Access management features prominently in IL 91-17, which states that "Access should be managed to protect caribou (Department of Energy 1991). Access management can take many forms, including education of the general public and field staff through signs, posters and workshops, and physically deterring access through reclamation of temporary roads, removing bridges and culverts, restricting plowing on seismic lines during winter, use of manned and unmanned gates and low impact seismic lines.

Numerous techniques exist to reduce the human footprint on the landscape. Buying, rather than shooting more seismic lines may help prevent further fragmentation in caribou areas, as will siting more wells per pad and using directional drilling to reduce surface disturbance. There has been recent, increased awareness about the importance of integrated resource plans (Government of Alberta 1999), but generally adoption of the principles of integrated resource management have been slow. The co-operative Gulf-Surmount project recently initiated between Alberta-Pacific Forest Industries and Gulf Canada may provide a useful model for mitigating disturbance in caribou habitat.

Multi-stakeholder committees in Alberta have done much to raise industry awareness about woodland caribou issues over the last ten years, but achieved little that addresses specific management issues on caribou range (Hervieux *et al.* 1996). Woodland caribou populations are now facing unprecedented levels of habitat perturbation, and tough decisions are necessary if caribou conservation is to be balanced with resource extraction in Alberta.

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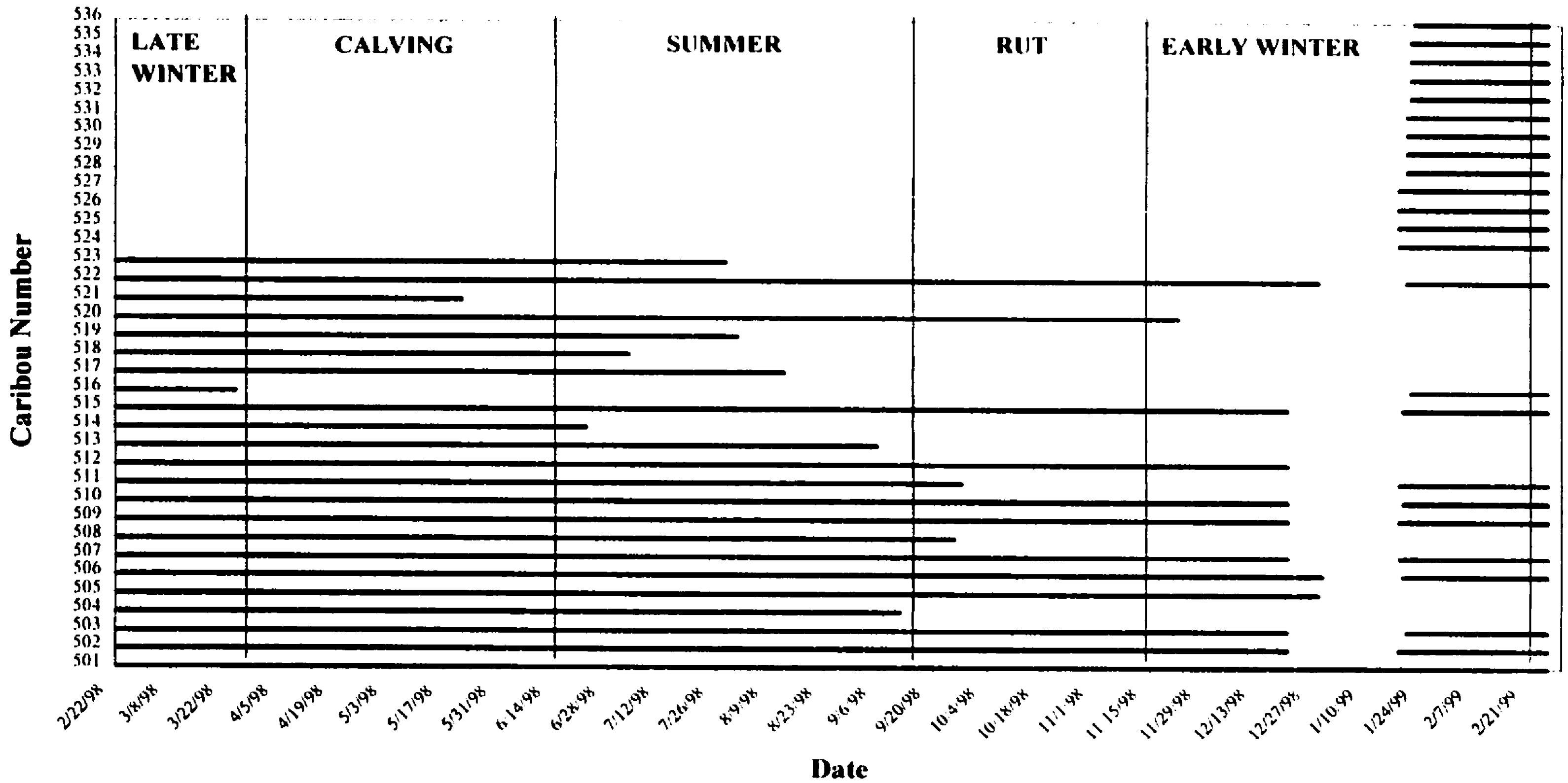


Appendix 3-1 Data collection performance of GPS collars. Gaps in coverage are due to caribou mortality, collar malfunction and battery failure.

Appendix 3-2. Log-ratio transformations of the proportion of caribou GPS locations in seismic line development buffers (late winter). Example.

$y = \ln (U_{a,n} / U_{b,n})$

Caribou #	A/B	C/B	D/B
501	-0.77	0.29	0.26
502	-0.61	0.32	0.62
503	-1.04	0.34	0.16
504	-1.31	0.61	0.75
505	0.02	0.29	-0.03
506	-0.54	0.61	1.00
507	-0.80	0.14	1.81
508	-0.76	0.22	-0.14
509	-0.64	-0.07	-0.46
510	-1.06	0.25	0.83
511	-0.46	0.75	2.68
512	-0.24	0.30	0.47
513	-2.83	2.04	3.58
514	-0.51	-0.06	-0.33
515	-1.38	0.80	0.56
516	0.02	0.55	0.08
517	-0.39	0.13	-0.52
518	-0.79	0.98	1.08
519	-1.33	0.15	-1.51
520	-0.04	0.58	-0.19
521	-0.42	0.55	-0.28
522	-0.51	0.18	-0.01
523	-0.42	-0.10	-1.69

Appendix 3-3. Log-ratio transformations of the proportion of each seismic line development buffer in each caribou home range (late winter). Example.

$Y_0 = \ln (A_{a,n} / A_{b,n})$

Caribou #	A/B	C/B	D/B
501	-0.28	0.22	1.03
502	-0.19	0.17	0.40
503	-0.11	-0.06	-0.38
504	-0.14	-0.01	-0.14
505	-0.11	-0.03	-0.32
506	-0.12	0.08	-0.17
507	-0.34	0.31	1.39
508	-0.14	0.04	-0.01
509	-0.14	0.01	-0.24
510	-0.10	-0.05	-0.07
511	-0.13	0.01	-0.03
512	-0.15	0.05	0.06
513	-0.26	0.22	0.75
514	-0.10	-0.08	-0.45
515	-0.16	0.07	0.15
516	-0.09	-0.01	-0.34
517	-0.10	-0.09	-1.30
518	-0.16	0.06	-0.087
519	-0.18	-0.06	-0.74
520	-0.10	-0.03	-0.28
521	-0.17	0.07	-0.01
522	-0.07	-0.12	-0.64
523	-0.11	-0.02	-0.26

Appendix 3-4. Log ratio difference scores of caribou GPS locations vs. availability of seismic line development buffers (late winter). Example.

$d = y - y_0$

Caribou #	A/B	C/B	D/B
501	-0.49	0.07	-0.78
502	-0.41	0.15	0.22
503	-0.92	0.40	0.55
504	-1.17	0.62	0.89
505	0.13	0.33	0.30
506	-0.42	0.54	1.17
507	-0.47	-0.18	0.41
508	-0.62	0.18	-0.13
509	-0.50	-0.08	-0.22
510	-0.96	0.30	0.89
511	-0.33	0.74	2.71
512	-0.09	0.26	0.41
513	-2.58	1.83	2.83
514	-0.40	0.02	0.13
515	-1.21	0.72	0.40
516	0.11	0.55	0.42
517	-0.28	0.23	0.78
518	-0.63	0.92	1.17
519	-1.15	0.21	-0.77
520	0.06	0.62	0.09
521	-0.24	0.48	-0.27
522	-0.44	0.30	0.64
523	-0.31	-0.08	-1.43

Appendix 3-5. Habitat selection. Log ratio means, standard errors and simplified ranking matrix for caribou use of seismic line development buffers (Late Winter). Habitats are ranked according to the log ratio scores. Significant differences between ranks are indicated by +++ or - - - in the ranking matrix. Example.

a) log ratio mean / SE

Buffer	A	B	C	D
A	-------------------	-4.78	-5.19	-3.76
B	4.78	-------------------	-4.48	-2.25
C	5.19	4.48	-------------------	-0.38
D	3.76	2.25	0.38	-------------------

b) ranking matrix

Buffer	A	B	C	D	Rank
A	---------------	- - -	- - -	- - -	0
B	+ + +	---------------	- - -	- - -	1
C	+ + +	+ + +	---------------	-	2
D	+ + +	+ + +	+	---------------	3

Appendix 3-6. Ranking matrix showing log-ratio means / standard errors for road development buffers in open coniferous wetland.

Late Winter, df = 6, t values > 2.45 indicate buffers that differ significantly at $\alpha = 0.05$

	A	B	C	D	E	F	G	No. positive
A	-----	-6.75	-3.55	-8.78	-7.78	-6.69	-11.07	0
B	6.75	-----	-0.16	-4.66	-2.54	-1.98	-3.98	1
C	3.55	0.16	-----	-2.64	-1.86	-1.19	-1.38	2
D	8.78	4.66	2.64	-----	1.45	1.33	-1.07	5
E	7.78	2.54	1.86	-1.45	-----	0.60	0.26	4
F	6.69	1.98	1.19	-1.33	-0.60	-----	-0.18	3
G	11.07	3.98	1.38	1.07	-0.26	0.18	-----	6

Calving, df = 6, t values > 2.45 indicate buffers that differ significantly at $\alpha = 0.05$

	A	B	C	D	E	F	G	No. positive
A	-----	0.39	-1.09	-2.91	-2.96	-3.54	-2.13	1
B	-0.39	-----	-1.48	-3.30	-3.35	-3.93	-2.51	0
C	1.09	1.48	-----	-1.81	-1.86	-2.45	-1.03	2
D	2.91	3.30	1.81	-----	-0.05	-0.63	0.78	4
E	2.96	3.35	1.86	0.05	-----	-0.58	0.83	5
F	3.54	3.93	2.45	0.63	0.58	-----	1.41	6
G	2.13	2.51	1.03	-0.78	-0.83	-1.41	-----	3

Summer, df = 5, t values > 2.57 indicate buffers that differ significantly at $\alpha = 0.05$

	A	B	C	D	E	F	G	No. positive
A	-----	-0.20	-0.83	-4.86	-0.47	-0.57	-3.66	0
B	0.20	-----	-0.75	-4.59	-0.44	-0.60	-3.42	1
C	0.83	0.75	-----	-4.50	-0.20	-0.21	-2.53	2
D	4.86	4.59	4.50	-----	1.15	1.25	-1.26	5
E	0.47	0.44	0.20	-1.15	-----	-0.04	-1.44	3
F	0.57	0.60	0.21	-1.25	0.04	-----	-2.22	4
G	3.66	3.42	2.53	1.26	1.44	2.22	-----	6

Rut, df = 5, t values > 2.57 indicate buffers that differ significantly at $\alpha = 0.05$

	A	B	C	D	E	F	G	No. positive
A	-----	-1.55	-1.89	-4.27	-4.75	-6.20	-6.05	0
B	1.55	-----	-0.29	-1.93	-2.31	-2.40	-2.69	1
C	1.89	0.29	-----	-1.67	-1.82	-1.59	-1.66	2
D	4.27	1.93	1.67	-----	-0.28	-0.92	-1.03	3
E	4.75	2.31	1.82	0.28	-----	-1.02	-1.21	4
F	6.20	2.40	1.59	0.92	1.02	-----	-0.57	5
G	6.05	2.69	1.66	1.03	1.21	0.57	-----	6

Appendix 3-7. Ranking matrix showing log-ratio means / standard errors for road development buffers in closed coniferous wetland.

Late Winter, df = 7, t values > 2.37 indicate buffers that differ significantly at α = 0.05

	A	B	C	D	E	F	G	No. positive
A	-----	-0.76	-3.50	-2.79	-2.74	-4.89	-6.06	0
B	0.76	-----	-2.94	-1.88	-2.45	-3.45	-3.93	1
C	3.50	2.94	-----	0.17	0.62	-0.91	-0.92	4
D	2.79	1.88	-0.17	-----	0.14	-0.89	-0.88	3
E	2.74	2.45	-0.62	-0.14	-----	-1.21	-1.06	2
F	4.89	3.45	0.91	0.89	1.21	-----	-0.25	5
G	6.06	3.93	0.92	0.88	1.06	0.25	-----	6

Calving, df = 4, t values > 2.78 indicate buffers that differ significantly at α = 0.05

	A	B	C	D	E	F	G	No. positive
A	-----	-2.56	-2.63	-1.45	-1.54	-0.57	-1.72	0
B	2.56	-----	-1.69	0.18	0.24	1.14	-0.43	4
C	2.63	1.69	-----	0.72	0.74	1.50	0.02	5
D	1.45	-0.18	-0.72	-----	0.16	0.98	-0.35	3
E	1.54	-0.24	-0.74	-0.16	-----	1.44	-0.42	2
F	0.57	-1.14	-1.50	-0.98	-1.44	-----	-1.05	1
G	1.72	0.43	-0.02	0.35	0.42	1.05	-----	6

Summer, df = 4, t values > 2.78 indicate buffers that differ significantly at α = 0.05

	A	B	C	D	E	F	G	No. positive
A	-----	-1.02	-2.30	-25.96	-1.02	-2.10	-5.54	0
B	1.02	-----	-2.16	-1.93	0.13	-0.24	-2.12	2
C	2.30	2.16	-----	-0.77	1.01	2.02	-0.86	4
D	25.96	1.93	0.77	-----	2.18	3.21	-0.68	5
E	1.02	-0.13	-1.01	-2.18	-----	-0.33	-1.71	1
F	2.10	0.24	-2.02	-3.21	0.33	-----	-2.38	3
G	5.54	2.12	0.86	0.68	1.71	2.38	-----	6

Rut, df = 4, t values > 2.78 indicate buffers that differ significantly at $\alpha = 0.05$

	A	B	C	D	E	F	G	No. positive
A	-----	0.29	-1.12	-4.21	-1.96	-1.82	-2.31	1
B	-0.29	-----	-2.28	-3.40	-4.31	-4.10	-1.26	0
C	1.12	2.28	-----	-2.41	-1.19	-1.19	-0.65	2
D	4.21	3.40	2.41	-----	1.04	1.12	0.81	6
E	1.96	4.31	1.19	-1.04	-----	-0.11	0.01	4
F	1.82	4.10	1.19	-1.12	0.11	-----	0.02	5
G	2.31	1.26	0.65	-0.81	-0.01	-0.02	-----	3

Appendix 3-8. Ranking matrix showing log-ratio means / standard errors for new wellsite development buffers.

Late Winter, df = 15, t values > 2.13 indicate buffers that differ significantly at $\alpha = 0.05$

	B	C	D	E	No. Positive
B	-----	-4.79	-4.18	-4.08	0
C	4.79	-----	-0.45	-0.41	1
D	4.18	0.45	-----	0.11	3
E	4.08	0.41	-0.11	-----	2

Calving, df = 12, t values > 2.18 indicate buffers that differ significantly at $\alpha = 0.05$

	B	C	D	E	No. Positive
B	-----	-1.46	-1.67	-4.21	0
C	1.46	-----	-0.80	-2.57	1
D	1.67	0.80	-----	-2.26	2
E	4.21	2.57	2.26	-----	3

Summer, df = 8, t values > 2.31 indicate buffers that differ significantly at $\alpha = 0.05$

	B	C	D	E	No. Positive
B	-----	1.22	-1.34	-0.73	1
C	-1.22	-----	-1.54	-0.95	0
D	1.34	1.54	-----	1.11	3
E	0.73	0.95	-1.11	-----	2

Rut, df = 7, t values > 2.37 indicate buffers that differ significantly at $\alpha = 0.05$

	B	C	D	E	No. Positive
B	-----	-1.76	-2.00	-2.45	0
C	1.76	-----	-1.41	-2.34	1
D	2.00	1.41	-----	-1.35	2
E	2.45	2.34	1.35	-----	3

Early Winter, df = 14, t values > 2.15 indicate buffers that differ significantly at $\alpha = 0.05$

	B	**C**	**D**	**E**	**No. Positive**
B	-----	-3.26	-3.45	-2.86	0
C	3.26	-----	-2.33	-1.36	1
D	3.45	2.33	-----	0.79	3
E	2.86	1.36	-0.79	-----	2

Appendix 3-9. Ranking matrix showing log-ratio means / standard errors for old wellsite development buffers.

Late Winter, df = 18, t values > 2.10 indicate buffers that differ significantly at $\alpha = 0.05$

	B	C	D	E	No. Positive
B	-----	-2.70	-4.61	-4.52	0
C	2.70	-----	-5.05	-3.76	1
D	4.61	5.05	-----	-2.05	2
E	4.52	3.76	2.05	-----	3

Calving, df = 12, t values > 2.18 indicate buffers that differ significantly at $\alpha = 0.05$

	B	C	D	E	No. Positive
B	-----	-1.09	-2.23	-2.95	0
C	1.09	-----	-1.95	-2.46	1
D	2.23	1.95	-----	-0.54	2
E	2.95	2.46	0.54	-----	3

Summer, df = 9, t values > 2.26 indicate buffers that differ significantly at $\alpha = 0.05$

	B	C	D	E	No. Positive
B	-----	-3.25	-2.57	-2.57	0
C	3.25	-----	-1.22	-1.04	1
D	2.57	1.22	-----	-0.49	2
E	2.57	1.04	0.49	-----	3

Rut, df = 8, t values > 2.31 indicate buffers that differ significantly at $\alpha = 0.05$

	B	C	D	E	No. Positive
B	-----	-1.42	-1.95	-1.77	0
C	1.42	-----	-1.41	-0.73	1
D	1.95	1.41	-----	-0.25	2
E	1.77	0.73	0.25	-----	3

Early Winter, df = 14, t values > 2.15 indicate buffers that differ significantly at $\alpha = 0.05$

	B	C	D	E	No. Positive
B	-----	-1.06	-1.85	-2.00	0
C	1.06	-----	-1.50	-1.39	1
D	1.85	1.50	-----	-0.51	2
E	2.00	1.39	0.51	-----	3

Appendix 3-10. Ranking matrix showing log-ratio means / standard errors for seismic line development buffers.

Late Winter, df = 22, t values > 2.07 indicate buffers that differ significantly at $\alpha = 0.05$

	A	B	C	D	No. Positive
A	-----	-4.78	-5.19	-3.76	0
B	4.78	-----	-4.49	-2.25	1
C	5.19	4.49	-----	-0.39	2
D	3.76	2.25	0.39	-----	3

Calving, df = 18, t values > 2.10 indicate buffers that differ significantly at $\alpha = 0.05$

	A	B	C	D	No. Positive
A	-----	-5.49	-4.61	-2.77	0
B	5.49	-----	-1.25	0.84	2
C	4.61	1.25	-----	1.92	3
D	2.77	-0.84	-1.92	-----	1

Summer, df = 11, t values > 2.20 indicate buffers that differ significantly at $\alpha = 0.05$

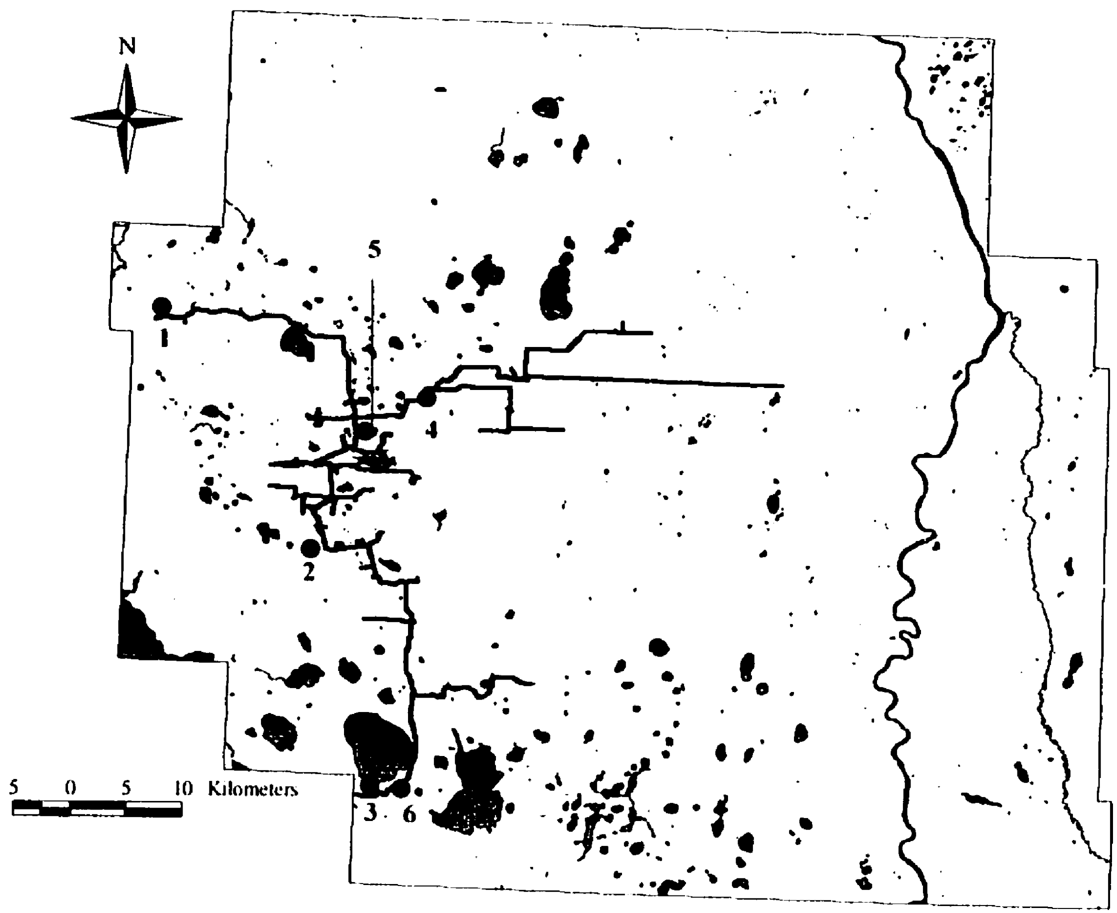
	A	B	C	D	No. Positive
A	-----	-2.88	-3.43	-2.27	0
B	2.88	-----	-1.82	-0.70	1
C	3.43	1.82	-----	0.12	3
D	2.27	0.70	-0.12	-----	2

Rut, df = 9, t values > 2.26 indicate buffers that differ significantly at $\alpha = 0.05$

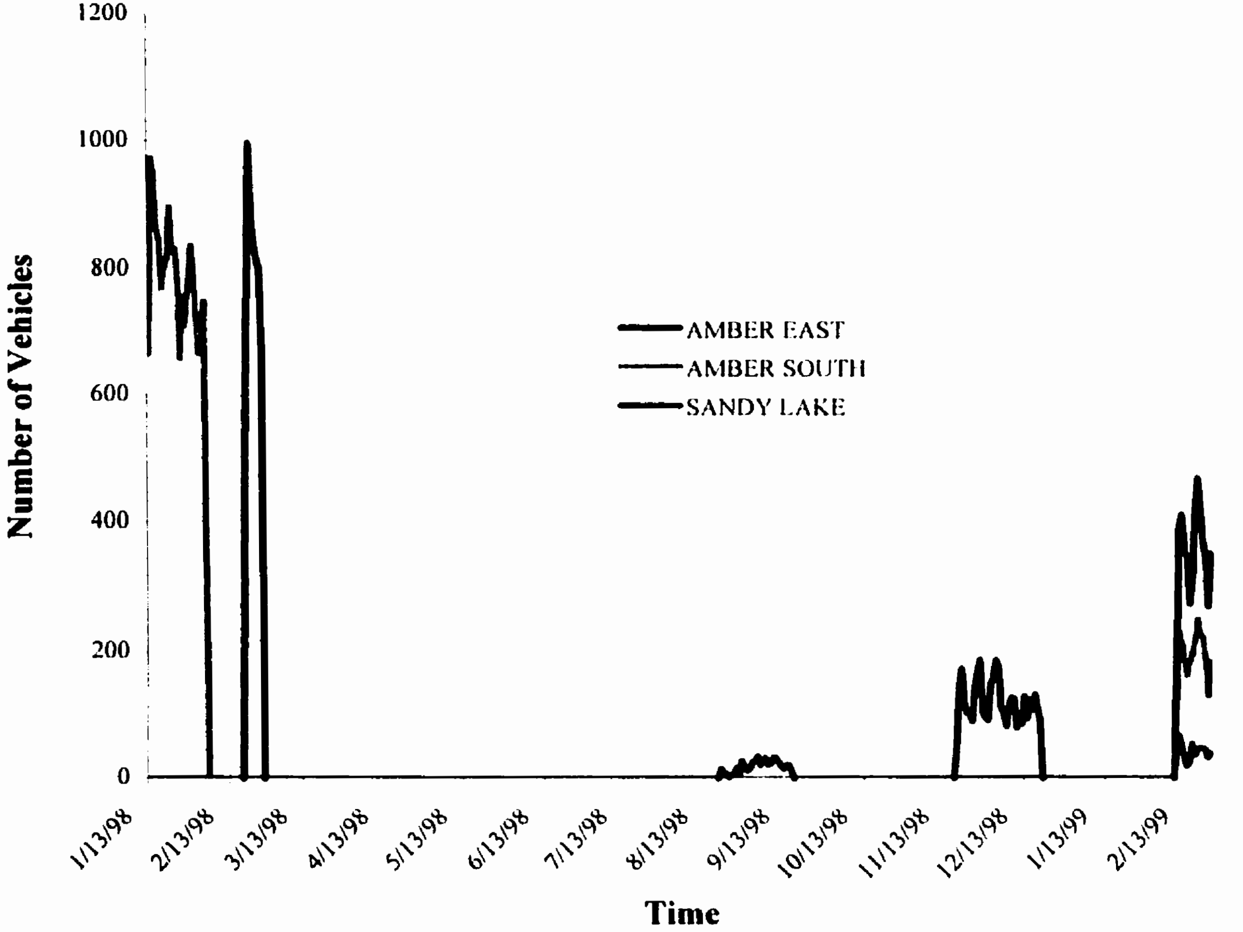
	A	B	C	D	No. Positive
A	-----	-3.85	-3.05	-3.97	0
B	3.85	-----	-1.28	-1.26	1
C	3.05	1.28	-----	-0.24	2
D	3.97	1.26	0.24	-----	3

Early Winter, df = 16, t values > 2.12 indicate buffers that differ significantly at $\alpha = 0.05$

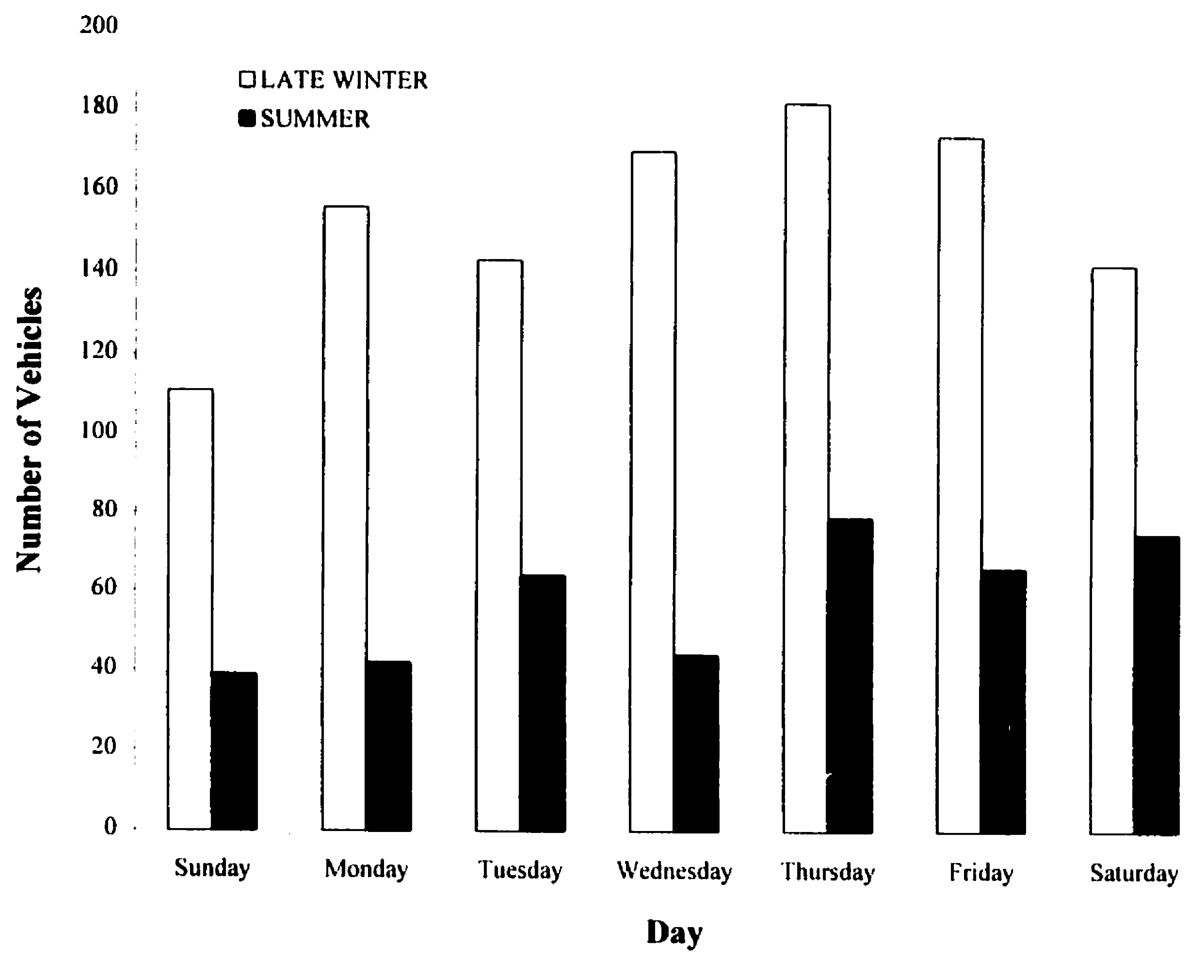
	A	B	C	D	No. Positive
A	-----	-4.75	-5.35	-4.81	0
B	4.75	-----	-2.31	-1.72	1
C	5.35	2.31	-----	-0.67	2
D	4.81	1.72	0.67	-----	3



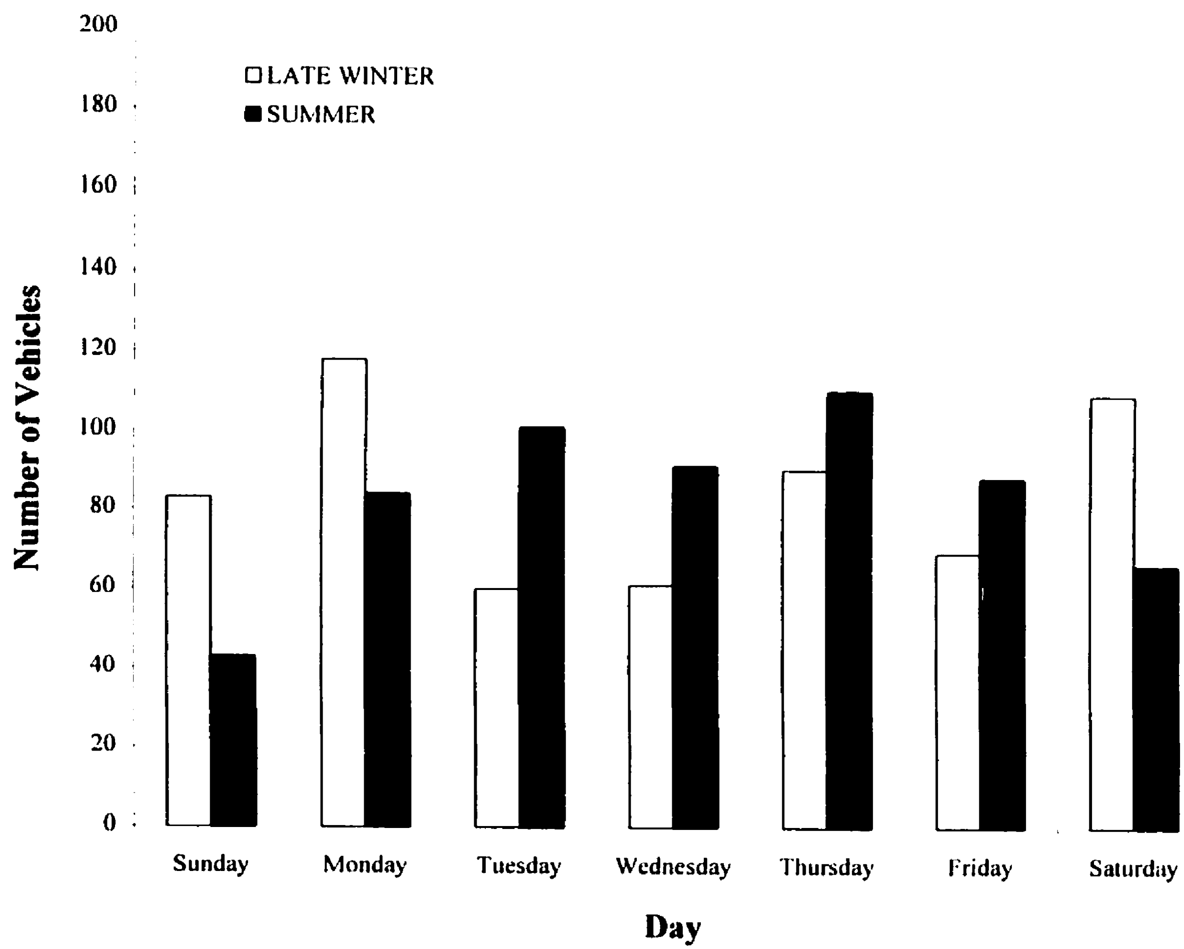
Appendix 4-1. Location of vehicle checkpoints and traffic classifiers in the study area. (1) Alpac-Amber checkpoint, (2) Pan-Canadian checkpoint, (3) Sandy Lake Road checkpoint, (4) Amber East classifier, (5) Amber South classifier, (6) Sandy Lake classifier.



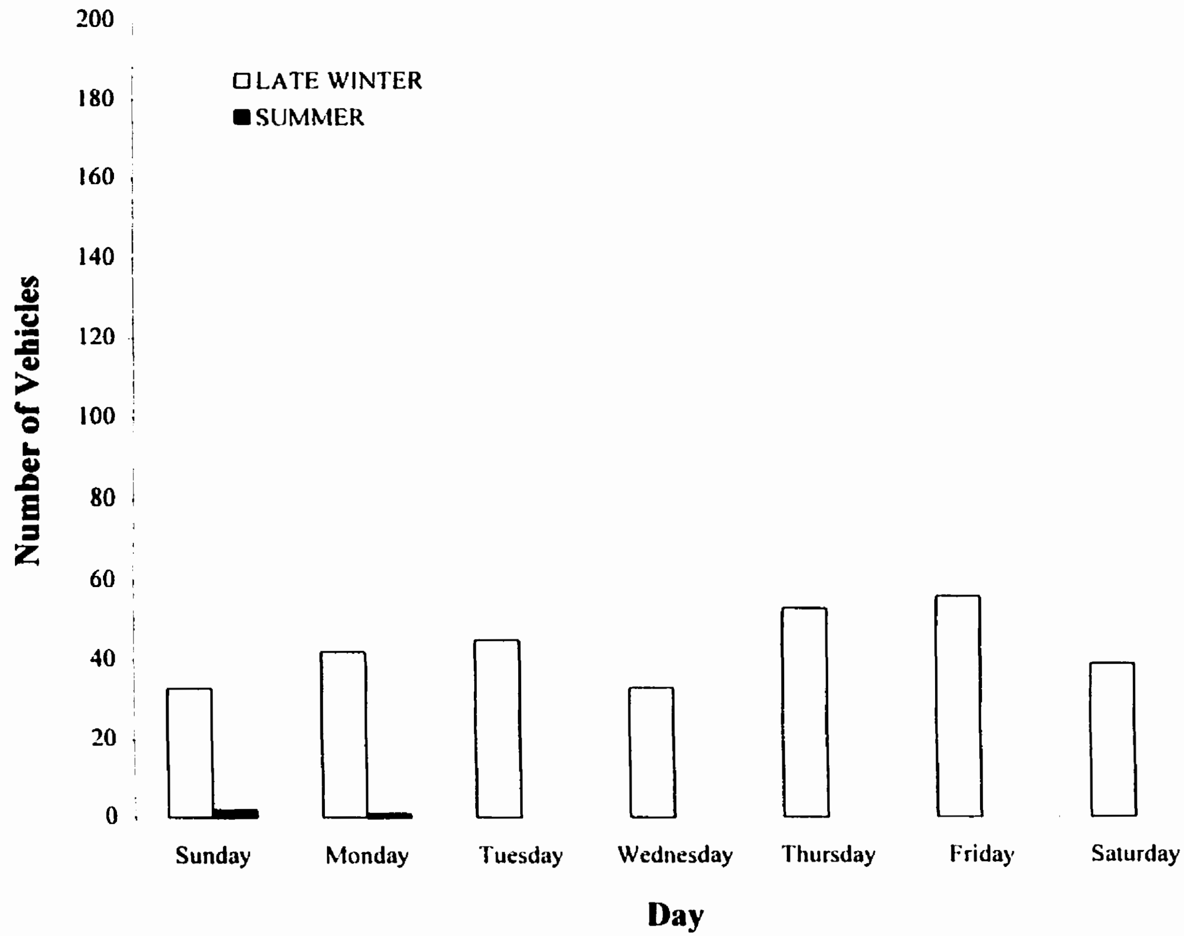
Appendix 4-2. Vehicle traffic classifier data collected during the study period. Although the coverage is fragmentary, notice the general trend of highest traffic levels during late winter, low traffic levels during the summer and moderate traffic levels during early winter.



Appendix 4-3. Comparison of number of vehicles passing Alpac-Amber intersection checkpoint (one direction) in late winter (February 5-11, 1998) and summer (August 23-29,1998).



Appendix 4-4. Comparison of number of vehicles passing Pan-Canadian intersection checkpoint (one direction) in late winter (February 5-11, 1998) and summer (August 23-29,1998).



Appendix 4-5. Comparison of number of vehicles passing Sandy Lake Road checkpoint (one direction) in late winter (February 5-11, 1998) and summer (August 23-24, 1998). No checkpoint was stationed at the Sandy Lake Road after August 24.