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Responses of Mountain Caribou to Linear Features In a West-central Alberta Landscape

By

Paula Rae Oberg ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

in

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ABSTRACT

Industrial expansion of resource extraction requires increased access to remote areas, which may have detrimental effects for some wildlife species, including populations of Alberta's threatened woodland caribou (*Rangifer tarandus caribou*). Linear landscape features, associated with increases in access, have been implicated as a possible cause for caribou decline. In this study I investigated the response of migratory mountain caribou to linear features, including streams, roads, and seismic lines, within the foothills of west-central Alberta. Global Positioning System (GPS) telemetry data from twelve mountain caribou were collected over two winters, 1998-2000, and compared to a base map of linear features in a Geographical Information System (GIS).

The base map of linear features was created in ArcView GIS by digitizing 1998 Indian Remote Sensing Satellite (IRS) imagery with 5 m pixel resolution. The type and width of linear features were interpreted using the IRS imagery and available development maps, and subsequently compared to ground truthed data. Linear features were correctly typed 93.8% of the time. Mean percent accuracy of width interpretations was 86.3% (± 4.5%). Vegetation cover attributes were not successfully interpreted, but other linear feature data were obtained using road activity surveys, and aerial photographs to determine relative post-disturbance age of the linear features.

Caribou locations were distributed non-randomly around streams and roads, with preference increasing as the distance from these linear features increased. Caribou avoided streams to a maximum distance of 250 m, and roads to a maximum distance of 500 m. Insufficient caribou locations occurred around active roads for separate analysis, but caribou avoided in-active roads to a distance of 250 m, signaling that the mechanism for avoidance may be more than a response to increased human activity. There was no significant avoidance or preference by caribou for seismic lines. However, caribou were 26% more likely to occur around seismic lines greater than 23 years of age than around more recent lines. The lack of avoidance response by caribou to seismic lines determined in this study may be attributed to low statistical power, the possible success of current low impact mitigation measures, or to aspects of mountain caribou life history.

This study contributes additional evidence that linear features are affecting woodland caribou distributions and may be leading to functional habitat loss. Management approaches prescribed by current industrial operating guidelines on caribou ranges are discussed and I present additional strategies for reducing disturbance effects of linear features on mountain caribou habitat in west-central Alberta.

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Chapter 1. Introduction

1.1 Background

Since 1985, woodland caribou (*Rangifer tarandus caribou*) have been designated as an endangered species in Alberta under the Wildlife Act, and classified as threatened by provincial policy (Wildlife Regulation 1999). Populations studied since the 1970's have been stable or declining, with no population increases documented over that time (Brown and Hobson 1998). Human activities resulting in linear landscape features and associated increases in access have been implicated as possible causes for this decline (Edmonds 1988; Bradshaw *et al.* 1997). Due to the economic importance of these human activities, it has become crucial to strive for caribou conservation while simultaneously addressing development goals in Alberta (Brown and Hobson 1998).

To facilitate development on caribou ranges, while ensuring the integrity and supply of caribou habitat, standing committees have been formed (Alberta Department of Energy 1991). The primary role of the committees are to act as advisory bodies to the government, and search for effective, efficient industrial operating guidelines (Hamilton and Edey 1998). The West-Central Alberta Caribou Standing Committee (WCACSC) was formed to develop and apply an effective regional management strategy for caribou, based on the involvement and cooperation of industries, the public, and government agencies. The west-central Alberta region recognizes nine woodland caribou ranges, extending from Banff National Park to north of the Wapiti River (Brown and Hobson 1998).

Access management, habitat supply, and timing of development are the primary mitigative strategies currently targeted by the WCACSC (WCACSC 1996). The effectiveness of these key strategies at mitigating long-term impacts of human activities on caribou range is unknown, as the strategies have never been rigorously examined, even in areas where they have been in use for extended periods (Jalkotzy *et al.* 1997).

1.2 Woodland Caribou Ecotypes

Woodland caribou in Alberta have been classified into two ecotypes, with the distinction based principally on habitat use and seasonal migration patterns. The boreal ecotype inhabits fens, muskegs and jack pine or lodgepole pine habitats of the boreal forest, and terrestrial lichen comprise the bulk of their winter diet (Edmonds 1991). These boreal herds are non-migratory remaining primarily within forested habitats throughout the year (Edmonds 1986). The second ecotype is the mountain ecotype. Mountain caribou inhabit mountainous terrain (for at least part of the year) where moderate snow depths allow for primary foraging on terrestrial lichens (Edmonds 1991). The majority of mountain caribou undertake migrations of 80 km or more between their winter ranges in the forested foothills, and alpine calving and summer range (Alberta Forestry, Lands and Wildlife 1990).

Previous work by Dyer (1999) and James (1999) on linear feature impacts on woodland caribou in Alberta focused on the boreal ecotype. Although the distinction between woodland caribou ecotypes does not imply subspecies differences, variable adaptations to habitat by caribou in Alberta are recognized (Edmonds 1991). As a result, the impact of industrial development on habitat and population parameters, and management needs, of these woodland caribou ecotypes may vary (Edmonds 1991). In the west-central region of Alberta, 8 of the 9 recognized caribou ranges are occupied by the mountain caribou ecotype. This research focused on the Redrock/Prairie Creek mountain caribou range in the west-central region (Figure 1-1).

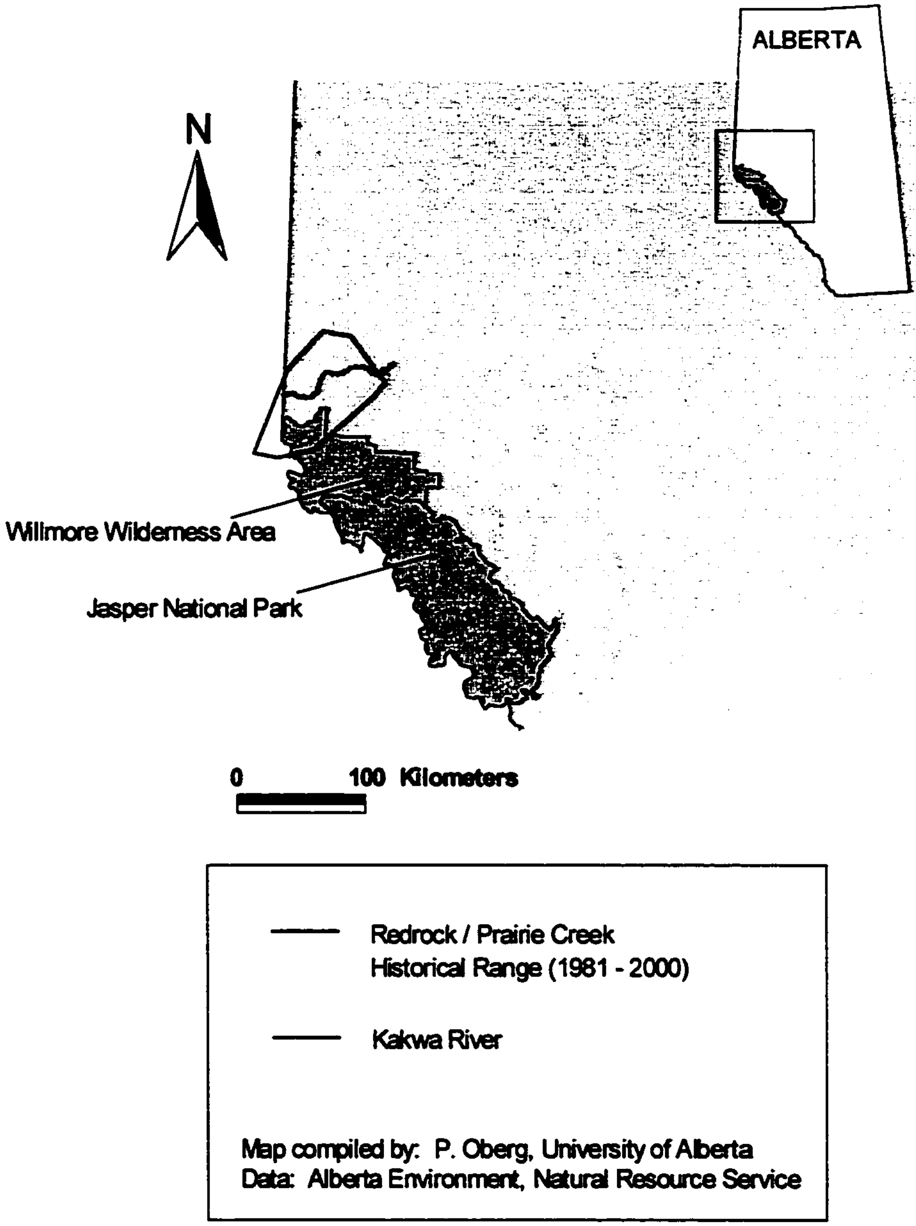
1.3 Human Activities in West-Central Alberta

Oil and gas exploration and production, forestry operations, and coal mining comprise the majority of industrial activities within west-central Alberta. Other land uses on provincial lands include recreational hunting, recreational vehicle use, grazing and commercial trapping (Brown and Hobson 1998). Primary land uses in national parks and wilderness areas are backcountry travel, recreational development, and recreational hunting (in wilderness areas only) (Brown and Hobson 1998). Measurement or mapping of land use activity types, levels, and access has not occurred (Brown and Hobson 1998).

Access within west-central Alberta is abundant. Access is provided by linear features, including a paved highway, roads for forestry and oil/gas production, and a railroad crossing a portion of the caribou winter range (Edmonds 1988). Cutlines, including seismic, pipeline right-of-ways (ROWs), and powerline ROWs, occur throughout the region (Table 1-1). Streams are also important linear features in the area. Although streams and rivers are not human developments, they are natural sinuous linear features that may facilitate movement of both humans and other animals, including predators (Seip 1992), into the region.

1.4 Linear Features in West-Central Alberta

A linear landscape feature is a relatively homogenous linear area that differs from its surroundings (Jalkotzy *et al.* 1997). Linear features have both internal and external



Map compiled by: P. Oberg, University of Alberta
Data: Alberta Environment, Natural Resource Service

Figure 1-1. Study area location in west-central Alberta.

structural characteristics. Internal characteristics can be grouped according to three attributes based on: width, internal entities (structures such as roads, ditches, powerline), and associated plant and animal community structure (Jalkotzy *et al.* 1997). The external structure of a linear feature relates to the surrounding landscape matrix, and includes attributes such as corridor length, density, curvilinearity and landscape connectivity (Jalkotzy *et al.* 1997). Both the internal and external characteristics may play a role in wildlife responses to linear features.

1.4.1 Roads

Roads in west-central Alberta can be categorized as all weather roads, dry weather roads or temporary winter access roads (WCACSC 1996; Smith *et al.* 2000). Access control measures (e.g., gates) are in place on temporary winter roads. Depending on their use, the width of the gravel surface for vehicular travel and surrounding ditch width will vary (e.g., wider ditches occur if a pipeline(s) is placed in the same corridor). Ditches in the region have erosion control measures in place, consisting primarily of self-sustaining vegetation cover (Alberta Energy and Natural Resources 1984).

1.4.2 Seismic Lines

Geophysical operations carried out by the petroleum industry when exploring for mineral reserves result in the creation of seismic lines across the landscape. As of 1984, seismic lines must not exceed 8 meters in width, although when detours are required the line may be another 3 meters wide (Alberta Energy and Natural Resources 1984) (note: lines created prior to 1984 may be wider than the 8 meter regulation). When approaching an all weather road, the cut line should be constructed at an appropriate angle to reduce line of sight (i.e. the distance that wildlife and humans can see down a line) (Alberta Energy and Natural Resources 1984). To prevent erosion, debris (e.g., felled trees) is spread over the line after exploration (Alberta Energy and Natural Resources 1984).

In designated sensitive areas for wildlife, exploration may be restricted to using heli-portable assisted equipment (Alberta Energy and Natural Resources 1984) and hand cut lines. This exploration, known as low impact seismic (LIS), produces meandering seismic lines with a targeted width of < 4.5 meters (WCACSC 1996). If a LIS line has a 5-6 meter width in caribou management zones, it requires government review (WCACSC 1996).

Once abandoned, seismic lines are revegetated with self-sustaining vegetation. In the Green Zone. which includes all forested lands, lines are seeded with commercial grass mixes (recommended seed mix includes fescue, wheat grass, timothy, alsike or white dutch clover) (Alberta Energy and Natural Resources 1984).

1.4.3 Pipeline ROWs

Pipelines are essential for transportation of energy reserves for production and export. The width of a pipeline ROW depends on several factors. The number of pipes, pipe diameter, working space required, slash disposal (burning vs. rollback of slash onto ROW after burial), amount of topsoil stripping, grading, depth of cover material, and trenching equipment all influence the ROW width (Alberta Environment 1988). Typically, pipeline ROWs range from 16 to 32 meters in width, and tree growth is restricted for operational service.

The Environmental Handbook for Pipeline Construction (Alberta Environment 1988) outlines environmental protection measures to be utilized by the pipeline industry. For example, during the planning of pipeline construction, it is recommended that the line of sight along the ROW be limited in forested areas of high wildlife value (AEP 1994). This can be accomplished through methods such as "doglegging" the ROW at selected road and trail crossings, which essentially deflects the ROW rather than maintaining it as a straight line (Alberta Environment 1988). Erosion control measures can include berms, and revegetation.

The objective of reclaiming a pipeline ROW after construction is to return the disturbed area to a land capability equivalent to the pre-construction state, through replacement and preparation of soil materials and the establishment of a self-sustaining protective vegetative cover (AEP 1994). Typically, a certified seed mix is used to revegetate the ROW (Alberta Environment 1988). The planting of shrubs on ROWs at road intersections may limit the line of sight in forested areas to encourage use of habitat by wildlife, but is not required (Alberta Environment 1988).

1.4.4 Powerline ROWs

Powerline ROWs have large, variable width clearings with occasional deflections to reduce the line of sight within forested areas (Alberta Energy and Natural Resources 1984). Once the powerline is in place, a self-sustaining vegetation cover (grass seed mixture) is established to stabilize the soil on the ROW. Tree growth on powerline ROWs is restricted for continuation of powerline service.

Table 1-1. Linear developments with variable attributes occurring in the study area.

Linear Feature	Width	Vegetation Cover
Roads	Variable (Typically > 30 m)	Gravel Road Surface Self-Sustaining Vegetation Cover in Ditches
Seismic Lines		
1. Conventional	5 – 15 m	Commercial Grass Seed Mix
2. LIS	< 4.5 m	Tree Growth not restricted
Pipeline ROWs	16 – 32 m	Commercial Grass Seed Mix Tree Growth Restricted
Powerline ROWs	> 30 m	Commercial Grass Seed Mix Tree Growth Restricted

1.5 Guidelines Applicable to Linear Features in West-central Alberta

The "Operating Guidelines for Industry Activity in Caribou Ranges in West-Central Alberta" became effective September 1, 1996 (WCACSC 1996). Since that time, the guidelines have been applied to operating approvals for resource-based industries, on a site-specific basis. The intent is that the guidelines will receive periodic review and modification based on experience in implementing the guidelines, new research information, and/or efficiency in conserving caribou populations and habitats (WCACSC 1996; NWRSCC 1997).

To achieve conservation of caribou populations and habitats, the operating guidelines are aimed at mitigating long-term impacts, while also managing short-term issues. Companies operating on caribou range must prepare an annual Caribou Protection Plan for their work programs. These plans are incorporated into operating approvals and serve as the wildlife mitigation strategy for dispositions (NWRSCC 1997). The WCACSC (1996) guidelines specific to linear features include (but are not limited to):

- Use of existing access;
- Use of shared/common access;
- Primary use of temporary access (< 2 years), which can be removed, reclaimed and reforested after use;
- Seek opportunities to reclaim and/or reforest existing access, well sites, and ROWs;
- Production operations to be primarily operated remotely and conducted without surface access;
- Use pipeline construction techniques which promote reforestation, and allow pipeline ROWs to revegetate;
- Place effective forms of public access controls on both temporary and permanent access (examples include signs, gates, patrols, manned access control, temporary rollback, blockage during non-active periods);
- Seismic lines should be low impact (LIS), cut with a narrow line width (target of < 4.5 m), be continuously meandering picking the path of least resistance, heli-portable where necessary, one pass operations, and hand cut lines where appropriate;

- Time activities to achieve the early in/early out philosophy for winter operations; and
- Fragmentation of habitat should be avoided within each caribou range. Various planning and operating options should be used to reduce the fragmentation concern.

Industry operators typically see operation restrictions as onerous and costly (Hamilton and Edey 1998). Even though members of the standing committees are involved in reviewing and ratifying caribou range guidelines, not all companies have demonstrated an equal commitment to applying them conscientiously at all times (Hamilton and Edey 1998). One problem is that the standing committees are strictly advisory bodies with no power to enforce compliance. Peer pressure and cooperation from within the bodies is relied upon to achieve compliance (Hamilton and Edey 1998). In addition, the effect of linear developments on woodland caribou remains poorly understood, and the biological basis of these regulations has been challenged by some industrial companies operating in caribou ranges (Dyer 1999).

1.6 Thesis Overview

The overall objective of this research was to provide a biological basis to assess the current operating guidelines within west-central Alberta with respect to linear features and mountain caribou. The potential impacts of linear features on caribou are reviewed in Chapter 2. To assess the existing guidelines, an accurate and up-to-date base map of linear features was created. Chapter 3 outlines the creation of a base map using a Geographical Information System (GIS), and the measurement of specific linear feature attributes (type, width, and vegetation cover). This base map was then used in Chapter 4 to determine the response of mountain caribou to different types of linear features.

Global Positioning System (GPS) caribou location data were obtained from the WCACSC and overlaid onto the base map to determine the response of caribou to linear features. Chapter 5 summarises the results and management recommendations developed from the base map creation and from the analysis of caribou responses to linear features with variable attributes. This concluding chapter also provides direction for future research with respect to linear features and mountain caribou within west-central Alberta.

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Chapter 2. Impacts of Linear Features on Caribou: A Literature Review

2.1 Introduction

Incremental increases in the abundance of roads, seismic lines, pipeline right-of-ways (ROWs), and powerlines are hypothesized to result in direct and indirect impacts on caribou populations. An impact can be defined as an alteration, which may degrade and/or enhance the environment, as a consequence of human land use or development activities (Shideler *et al.* 1986). Shideler *et al.* (1986) define direct impacts as those acting on the animals themselves, and indirect impacts as those acting on the habitat, either by changing it or by disrupting its use by caribou and other wildlife species.

Previous research conducted on linear developments has shown that caribou can be directly impacted from the creation of physical barriers to movement (e.g., Curatolo and Murphy 1986), and direct mortality (e.g., James and Stuart-Smith 2000). These direct impacts generate the indirect effects of habitat alteration (e.g., Banfield 1971), habitat avoidance (e.g., Dyer 1999), habitat loss (e.g., Hornbeck and Eccles 1991), increased human and predator access, and reduced spatial separation from alternative prey species (e.g., James and Stuart-Smith 2000). The hypothesized direct and indirect impacts of linear developments on caribou are summarized in Table 2-1.

2.2 Direct Impacts

2.2.1 Physical Barrier to Movement

Physical barriers to movement recorded for caribou include steep road cuts, berms and slash piles along roads and main highways (Bloomfield 1979, 1980b; Carlton 1982;

Table 2-1. Hypothesized direct and indirect impacts of linear developments on caribou.

HYPOTHESIZED IMPACT

Direct Impacts

1. Physical Barrier to Movement
   - Aboveground pipelines
   - Berms, debris, fences, etc.
2. Direct Mortality
   - Vehicle collisions

Indirect Impacts

1. Habitat Alteration
   - Snow characteristics
   - Vegetation composition
   - Increased mobility
   - Forage / salt source
2. Habitat Avoidance
   - Group distribution / composition changes
   - Fragmentation and reduction of range
   - Abandonment of range
   - May lead to dispersion into areas with increased predation risk
3. Habitat Loss
4. Increased Access
   - Predator mobility and access into previously inaccessible range
   - Legal and illegal hunting pressures
   - Recreational users
5. Reduced Spatial Separation from Alternative Prey Species
   - Increase in forage availability for alternative prey on linear developments (early successional vegetation species)
   - Alternative prey may increase in response to increase in forage availability
   - Predators numerical response to prey abundance
6. Traveling down linear features may divert migration patterns
7. Habituation to linear features may lead to an increase in predation risk

van Zwoll 1983), snowberms (Klein 1971; van Zwoll 1983), snowfences to protect highways and railroads (Klein 1971; Skogland and Molmen 1980), and pipelines laid on or near the ground (Villmo 1975).

Caribou may find berms associated with pipelines a visual barrier that results in behavioral disturbance in a manner similar to other ungulates (Jalkotzy *et al.* 1997). Bloomfield (1979) noted that windrows of logging slash created a physical barrier to passage for caribou. Hanson (1981) monitored caribou behavior in relation to an experimental pipeline berm and responses indicated that a visual barrier greater than 1.2 meters above ground had a pronounced effect on deflecting caribou movements. Animals readily traversed low berms (< 1.2 meters) but avoided higher berms (Hanson 1981).

Morgantini (1982) reported that pipeline ROWs did not represent a significant barrier to animal movement. Seven caribou crossings were recorded along the Grande Prairie Lateral and Elmworth Pipelines in Alberta one year after construction. The overall impact of the ROW during construction consisted of a reduction of wildlife range due to avoidance of the area in the immediate vicinity of the ROW (Morgantini 1984). The greatest impact on wildlife resulted from the presence of barriers to movement in the form of an extensive slash berm, an open ditch, and long stretches of welded pipe on the ground surface with no gaps (Morgantini 1984).

Caribou in the Prudhoe Bay and Kuparuk oil fields were only affected by linear developments when aboveground pipelines ran parallel to a road with traffic (Curatolo and Murphy 1986). Crossing success increased at sections of buried pipe isolated from road traffic. By comparison, Smith and Cameron (1985) reported that only 64% of caribou crossed the Kaparuk pipeline (after several attempts) and 247 caribou left the initial migrating group, changing the original herd composition and migration patterns. The authors concluded that the elevated pipelines created a physical barrier to the migrating caribou (Smith and Cameron 1985).

Carruthers and Jakimchuk (1987) consider the Trans-Alaska Pipeline to be properly constructed, having no affect on the traditional migration route of the Nelchina Herd. Buried sections of the pipeline at traditional migration passes and special crossing structures (e.g., ramps) have apparently helped maintain the travel route (Carruthers and Jakimchuk 1987) by allowing caribou to cross the aboveground pipeline.

Observations of tracks on and in the vicinity of a buried pipeline ROW in northern Alberta indicated that the pipeline did not obstruct movement. However, some animals were deflected for short distances (Eccles and Duncan 1986), which may have disrupted traditional movement patterns.

Dyer (1999) utilized GIS technology to examine if linear developments were causing a barrier to woodland caribou movements in northeastern Alberta. He concluded that roads might be acting as a barrier, as caribou crossed roads significantly less than randomly generated controls during both high and low vehicle traffic levels (Dyer 1999). Seismic lines however, were crossed at a similar frequency to controls (Dyer 1999).

2.2.2 Direct Mortality

Collisions with vehicles are an important source of mortality for the small woodland and mountain caribou herds in western Canada. For example, in 1963 the TransCanada Highway was constructed through the Selkirk caribou herds range and across its migration corridors through the Kootenay Pass area of British Columbia

(Shidelar *et al.* 1986). Construction of this major highway resulted in a proliferation of logging roads further into the herd's range. This created a direct source of mortality due to the animals' attraction to roads as a salt lick and resultant collisions with vehicles (Freddy and Erickson 1975; Johnson and Miller 1979).

Deaths of caribou, from the A la Peche herd due to vehicle collisions on Highway 40 near Grande Cache, Alberta have been high during some years (Brown and Hobson 1998). These caribou encounter the highway during the late fall and early winter as they return to winter ranges. They have been attracted to the asphalt road surface to lick salt applied during routine road maintenance. Mitigative programs, including actively harassing caribou to move off the highway and increased signage, reduced mortalities from 17 to 2 caribou between 1991 and 1995 (Brown and Hobson 1998).

2.3 Indirect Impacts

2.3.1 Habitat Alteration

Effects of habitat alteration associated with linear features depend on the specific situation. The type, width, surrounding vegetation and replanted vegetation all play a role in determining the level of habitat alteration. In Sweden, for example, domestic reindeer resist crossing under powerlines. Researchers attribute this behavior to the habitat alteration created by the combination of the powerline hum noise and changes in snow conditions with large forest openings (Villmo 1975).

Although caribou are adapted to movement in deep snow, depths of one meter or greater appear to affect woodland caribou feeding strategies (Brown and Theberge 1990; Bradshaw *et al.* 1997) and caribou distribution (Pruitt 1959). Caribou may move into denser forest stands during periods of high snow (Darby and Pruitt 1984; Edwards and Bloomfield 1984; Stuart-Smith *et al.* 1997), likely due to the increased energetic costs associated with cratering and moving through deeper snow in open areas (Fancy and White 1987). As well, the extensive open areas created by clearcutting are avoided by mountain and woodland caribou (Bloomfield 1979; Freddy 1979; Carlton 1982; Stevenson and Hatler 1985; Smith *et al.* 2000). Snow depth is considered a significant attribute in explaining this avoidance.

The relationship between linear features within a forest and overall habitat alterations based on snow depths and caribou movements is not fully known. However, the Porcupine Caribou herd in the Yukon were quick to use seismic line clearings and winter roads for travel routes. Banfield (1971) felt that the clearings provided unrestricted view and compact snow conditions for easy travel. Banfield (1971) also notes that this usage of linear corridors may have diverted pregnant females from reaching appropriate calving grounds by diverting movements down the line.

Incidental sightings of caribou tracks along the Norman Wells-Zama Oil Pipeline in the Mackenzie River and northern Alberta area indicated that the ROW was used year round for travel and as a spring and summer forage source (Eccles *et al.* 1985; Eccles and Duncan 1986). Cameron and Whitten (1980) found that caribou were attracted to new shoots of *Equisetum spp.* and *Eriophorum spp.* growing in the dust-covered wet meadows along the Trans-Alaska pipeline haul road. Some forest harvest operations have reported enhanced availability of forage for caribou by providing openings in dense forests that allow for colonization by terrestrial lichens (Shidelar *et al.* 1986).

Results from a study in the Alberta Caribou Mountains and Red Earth caribou ranges indicated high use of burns, cutlines, bogs, and roads for travel by caribou (Morton and Wynes 1997). During their study of mountain caribou in west-central Alberta and along the British Columbia border, Edmonds and Bloomfield (1984) witnessed the increased use of a recently constructed highway ROW by caribou, primarily to obtain forage in revegetated portions and salt from the roads.

2.3.2 Habitat Avoidance

In North America, the study of habitat avoidance by caribou in the vicinity of linear features began in the early 1970's, on Alaska's North Slope. In particular, the movements of barren-ground caribou in relation to the Trans-Alaska Pipeline corridor and haul road were monitored. The majority of this pipeline occurs aboveground, with caribou crossings implemented in traditional migration route paths (e.g., gravel pad/ramps, buried sections). Cameron *et al.* (1979) and Smith and Cameron (1983) reported that female caribou with calves avoided the Trans-Alaska pipeline and haul road. More pairs occurred further away from than near the disturbance corridor.

Roby (1978), Cameron *et al.* (1979), Cameron and Whitten (1980), and Fancy (1983) all reported local abnormalities in caribou distribution and group composition along the Trans-Alaska Pipeline corridor. They interpret these abnormalities as avoidance of the corridor (Cameron *et al.* 1995). However, Bergerud *et al.* (1984) suggest that all documented shifts in migration patterns can be attributed to changes in population sizes and concurrent reductions in range sizes, not the avoidance of linear features. Bergerud *et al.* (1984) pointed out that the Central Arctic herd continued to migrate north and south, parallel to the Trans-Alaska Pipeline System and the Dalton Highway, with the population increasing at an average annual rate of 13% (1973 – 1982). The construction of an oilfield access road and oilfield complex through a calving concentration area, in the Prudhoe Bay area of Alaska, altered the previous distribution of calving caribou (Cameron *et al.* 1992). Mean caribou density on the calving concentration area dropped from 1.41 to 0.31 caribou / km^2 within 1 km of the access road and increased from 1.41 to 4.53 caribou / km^2 at 5.6 km away from the road (Cameron *et al.* 1992).

In Newfoundland, caribou herds are distributed in areas away from high-use road systems and settlements, with calving areas located at maximum distances from these developments (Mercer *et al.* 1985; Northcott 1985). Northcott (1985) reported that caribou movements were disrupted by vehicular traffic during a construction period, but returned to pre-construction locations after the development was completed. Caribou approached trafficked access roads, reversed direction and moved 1.5 km from the area (Northcott 1985). Those animals that did cross did so when roads were closed to traffic, or at night when traffic levels were low (Northcott 1985).

During a well-controlled study in which Cumming and Hyer (1996) examined the effect of log hauling through a caribou wintering area. Prior to plowing the road, caribou utilized the road area as part of their habitat. Possible habituation to the presence of the road was suggested (Cumming and Hyer 1996). After experimental log hauling and plowing of the road occurred, the authors concluded that hauling logs caused caribou to avoid their winter ranges near the road, as animals occurred in areas farther from the haul road, some returning to summer habitat (Cumming and Hyer 1996). The areas to which the animals dispersed were considered to have higher predation risk (Cumming and Hyer 1996).

In northeastern Alberta, caribou locations are reported to occur further from linear corridors (corridors not classified) than random points, indicating avoidance of the corridors (James 1999; James and Stuart-Smith 2000). Further research by Dyer (1999), who classified the corridors, reaffirmed this result when he found that the density of caribou locations was significantly lower in areas closer to roads and seismic lines than expected, reporting a road avoidance of 250 m and a seismic line avoidance varying from 100 m (calving, summer, rut, early winter) to 250 m (late winter) depending on the season. Such avoidance patterns are believed to reduce the useable habitat for caribou considerably (Dyer 1999).

2.3.3 Habitat Loss

The activities associated with linear feature developments lead to a direct habitat loss for caribou. Woodland caribou have been characterized as "lichen specialists" dependent on old growth forests as a lichen supply (Thomas *et al.* 1996; Terry *et al.* 1996). Therefore, the potential loss of lichen supplies, with regeneration taking from 50 to 100 years (Cichowski 1996), must be considered a major component of caribou management plans (Thomas *et al.* 1996). However, compared to forestry and settlement activities, the habitat loss associated with linear features is not substantial in many areas. For example, in the Pedigree study area of northern Alberta, Hornbeck and Eccles (1991) estimated, using an average ROW width of 10 meters, that only 2% of caribou habitat had been physically removed due to linear developments. What may be more substantial than this 2% loss of potential lichen supplies are the indirect impacts associated with fragmentation and increased human and predator access from linear features.

2.3.4 Increased Human Access

Overharvesting of caribou herds has been the apparent cause of extirpation or severe decline of most North American caribou populations (Shideler *et al.* 1986). Linear features have been deemed the most important factor in determining the level of hunting mortality a caribou population experiences (Bergerud *et al.* 1984; Harrington 1996; Seip and Cichowski 1996).

Linear features provide increased access for hunters into caribou ranges, thereby increasing legal and illegal hunting pressure (Bergerud *et al.* 1984; Jalkotzy *et al.* 1997). In Alberta, recreational hunting of caribou was closed in 1981 (Bloomfield 1980a). Currently only Treaty Indians can hunt caribou in Alberta, but the animals are believed to provide only a minor source of meat and hides for these legal hunters (Edmonds 1986).

Nevertheless, poaching and hunter misidentification kills continue to affect local caribou populations and the continued development of road systems has provided ready access for hunters and poachers (Shideler *et al.* 1986). James and Stuart-Smith's (2000) data from northeastern Alberta reveals a trend that human caused mortalities of woodland caribou occur closer to linear features than expected. Of 31 known caribou mortalities in west-central Alberta between 1979-1984, 17 were illegally shot and three were native harvests (Edmonds 1988). Eighty three percent of all kills were found close to frequently traveled roads (< 50 m) and all were found during the winter season (Edmonds 1988).

Linear features also open up new terrain for recreational users (hikers, skiers, snowmobiles) (Simpson *et al.* 1996). Simpson *et al.* (1996) concluded that the unpredictability of humans on snowmobiles could displace caribou and force them into more rugged habitats where they could face increased energy expenditures and mortality risk from avalanches. During an experimental disturbance study, Simpson (1987) was able to determine that snowmobile use on Frisby Ridge, British Columbia, caused caribou distributions to shift. He believes that caribou were able to tolerate low levels of snowmobile use and if they were not harassed by snowmobiles their tolerance would likely increase. Caribou were capable of locating and avoiding a few machines but with many machines caribou abandoned the area (Stevenson and Hatler 1985; Simpson 1987).

Roads may also be affecting caribou within their seemingly protected refuges of National and Provincial parks. Dean and Tracey (1978) recorded that vehicle traffic within Denali National Park was affecting the feeding times and spatial distributions of caribou. It is believed that the disruption was a result of the associated dust, noise and motion stimuli. Ten years later, evidence from Singer and Beattie (1986) pointed towards caribou in the park becoming habituated to the road. However it was noted that avoidance responses to the road increased when visitors were out of their vehicles versus when vehicles alone were present (Singer and Beattie 1986).

There is evidence that the physical presence of linear developments may not act as an avoidance barrier to caribou movements (Bergerud 1974; Bergerud *et al.* 1984; Edmonds 1986). However, associated human access and, in particular, people and hunters outside of vehicles may be causing disturbance to individual caribou. This disturbance may be enough to lead to serious problems for those populations already seriously threatened.

2.3.5 Increased Predator Mobility

Wolf predation is often cited as a main cause of caribou mortality (Fuller 1989; Gasaway *et al.* 1989; Bergerud *et al.* 1984; Edmonds and Bloomfield 1984; Edmonds 1988; Seip 1992; Brown *et al.* 1994; Morton and Wynes 1997; Stuart-Smith *et al.* 1997). It has been speculated that linear features provide increased access for predators, most notably wolves, into caribou habitat (Bergerud *et al.* 1984; Edmonds and Bloomfield 1984; Thurber *et al.* 1994; Seip and Cichowski 1996; Stuart-Smith *et al.* 1997; James and Stuart-Smith 2000). Although wolves tend to avoid areas with high densities of roads (Theil 1985; Mech *et al.* 1988; Fuller 1989; Fuller *et al.* 1992), corridors that receive little human use may be attractive to wolves as easy travel corridors (Edmonds and Bloomfield 1984; Eccles and Duncan 1986; Horejsi 1981; Thurber *et al.* 1994).

For example, Horejsi (1979) and Morgantini (1984) found that wolves made extensive use of pipeline ROWs as travel corridors. This has been attributed to more favorable snow depth conditions on ROWs for wolves that allowed for easy travel over the entire region and facilitated hunting (Morgantini 1984). As well, increases in recreational activities, such as snowmobiling, are associated with an increase in linear corridors. Extensive snowmobile trails through winter range provide a means of easy travel for wolves (Edmonds and Bloomfield 1984). Cumming and Hyer (1996) noted, during track surveys, that wolves were following snowmobile trails. When caribou of the

Porcupine Herd in the Yukon were hunted by wolves along cleared lines, wolves had a clear advantage over their prey (Banfield 1971).

James and Stuart-Smith (2000) calculated wolf locations to be closer than random locations to linear corridors. Telemetry data provided evidence of wolves traveling on linear corridors in areas with limited activity (James and Stuart-Smith 2000). James (1999) discovered that not only were wolves utilizing linear corridors but they were also traveling up to 2.8 times faster on corridors than in the forest, which may be improving their search efficiency for prey, and their kill sites were closer to corridors than expected.

Park roads plowed for visitor use during the winter months may also be affecting predator/prey interactions. For example, Brown and Hobson (1998) recorded a caribou mortality close to a road, which had been plowed and served as a travel corridor for wolves into the South Jasper / White Goat caribou herds range.

The consequence of increased predator mobility is the increased chance of prey encounters and ultimately, predation (Bergerud 1983). Confounding this is evidence that caribou may be attracted to linear features for high quality forage (Banfield 1971) and ease of travel (Edmonds and Bloomfield 1984; Eccles *et al.* 1985; Eccles and Duncan 1986). If caribou are in fact attracted to linear corridors, it may be easier for wolves to cue in on denser and more predictable prey patches (Huggard 1993). It has been hypothesized that woodland caribou movements and their need for large home range sizes are a predator avoidance mechanism (Bergerud *et al.* 1984). Thus, an indirect impact of industrial related linear features may be the resultant fragmentation of predator avoidance mechanisms through a once largely inaccessible range.

2.3.6 Reduced Spatial Separation

Linear features may enhance an area for wildlife by providing a variety of browse, and by acting as travel corridors (Hurst 1997; Revel *et al.* 1984). Predators, wolves in particular, are attracted to linear features as easy travel corridors (Eccles *et al.* 1985; Seip 1992). They use frozen rivers as travel routes to search for prey (Huggard 1993), and may exploit linear features caused by human activities in a similar fashion. Prey species, such as moose and elk, are also attracted to the early successional browse found near natural linear features, such as streams (Seip 1992), as well as that found on and near anthropogenic linear features (Revel *et al.* 1984).

There are concerns that landscape changes associated with resource development may affect the predator-prey dynamics to the detriment of caribou (Edmonds 1988). Bergerud *et al.* (1984) suggest that caribou selection of low productivity habitat creates a spatial separation from other prey species (commonly moose), as an anti-predator strategy against wolves. Results supporting this hypothesis from northern Ontario (Cumming and Hyer 1996) and northeastern Alberta (James 1999), documented that caribou were separating themselves spatially from moose. Linear features have been hypothesized to erode the effectiveness of these habitat refuges by providing access routes for alternative prey, increasing the biomass of prey which could allow wolf numbers to increase to high levels, ultimately leading to a predicted increase in caribou predation (Bergerud *et al.* 1984; Seip 1992).

2.4 Summary

Linear features and associated access have been implicated as a limiting factor for woodland caribou in Alberta (Bradshaw *et al.* 1997; Edmonds 1996; James 1999). While caribou may be impacted from linear features as physical barriers to movement, direct mortality, through habitat alteration, avoidance, and loss, and through increased access to humans, predators and alternative prey species, previous research has focused on barren-ground caribou (see Roby 1978; Cameron *et al.* 1979; Cameron and Whitten 1980; Smith and Cameron 1983; Bergerud *et al.* 1984; Mercer *et al.* 1985; Curatolo and Murphy 1986; Cameron *et al.* 1992; Cumming and Hyer 1996). Only recently have woodland caribou movements and distributions been examined in relation to linear features within Alberta, and these studies have been conducted on the boreal, non-migratory woodland caribou ecotype (see Dyer 1999; James 1999). Although the distinction between woodland caribou ecotypes does not imply subspecies differences, different adaptations to habitat variation by caribou in Alberta are recognized (Edmonds 1991). As a result, the impact and management of linear features on woodland caribou habitat and population parameters may also vary between boreal and mountain ecotypes (Edmonds 1991). Future research on mountain caribou in west-central Alberta must focus on the response to expanding development, including the linear features resulting from this development (Brown and Hobson 1998).

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Chapter 3. GIS and Remote Sensing: Tools for Creating a Base Map of Linear Features in West-central Alberta

3.1 Introduction

Since 1985, woodland caribou (*Rangifer tarandus caribou*) have been designated as a threatened species in Alberta under the Wildlife Act (Wildlife Regulation 1999). Populations studied since the 1970's have been stable or declining, with no population increases documented over that time (Brown and Hobson 1998). Human activities resulting in linear landscape features, and associated increases in access, have been implicated as a possible cause for these declines (Edmonds 1996; Bradshaw *et al.* 1997; James and Stuart-Smith 2000).

Little is known about the effects of linear features on the woodland caribou mountain ecotype, which migrates from the Rocky Mountains to winter in the foothills of west-central Alberta. Most research on pipelines and roads has focused on barren-ground caribou (Curatolo and Murphy 1986; Cameron *et al.* 1992). Only recently have woodland caribou (boreal ecotype) movements and distributions been examined in relation to the linear features within Alberta (Bradshaw *et al.* 1997; Dyer 1999; James 1999; James and Stuart-Smith 2000), and it is not clear whether results from the boreal, non-migratory ecotype also apply to mountain caribou. Current industrial operating guidelines in west-central Alberta (WCACSC 1996) identify the width of right-of-ways (ROWs) and access management as primary mitigative strategies, but little is known about the effectiveness of these measures.

To investigate the distribution of mountain caribou in relation to different types of linear developments with variable attributes, wintering female caribou from the Redrock /

Prairie Creek herds were fitted with Global Positioning System (GPS) transmitters. Non-differentially corrected GPS data were collected for five caribou during the 1998/1999 winter and differentially corrected data were collected for eight caribou during the 1999/2000 winter. GPS transmitters are a relatively new animal location technique capable of collecting many accurate locations in a relatively short time, which is necessary to effectively examine subtle changes in caribou habitat use in response to human developments (Dyer 1999). The accuracy of GPS transmitters has been identified to be within 100 m using non-differentially corrected data and to within 10 m for differentially corrected data under a boreal forest canopy (Remple *et al.* 1995). Testing of GPS transmitters has found that position accuracy is not affected by tree species, spacing, height, basal diameter, or canopy closure of variable forest types, however open fields have a greater mean observation rate of satellites than in forested stands (Rodgers *et al.* 1997). GPS locations are also readily overlain onto map coverages within a Geographical Information System (GIS) (Rempel and Rodgers 1997). GIS is a powerful tool for accurately integrating and analyzing digital wildlife location data, but requires accurate digital map data on habitat and human development (Barnes *et al.* 1997; Rodgers *et al.* 1997).

Access within west central Alberta is abundant (Edmonds 1988) and is provided by linear features, including roads for forestry and oil/gas production, seismic lines for energy exploration, pipeline ROWs, and powerlines. There has been no measurement or mapping of linear feature attributes in this area, such as type, density, human access, or internal attributes, including width and vegetation cover (Brown and Hobson 1998). Although provincial government agencies maintain development and exploration records, these records are not currently in digital format, are extensive in quantity, and are extremely confidential as they are intended for seismic exploratory work (R. Jamison, pers. comm.). To facilitate the analysis of caribou distribution in relation to linear features, with variable attributes, an accurate and up-to-date base map of linear features was required that could be used within a GIS.

3.2 Objectives

This study had three objectives. The first objective was to develop a mapping technique that would allow linear features within the study area to be digitized into map coverages usable within a GIS. The second objective was to determine the accuracy of interpreting linear feature type, width, and vegetation attributes during the digitizing process. The third objective was a repeatability assessment of the mapping process and an assessment of observer bias. Both the second and third objectives required ground truthed data that were collected during July 1999.

3.3 Study Area

The study area occurs along the eastern ranges and foothills of the Rocky Mountains in west-central Alberta (54°N, 119°W). Bisected by the Kakwa River, the area encompasses the winter ranges for the Redrock / Prairie Creek caribou herds (see Figure 1-1). The topography is dominated by major ridges running in a northwest direction and dissected by numerous small drainages flowing into larger rivers (Edmonds and Bloomfield 1984). Lakes are uncommon.

The study area is comprised of two natural regions: the Subalpine and the Upper Foothills (Beckingham and Archibald 1996). Elevation ranges from 1100 m to 1800 m (Kansas and Brown 1993). The climate is subarctic, characterised by short, cool, wet summers and long, cold, dry winters (Smith *et al.* 2000). The Foothills Region is well forested, and has been described in detail by Edmonds and Bloomfield (1984). Dry sites support primarily lodgepole pine (*Pinus contorta*) or lodgepole pine/black spruce (*Picea mariana*) forests. At higher elevations, mixed fir (*Abies spp.*), spruce (*Picea spp.*) and lodgepole pine forest predominates. Willow (*Salix spp.*) and birch (*Betula glandulosa*) meadows, interspersed with dry grassy benches, are found along the drainages.

Primary land uses in the study area include: timber harvesting, extensive oil and gas exploration and development, coal mining, non-motorized outdoor recreation (hiking, horse travel, camping, fishing), off-road vehicle use (snowmobile, all-terrain vehicles), recreational hunting, and commercial trapping (Brown and Hobson 1998). Access in the area exists in the form of all-weather and dry-weather resource roads, and ROWs for pipelines, powerlines and seismic lines (Smith *et al.* 2000).

The study area selected for digitizing was restricted on the west and south borders by the availability of linear feature map data. The west border was delimited by the British Columbia / Alberta provincial border. The south border became the south border of Provincial Map Sheet #83. The east, west, and north borders were delineated from a buffer of 5000 m around a historical management zone for the ranges of the Redrock / Prairie Creek herds. The total study area encompasses approximately 4,200 km^2.

3.4 Methods

3.4.1 Data Source Assessment

A thorough investigation of available digital data on linear features in the study area revealed that current maps of human access routes were insufficient for the intended analyses. Weyerhaeuser Canada Ltd. provided Phase 3 Forest Inventory coverages containing forest polygon attributes, seismic lines, roads, and pipelines. However, the accuracy and temporal span of these linear feature coverages was not known (L. Miller, pers. comm.). As well, internal characteristics of the linear features were not interpreted. Aerial photographs (1:60 000) were available from the spring and fall of 1996 (missing 4 years of development). Orthorectified photos (1:15 000) in tiff image format, produced from the aerial photos, were provided by Weyerhaeuser Canada Ltd.; although orthorectified, they carried the same age limitations as the original aerial photos.

Available 1998 satellite imagery, from the Indian Remote Sensing Satellite (IRS) (5 m pixel resolution, acquired during April, October, and November with some overlap of images), provided the most current coverage of seismic lines, roads, pipeline ROWs, and powerlines in the study area. IRS imagery, in tiff file format, was obtained from Alberta Environment, Resource Data Division. The tiff files were built from mosaiced, orthorectified IRS imagery (6 bit data, resampled to a 5 m pixel resolution), UTM Projection, NAD 83. All tiff files had a spatial positioning accuracy of ± 10 meters, with some degree of radiometric enhancement for access feature delineation (R. Sleep, pers. comm.). The IRS imagery was used to create the base map, while the available aerial photographs, orthophotos, and resource access maps were used as additional references.

3.4.2 Digitizing the Base Map

ArcView GIS Version 3.1 (Environmental Systems Research Institute Inc. 1993) was used to digitize the linear features on the IRS imagery. To geographically reference each linear feature, the view was projected using Universal Transverse Mercator (UTM) Nad 83, which coincided with the previously referenced IRS tiff images. Each linear feature was digitized into an appropriate linear feature theme. Linear feature themes included: powerline, seismic line, pipeline, and road.

To record changes in width along each linear feature, a point theme was drawn. A point was drawn before and after every apparent change in width down the line, or at approximate intervals of 50 meters if the line had a continuous width. These intervals between points then became a single interpreted sample site along the linear unit. Using the Movement Analysis extension within ArcView, all points were selected, given X, Y coordinates, and then used to create a polyline (from point theme). Within the polyline attribute table, fields were added for width and type of line. Width was measured for each interpreted sample site along the linear unit using the ArcView 3.1 measuring tool, and added to the width field in the line attribute tables. Type was interpreted using a set of decision rules (Table 3-1). After the polyline theme was complete, it was merged into the appropriate linear feature theme.

Once themes were completed, they were converted to shapefiles and exported into ARC/INFO software (Environmental Systems Research Institute Inc. 1990). ARC/INFO was used to convert shapefiles to coverages, allowing projection of the original themes into UTM Nad 27. This projection is the current standard for caribou location data.

Table 3-1. Decision rules used to assign linear features to type classes.

LINEAR FEATURE	WIDTH	CURVATURE	ORIGINS	PANCHROMATIC TONE	OTHER
Seismic Lines	< 15 m	Meandering to Straight	No true beginning or end points [2].	Variable - relatively darker grey than other lines due to narrow width, tree overhang, regrowth of trees/shrubs, potential rollback.	Delineated on Resource Access Maps [4] as trails if origin prior to 1994.
Pipeline ROWs	15 - 30 m [1]	Straight	True beginning and end points [3].	Very light grey due to grass cover. Edge borders distinct.	Not delineated on Resource Access Maps.
Powerlines	> 30 m [1]	Straight	True beginning and end points.	Very light grey due to grass cover. Edge borders distinct, although edge boundary may change with variable width.	Delineated on Resource Access Maps as transmission lines.
Roads	> 30 m [1]	Meander	True beginning and end points.	Extremely light grey tones on gravel road surface, light grey in grass/shrub dominant ditch cover.	Delineated on Resource Access Maps as roads. Commonly include pipelines and seismic exploration (marked with shot hole tags) along ditches.

[1] Variable width as you move along some lines, due to number of pipelines in ROW, construction methods, etc.

[2] Seismic lines do not necessarily lead to a wellsite or road, but commonly start at a ROW or another point of access.

[3] True beginning and end refers to a line running from a wellsite to wellsite, or wellsite to road.

[4] Alberta Environmental Protection Resource Access Map 83 covers the study area. This map contains access information prior to 1994.

3.4.3 Ground Truthing

Sample sites along representative linear features within the Redrock / Prairie Creek herd's winter range were selected for ground truthing from 19 – 29 July, 1999. Sample sites were selected opportunistically, selecting for representative sites of variable linear feature type, width and vegetation cover. These sample sites were used to verify the base map generated from the satellite imagery. At each sample site, GPS location, type of development, and internal characteristics of the linear feature, including width, and vegetation coverage, were recorded.

The width of each linear feature sample site was measured from one distinguishable edge to another. As a general rule, edges were determined to start at the first mature tree (DBH > 10 cm) from the disturbed area. If more than one edge was clearly distinguishable (e.g. road surface and ditch to tree width), multiple measurements were recorded. Photographs were taken along edges and notes taken on the edge properties (sharp vs. gradual). I also recorded any overhang of trees or high vertical trees that may cause a shadow effect on satellite imagery, corridor features (vehicle tracks, berms, slash, road surface), and animal sign (tracks, scat, browsing).

A vegetation plot was established at the mid point of each sample site. Each plot was a circular quadrat with a radius of 10 m. If the corridor's width was < 10 m wide, the plot consisted of a 20 m transect down the corridor's length from edge to edge. Within the vegetation plot, the percent cover of the tree layer, shrub/seedling layer, forbs and grass-like plants layer were recorded. Layers were defined as follows: tree layer included all woody plants with > 10 cm DBH; shrub/seedling layer included all woody plants with a DBH < 10 cm; and the grass/forb layer included all herbaceous plants regardless of height, as well as some low woody plants (< 15 cm height). If gravel on a road surface or bare ground occurred within the plot, a percent cover was recorded for bare ground. The dominant and co-dominant tree species occurring within the sample quadrat and surrounding forest were also recorded. Percent cover of any lichen species was recorded. Any occurrences of non-native, potentially attractant, grass species, such as clover or alfalfa, were also noted.

3.4.4 Vegetation Cover Assessment

The IRS images containing the study area were acquired on the 23 April, 24 October, and on November 30, 1998. These imaging acquisition dates were not ideal for interpreting vegetation cover on the linear features, due to snow cover and low solar altitude. Thus, black/white aerial photography was chosen as the best available source for vegetation cover interpretations. The most recent aerial photography available was acquired on 29 May and 20 September 1996.

Prior to interpreting the vegetation cover for the entire set of linear feature map coverages, an analysis to determine if vegetation cover attributes, on linear features of varying type and width, could be interpreted from the available aerial photographs was completed. Ground truthed sample sites were randomly split into two groups. During the randomization process, care was taken to ensure that approximately half of the sites from each of the dominant vegetation cover categories (tree, shrub/seedling, grass/forb, gravel/bare ground) were placed into each of the two groups. The first group of sample sites (n = 28) was used to develop a vegetation cover interpretation key. This key contains grey tone, texture, and general appearance characteristics for each vegetation cover category (Table 3-2). Using this key as a guide, the remaining 37 sample sites were interpreted and overall accuracy was assessed using a classification error matrix. Using the matrix, the percent commission errors (number of sample sites identified as cover type X but known to be another cover type) and percent omission errors (the number of sample sites of cover type X identified as some other cover type) were also calculated from the interpretations.

3.4.5 Accuracy Assessment

The location of each sample site was spatially referenced on the base map and compared to the interpreted digitized measurements for verification of attributes. Percent relative errors in mapping of linear feature width were calculated for each sample site according to the following formula (Rowe *et al.* 1999):

$$\text{PRE} = \frac{\text{(Absolute value of difference in linear feature width)}}{\text{(Actual field width)}} * 100$$

This percent error was then interpreted as percent accuracy (100 – PE). Typing of lines and vegetation cover were assessed as percent of lines correctly interpreted.

Table 3-2. Characteristics of dominant vegetation cover classes on aerial photographs, acquired on 29 May and 20 September 1996.

Characteristics	Tree	Shrub / Seedling	Grass / Forb	Gravel / Bareground
Tone	dark grey	medium grey	varies from very bright to medium grey	bright/light grey (road surfaces) medium grey in ditches around roads
Texture	speckled with carpetlike appearance	speckled, changing slightly throughout	varies from very smooth to speckled	smooth texture (road surface)
General Appearance	very similar in appearance to surrounding forests	very similar to recent clearcuts and meadows	depending on width of line, grass/forb cover varies in appearance from road like to shrub-like very narrow lines appeared tree covered in reflectance	can see road surface surrounded by shrub/grass covered ditches

NOTES:

- wider lines had more distinctive differences between the dominant cover classes
- narrow lines, if grass/forb or shrub covered, exhibited shadows from surrounding forests
- lines which ran SW ↔ NE were much brighter than lines which ran NW ↔ SE, due to the sun's reflection
- 51% of the sample sites used to determine characteristics were influenced by shadows from surrounding forests

3.4.6 Repeatability Assessment

One interpreter completed the digitizing of the base map. To verify the digitizing methods and to test for observer bias, a second interpreter was used. This second interpreter digitized linear features containing 39 of the ground truthed sample sites, as well as one complete township (Twp 63, Range 8, W5M). Percent error and percent accuracy were determined for the second interpreter based on the ground truthed sample sites. As well, 55 road, 25 seismic, and 10 pipeline sites were selected from the second interpreter's completed township. From these sites, the interpreted line width from the original interpreter was compared to the second interpreter's data.

3.5 Results

An up-to-date base map of linear features with type and width attributes was constructed (Figure 3-1). A total length of 2,804 km of seismic lines, 59 km of powerlines, 62 km of pipelines, and 1,346 km of roads were digitized. Table 3-3 outlines the total length, total number of segments per line, and a summary of each linear features segment widths. Cutblocks, wellsites, and open pit mines were also digitized as polygon features on the final base map (Table 3-4).

3.5.1 Vegetation Cover Assessment

Using the aerial photographs and vegetation interpretation key, vegetation cover interpretations were 60% correct overall when compared to the ground truthed sample sites (Table 3-5). However, this percent correct means very little since the variability for correctly interpreting dominant cover classes ranged from 0% - 92%: 92%

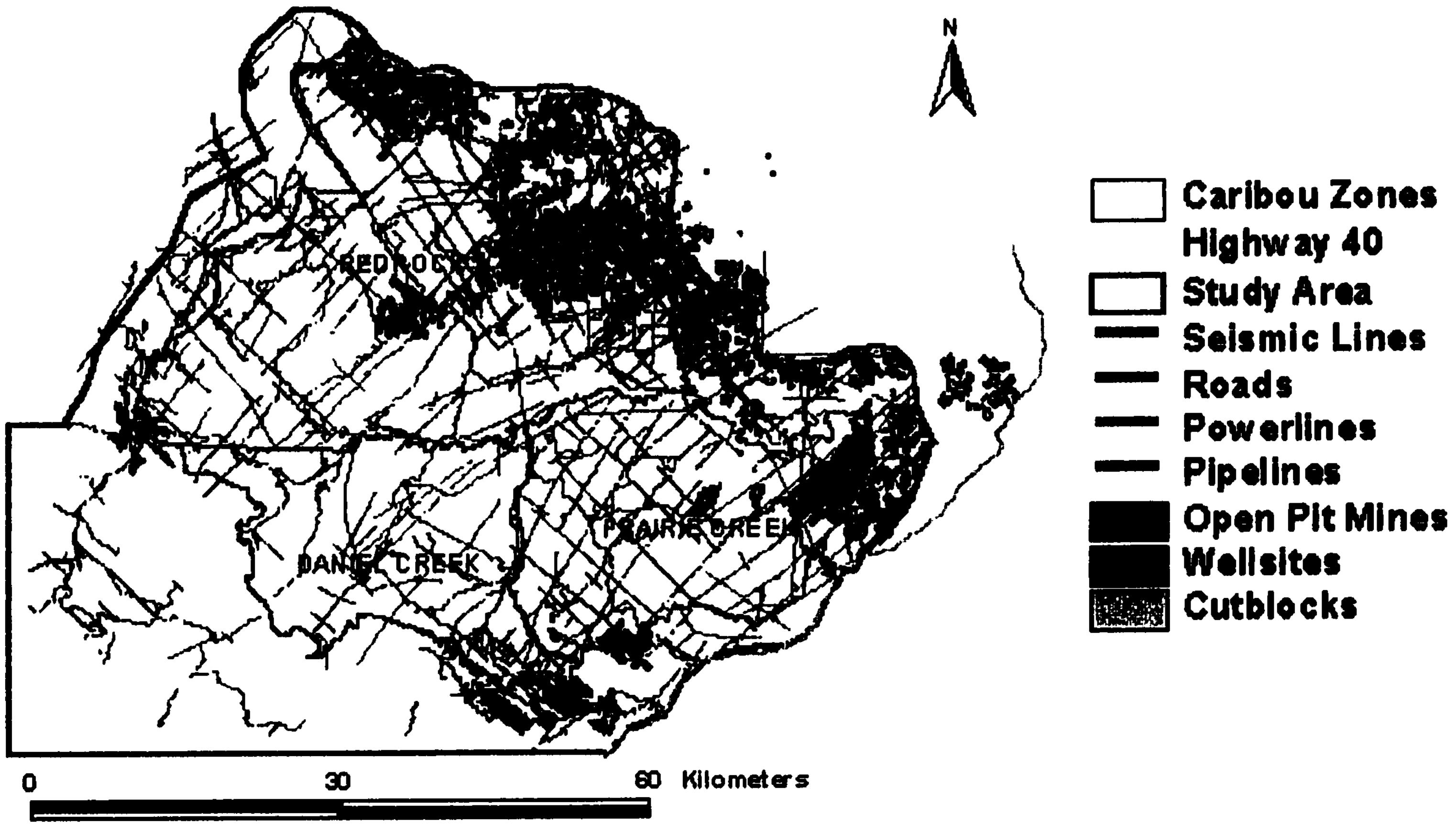

Figure 3-1. Linear feature base map digitized from IRS imagery.

Table 3-3. Summary of digitized linear feature map coverages.

Linear Feature	*Total Length (km)*	*Total Segments*	*Total ID's*	*Segment Length*				*Segment Width*			
				Mean (m)	Median (m)	SD (m)	5^{th}-95^{th} Percentile (m)	Mean (m)	Median (m)	SD (m)	5^{th}- 95^{th} Percentile (m)
Seismic Lines	2,803.7	45,432	872	62	44	72	17-156	9	8.3	3	6-14
Powerlines	59.2	680	4	87	57	89	22-204	45	40	9	35-70
Pipelines	61.7	928	33	67	42	78	20-174	19	18.0	7	14-26
Roads	1,345.7	30,425	340	44	37	40	16-92	21	18.0	12	9-44

Table 3-4. Summary of digitized polygon map coverages.

Polygon Feature	Total # Polygons	Total Area (km^2)
Cutblocks	738	231.2
Wellsites	137	1.8
Open Pit Mines	20	15.8

Table 3-5. Vegetation cover classification error matrix.

		"Ground Truthed" Data					
	Cover Type	Tree	Shrub/Seedling	Grass/Forb	Gravel/Bareground	Row Total	No. Committed
	Known Totals	*2*	*4*	*19*	*12*	*37*	
Classification Data	Tree	0	2	5	0	7	(7/7) 100%
	Shrub/Seedling	2	1	4	0	7	(6/7) 86%
	Grass/Forb	0	1	10	1	12	(2/12) 17%
	Gravel/Bareground	0	0	0	11	11	(0/11) 0%
	Column Total	2	4	19	12	37	
	% Correct	(0/2) 0%	(1/4) 25%	(10/19) 53%	(11/12) 92%		
	% Omitted	100%	75%	47%	8%		

Overall:

% Correct	60%
% Omission	41%
% Commission	41%

gravel/bare ground dominant; 53% grass/forb dominant; 25% shrub/seedling dominant; and 0% for tree dominated cover (Table 3-6).

Commission (inclusion) errors represent classification of a sample site into a category when it does not actually represent that category (Lillesand and Kiefer 1994). Omission (exclusion) errors represent not classifying a sample site into a given category when it represents that category (Lillesand and Kiefer 1994). Using the vegetation cover classification error matrix, commission errors were calculated at 41% (100% for tree dominated, 86% for shrub/seedling dominant), and omission errors at 41% (Table 3-5).

3.5.2 Accuracy Assessment

The primary interpreter correctly classified 94% of the ground truthed linear features as the appropriate linear feature type (n = 48 sample sites) (Table 3-7). The most common error for typing lines occurred between seismic lines and pipelines. Roads were interpreted correctly 100% of the time. The mean percent accuracy for width interpretation was 86%, with a 95% confidence interval of 82% to 91% (n = 65 sample sites) (Table 3-8). Linear features with a width less than 5 m (i.e. low impact seismic) could not be interpreted from the IRS imagery due to pixel size limitations, and therefore were not included in this analysis.

3.5.3 Repeatability Assessment

The second interpreter correctly typed 79% of the linear feature sample sites (n = 19 sample sites). This interpreter had a mean width interpretation accuracy of 66%, which ranged from 54% to 78% (95% confidence interval) (n = 39 sample sites)

Table 3- 6. Vegetation Cover Interpretation Accuracy.

Dominant Vegetation Cover	No. Sample Sites	No. Sample Sites influenced by Shade	No. Sample Sites Correctly Interpreted	% Correct
Tree	2	0	0	0 %
Shrub / Seedling	4	2	1	25 %
Grass / Forb	19	10	10	53 %
Gravel / Bareground	12	3	11	92 %
Overall	37	15	22	60 %

Table 3- 7. Accuracy of linear feature type interpretations using IRS imagery.

LINEAR FEATURE	No. sample sites	No. correctly identified	Accuracy (%)
Seismic	24	23	94
Pipelines	5	3	60
Powerlines	1	1	100
Roads	18	18	100
TOTALS	48	45	**94%**

Table 3- 8. Accuracy of linear feature width interpretations. Percent accuracy calculated from mean width absolute difference between IRS imagery and ground truthed (actual) measurements.

LINEAR FEATURE	*Ground Truthed Values*		*Width Accuracy*	
	Mean Width (m) (min-max)	No. Sample Sites	Mean Width Abs. Diff. (m)	Mean Width Accuracy (%)
Seismic	7.5 (1.5 - 15.0)	33	1.0 ± 0.3	84 ± 9
Pipelines	16.6 (13.3 - 20.4)	11	1.7 ± 0.7	90 ± 4
Powerlines	52.6 (45.1 - 60.0)	2	2.1 ± 3.8	97 ± 6
Roads	28.2 (9.1 - 49.9)	19	3.6 ± 1.1	88 ± 3
TOTALS		65		**86 +/- 5**

(Table 3-9). The mean difference between the two interpreters in road width interpretation was 5.1 m ($p < 0.001$, paired t-test). This mean difference in width is estimated to be between 3.9 m and 6.3 m (95% confidence interval). The mean difference between the interpreters in seismic line width interpretation was 2.6 m ($p < 0.001$, paired t-test). The mean difference in seismic line width was estimated to be between 1.9 m and 3.3 m between the two interpreters (95% confidence interval). For pipelines, the mean difference in width between the two interpreters was 3.3 m ($p < 0.020$, paired t-test). The mean difference in pipeline width interpretations was estimated to be between 0.7 m and 5.8 m (95% confidence interval, Table 3-10).

3.6 Discussion

The relatively new technology of GPS animal location data, coupled with the use of a GIS, permits the investigation of relatively fine-scale influences of linear features. Prior to analysis, however, researchers must ensure that base maps used within the GIS are an appropriate source of landscape information (Walker *et al.* 1986). Previously, 30-meter resolution Landsat Thematic mapper-derived habitat data was deemed an appropriate scale for analysis with GPS collar location data (Rempel *et al.* 1995). The IRS imagery, at 5-meter resolution, offers an even finer scale resolution when analyzed with the GPS caribou location data.

The greater than 85% classification accuracy, for both type and width attributes, obtained using the IRS imagery is adequate when investigating the distribution of mountain caribou in relation to linear features using a GIS. Type and width accuracy greater than 85% allows linear features to be separated into designated linear classes.

Table 3- 9. Accuracy of linear feature type and width interpretations from a second interpreter.

LINEAR FEATURE	***Type Accuracy***			***Width Accuracy***		
	No. Sample Sites	No. Correctly Identified	% Typing Accuracy	No. Sample Sites	Mean Width Ab. Diff. (m)	Mean Width Accuracy (%)
Seismic	7	6	86%	16	4.3 ± 1.3	40 ± 23
Pipelines	4	2	50%	10	1.8 ± 1.2	89 ± 7
Powerlines	1	0	0%	2	21.6 ± 9.2	56 ± 37
Roads	7	7	100%	11	3.8 ± 1.7	85 ± 8
TOTALS	19	15	**79%**	39		**66 ± 12**

Table 3- 10. Repeatability assessment of mapping technique. Mean width difference between two interpreters as compared to mean width of linear features sampled during ground truthing.

LINEAR FEATURE	***Ground Truthed Values***	***Repeatability Assessment***
	Mean Width (m) (min – max)	Mean Width Diff. (m)
Seismic	7.5 (1.5 - 15.0)	2.6 ± 0.7
Pipelines	16.6 (13.3 - 20.4)	3.3 ± 2.5
Powerlines	52.6 (45.1 - 60.0)	n/a
Roads	28.2 (9.1 - 49.9)	5.1 ± 1.2

Linear features were typed correctly for 94% of the ground truthed sites. Seismic lines and pipelines incurred the greatest amount of overlap. Mean width accuracy of 86% is considered adequate for measuring line widths in the study area. At this accuracy, linear features can be placed into width categories based on intensity of development (e.g., number of pipes and pipe diameter determine pipeline ROW width). These categories are relevant to current forestry and oil/gas operating guidelines (WCACSC 1996). However, this accuracy assessment did not include low impact seismic lines (< 4.5 m), the current operating goal for exploration in the study area, due to the pixel size on the IRS imagery. As well, the linear feature widths measured lacked variability within each of the linear feature types. As a result, measuring the width of lines proved to be helpful in classifying a linear feature into the appropriate type class but may not have shown enough variation in widths to discriminate whether caribou are avoiding linear features based on the width of a line, or whether they are avoiding a linear feature based on the type of linear feature.

In any remote sensing project, especially when visual analyses are involved, the data derived from one interpreter may be biased by numerous subjective factors (Crown 1979). These factors include familiarity with the study area, personal preference for one type of imagery over another, ability to discriminate various hues/tones or changes in tones, analyst fatigue, image quality variability on computer screens, etc. To determine the observer bias inherent in any remote sensing strategy, often a number of interpreters work with the imagery and all of their interpretations are compared to ground truthed data (Lillesand and Kiefer 1994). In this situation, only two interpreters were available for a comparison to the ground truthed data. The observer bias inherent in this exercise would presumably have decreased had more than two interpreters been used. As well, the lower percent accuracy for the second interpreter could be related to the lower sample size of ground truthed locations interpreted as compared to the initial interpreter. Although the overall width accuracy for the second interpreter was only 68%, the accuracy for pipelines and roads was still greater than 80%. The observer bias factors, lower sample size, narrow width of seismic lines, and use of a lower resolution computer screen by the second interpreter may all have contributed to the error associated with measuring seismic line widths.

The quality of the IRS images was variable on different computer screens. The initial interpreter utilized a 19 inch, MicroScan 6P color monitor, with a 1600 x 1200 resolution mode (at 75 Hz) (ADI Corporation 1999a). The second interpreter utilized a 17 inch, MicroScan 5P color monitor, with a 1280 x 1024 resolution mode (at 60 Hz) (ADI Corporation 1999b). These differences in computer monitors resulted in variable quality of the IRS images. To avoid potential differences during the digitizing process the same computing system and screen are recommended when completing the digitizing. The implications of a poor image during the digitizing process led to the inability to provide width measurements for some of the segments along the linear features. A width value of 0.9 for these segments was added into the attribute tables to verify which segments could not be interpreted.

Nevertheless, the significant repeatability between interpreters in width measurements indicates that use of the measuring tool within ArcView provided a relatively precise method for determining linear feature widths. A major complaint by the two interpreters was the difficulty in interpreting the type of line, particularly when making judgments between seismic lines and pipelines. The established rules for typing a line were useful and although the ability of typing lines cannot be increased any further, unless development and exploration records are obtained, the digitizing process was modified to better incorporate these rules. This involved adding several more fields to the linear feature attribute tables (start point, end point, map occurrence, and general reflectance).

The accuracy attained using the available aerial photographs to interpret vegetation cover on linear features was very low (60%), extremely variable (92% - 0%) and there was no detection of dominant tree cover. These low and variable accuracies are due to inconsistencies in vegetation cover patterns, as noted during creation of the vegetation cover key. These inconsistencies are likely the result of varying levels of sunlight on lines. Lines that ran SW to NE were very bright, and lines that ran SE to NW all tended to be dark, with shadows from surrounding forest. Lines that were shadowed were confused as tree covered (100% commission error). This image tone is consistent with the acquisition date of the photos and the sun's position (May 29th = max. altitude 58^0, azimuth 240^0; Sept 20th = max. altitude 37^0, azimuth 215^0 (U.S. Naval Observatory 2000)). In northern latitudes the sun has relatively low altitudes. As a result, during both acquisition dates the sun was low and sunrays were running SW to NE, resulting in 41% of measured lines affected by shade (Table 3-6).

During the vegetation cover key creation, I concluded that shrub dominant cover resembled meadows, road ditches, and clearcuts. A distinction between shrubs and grass could be made only when there was no shadowing from surrounding forests. Gravel road surfaces could always be seen, but gravel/bare ground dominant cover on seismic lines could not be determined. Coniferous tree cover could be interpreted, but deciduous tree stands could not be distinguished from deciduous shrub dominant cover. Wider lines tended to have clearer vegetation reflection attributes. As one moved into narrower lines (seismic), shadows tended to take over and make interpretations difficult.

Due to the inconsistencies found within the vegetation cover interpretation key, and the extremely variable and low accuracies for vegetation cover interpretation, vegetation cover on linear features could not be interpreted for the study area. These poor and variable results indicate that the available aerial photography was not sufficient for interpreting vegetation cover classes on the linear features in west-central Alberta.

3.7 Management Recommendations

Although access within west-central Alberta is abundant and has been targeted as a management concern for caribou, mapping of land use activity types and attributes had not previously occurred. With the creation of the base map, there is now sufficient digital information to analyze caribou location data with respect to linear features with variable attributes in a portion of west-central Alberta. As well, the method outlined provides a means for acquiring accurate digital base data, on type and width attributes, that can be used for wildlife studies investigating habitat selection and disturbance within a GIS.

Vegetation cover attributes of linear features within caribou ranges are focused on by current industrial operating guidelines (WCACSC 1996). Specifically, managers request that operators seek opportunities to reclaim and / or reforest existing linear developments on caribou range. However, the requirements of reclaiming a pipeline ROW after construction, for example, is to return the area disturbed to a land capability equivalent to the pre-construction state, through the establishment of a self-sustaining protective vegetation cover (AEP 1994). Typically, a certified seed mix is used to revegetate the pipeline ROW (Alberta Environment 1988). Before differing operating practices, like reclamation versus reforestation of pipeline ROWs, can be evaluated for their effectiveness in achieving caribou conservation, vegetation attributes on linear features need to be accurately mapped. Once mapped, caribou responses to the vegetation cover on linear features can be determined.

For vegetation cover interpretations to be made, an alternative source of imagery will have to be obtained for west-central Alberta. The imagery obtained should provide interpreters with the ability to eliminate the inconsistencies found in the vegetation cover interpretation key (specifically remove shadows), and should enhance tonal differences between vegetation cover classes (e.g., using small aircraft fly as close to ground as possible, using the visible and infra-red spectrums for image acquisition). To assess the accuracy of any future alternative imagery, I also recommend that the number of ground truthed sites be increased to allow for a sufficient number of sites to be split into those used to develop the interpretation key and those used in the accuracy assessment.

Currently, exploration activities occurring within west-central Alberta's caribou ranges involve low impact seismic (LIS) techniques. These techniques include a narrow line width of less than 4.5 m. It is believed that LIS will minimize the effect of exploration lines on the quantity and quality of caribou habitat (WCACSC 1996). The IRS imagery used in this research did not have the resolution to detect linear features less than five meters. I recommend that future research examine the true benefit that these low impact linear features have on caribou. This would require imagery with a one-meter resolution to be obtained. In September 1999, the satellite IKONOS was launched by

Space Imaging, providing the first commercially available one-meter earth imagery (ERDAS News 2000). This imagery would not only allow LIS to be detected, but would also reduce the width of pixelation and thereby increase the accuracy of measuring all linear feature widths.

Although mapping of linear features was completed, the method developed was extremely time intensive. However, due to the importance of having accurate base map data, I recommend that this digitized base map be maintained and updated periodically to assist future research on caribou and linear features in west-central Alberta. This base map maintenance could be achieved by repeating the methods used for the base map creation. Alternatively, digital records of construction, development and exploration could be added to the current base map as the activities are carried out. Compiled records could include not only the location of the activity, but attributes such as width, age, abandonment date, and re-vegetation strategies. However, this method of maintaining the base map would have to ensure that confidentiality for industry is maintained.

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Chapter 4. Responses of Mountain Caribou to Linear Features

4.1 Introduction

Populations of woodland caribou (*Rangifer tarandus caribou*) in Alberta have declined substantially in recent decades (Edmonds 1988). Concurrently, resource-based industries associated with the forestry and energy sectors have expanded dramatically (Edmonds 1988). Whereas rivers and creeks intersect a natural forested landscape, this industrial expansion has resulted in an increased network of rights-of-ways (ROWs) for seismic exploration, pipelines and roads. Human activities resulting in such linear landscape features, and the associated increases in access, have been implicated as possible causes for caribou declines (Edmonds 1996; James and Stuart-Smith 2000).

Linear features may enhance an area for wildlife by providing a variety of browse, and by acting as travel corridors (Revel *et al.* 1984; Hurst 1997). Predators, wolves in particular, are attracted to linear features as easy travel corridors (Eccles *et al.* 1985; Seip 1992). They use frozen rivers as travel routes to search for prey (Huggard 1993), and may exploit linear developments created by human activities in a similar fashion. Prey species, such as moose and elk, are attracted to the early successional browse found near natural linear features, such as streams (Seip 1992), as well as browse found near anthropogenic linear features (Revel *et al.* 1984).

There are concerns that landscape changes associated with resource development in the Alberta foothills may affect predator-prey dynamics to the detriment of caribou (Edmonds 1988). Bergerud *et al.* (1984) suggest that caribou select low productivity wintering habitat creating a spatial separation from other prey species (commonly moose), as an anti-predator strategy against wolves. Linear features have been hypothesized to erode the effectiveness of these habitat refuges for caribou by providing access routes for both alternative prey and predators, and increased search efficiency by predators in caribou ranges (Jalkotzy *et al.* 1997; James 1999).

Woodland caribou in Alberta have been classified into two ecotypes based principally on habitat use (Edmonds 1991). The boreal ecotype inhabits fens, muskegs and jack pine or lodgepole pine habitats of the boreal forest, and herds are non-migratory. The mountain ecotype inhabits mountainous terrain for spring calving and during the summer, migrating down into the lower elevation forested foothill habitats to winter. Management needs of these woodland caribou ecotypes may vary, as well as the impacts of industrial development on their habitat (Edmonds 1991).

Little is known about the effects of linear features on the woodland caribou mountain ecotype, which migrates from calving grounds in the mountains to winter ranges in the resource-rich foothills of west-central Alberta. Most research on pipelines and roads has focused on barren-ground caribou (Curatolo and Murphy 1986; Cameron *et al.* 1992), and only recently have woodland caribou movements and distributions been examined in relation to linear development features in northeastern Alberta (Dyer 1999; James 1999). James (1999) found that woodland caribou showed a strong selection for habitat different from moose and wolves. Caribou tended to occur further from linear developments, while wolves and their kill sites were closer than random to linear developments (James 1999; James and Stuart-Smith 2000). Wolves were also found to travel faster on linear developments than in the surrounding forest, which may improve their predation efficiency (James 1999). Dyer (1999), found that the density of caribou locations were significantly lower in areas closer to roads and seismic lines than expected, and that caribou crossed roads less frequently than expected from random movement. Such avoidance patterns may reduce the useable habitat for caribou considerably, and linear developments may be forming movement barriers for woodland caribou (Dyer 1999). It is not clear whether these results from the boreal, non-migratory ecotype also apply to migratory mountain caribou in Alberta and woodland caribou in other regions.

To sustain industrial activity on caribou ranges, while maintaining the integrity and supply of caribou habitat, regionally specific operating guidelines have been developed. The "Operating Guidelines for Industry Activity In Caribou Ranges in West-Central Alberta" became effective September 1, 1996. Access development and management, habitat supply, and timing of activities are the primary mitigation strategies targeted within the caribou range operating guidelines (WCACSC 1996). The guidelines will receive periodic review and modification based on experience in implementation, new research information, and/or efficiency in conserving caribou populations and habitats (WCACSC 1996).

4.2 Objectives

The objective of my study was to determine the distribution of mountain caribou in relation to natural linear features (streams) and anthropogenic linear features of varying type (seismic lines, roads, pipelines, powerlines), in order to identify avoidance patterns. Caribou distributions were determined by overlaying Global Positioning System (GPS) caribou locations onto accurate base map coverages of linear features within a Geographical Information System (GIS). Caribou response and avoidance effects from linear feature types, and active versus in-active roads, were determined using compositional analyses (Aebischer *et al.* 1993). I predicted that the frequency of caribou locations would increase as the distance from linear features increased, and that caribou would avoid active roads at greater distances than in-active roads and seismic lines. I also predicted that streams, as natural linear features and documented predator travel corridors (Seip 1992), would be avoided by caribou.

4.3 Study Area

The study area is part of the eastern slopes and foothills of the Canadian Rocky Mountains in west-central Alberta, adjacent to Jasper National Park (54°N, 119°W) (see Figure 1-1). It covers the winter ranges of the Redrock / Prairie Creek mountain caribou herds, which calve in June above treeline in the alpine areas of Willmore Wilderness Area and adjacent mountains in British Columbia. Alpine rutting grounds are used in September and October, and with increasing snowfall caribou migrate to lower elevation forests in November and December (Edmonds 1988). The core of the winter range of the Redrock / Prairie Creek herds is located on either side of the Kakwa River (Brown and Hobson 1998).

The study area covers the caribou management zone, which reflects previously recorded winter distributions of the caribou herds (Brown and Hobson 1998), and an added 5 km buffer to this zone. Adjacent areas, occurring within Willmore Wilderness Area, were not included, as no development is planned in wilderness parks (Willmore Wilderness Park Act 1996). This study area encompasses a total area of 4,202 km^2.

Elevation within the study area ranges from 1100 m to 1800 m (amsl) (Kansas and Brown 1996), and includes portions of the Subalpine and the Upper Foothills natural subregions (Beckingham and Archibald 1996). The area is bisected by the Kakwa River flowing in a northeast direction. The topography is dominated by this river and its numerous tributaries, with variable terrain and moderate to steep slopes and ridges (Edmonds and Bloomfield 1984). The climate is subarctic, characterized by short, cool, wet summers and long, cold, dry winters (Bjorge 1984). The Foothills Region is well forested and has been described in detail by Edmonds (1988). Dry sites support primarily pure lodgepole pine (*Pinus contorta*) or lodgepole pine/black spruce (*Picea mariana*) forests. At higher elevations, mixed fir (*Abies spp.*), spruce (*Picea spp.*) and lodgepole pine forest predominates. Willow (*Salix spp.*) and birch (*Betula glandulosa*) meadows, interspersed with dry grassy benches, are found along the drainages.

Primary land uses in the study area include timber harvesting, oil and gas exploration and development, coal mining, non-motorized outdoor recreation (hiking, horse travel, camping, fishing), off-road vehicle use (snowmobile, all-terrain vehicles), recreational hunting, and commercial trapping (Brown and Hobson 1998). Access occurs in the form of all-weather and dry-weather resource roads, and pipeline, powerline and seismic line ROWs for petroleum exploration (Smith *et al.* 2000).

4.4 Methods

4.4.1 Caribou Location Data

A total of thirteen wintering female caribou from the Redrock / Prairie Creek herds were fitted with GPS transmitters during the 1998/1999 and 1999/2000 winters.

Experienced, professional capture crews located caribou visually from a helicopter and then captured animals using a hand-held net gun. Animal treatment procedures were approved by the Faculty of Agriculture, Forestry and Home Economics Animal Policy and Welfare Committee, subject to the Canadian Council on Animal Care (Protocol No. 99-75D). GPS data (non-differentially corrected) were collected for five female caribou during the 1998/1999 winter, and differentially corrected data were obtained for eight females during the winter of 1999/2000. The accuracy of GPS transmitters is within 100 meters, 95% of the time, for non-differentially corrected data (Lotek Engineering Inc. 2000) and within 10 meters for differentially corrected data, under a boreal forest canopy (Rempel *et al.* 1995). GPS caribou locations from the winter of 1999/2000 were differentially corrected using N-4 Version 1.1895 software (Lotek Engineering Inc. 2000). All locations were imported into ArcView Version 3.1 (Environmental Systems Research Institute Inc. 1993).

The following criteria were applied to select caribou location data for this study:

1) Winter location data, collected between December 1 and April 30 of both winters;
2) Only locations within forested caribou winter ranges were included for analysis. As both winters of study were mild, several caribou returned to alpine ranges when little snow cover was left. As caribou may behave differently in or at the edge of open alpine areas, locations occurring above treeline, in the Alpine and higher Subalpine regions (elevation > 1800 m), were not considered for analysis;
3) To maintain consistency between variable data collection schedules of the transmitters, and to maintain reasonable independence between subsequent

locations, only one location per animal per day was used in the analysis (at, or closest available to noon).

As caribou on their winter ranges did not have stable home ranges, but showed nomadic movements on a portion of the study area, I applied a buffer technique to determine the availability of linear features to each individual. Instead of delineating a home range using a minimum convex polygon approach (Aebischer *et al.* 1993), I buffered caribou locations by the approximate maximum distance traveled in a day, and used these combined buffers as a more realistic representation of what portion of the landscape was available to each caribou (Figure 4-1). The distance each caribou moved per day was calculated by comparing the location of the individual with its previous location. I calculated the 90th maximum percentile of subsequent daily location distances (Arthur *et al.* 1996). This distance was then used to define the buffer radius for each animal's locations using ArcView 3.1 (Figure 4-1). Buffers were merged, overlaps dissolved, and a final available area calculated for each animal (Table 4-1).

4.4.2 Linear Feature Map Coverages

Accurate base map coverages of linear features (roads, seismic lines, pipeline ROWs, and powerline ROWs), as well as cutblocks and wellsites, were obtained by digitizing 1998 Indian Remote Sensing Satellite (IRS) imagery (5 m x 5 m pixels, rectified, UTM Nad 27) using ArcView GIS. Stream data coverages were obtained from the Resource Data Division of Alberta Environment. Rivers and streams that occurred perennially throughout the study area were used in the analysis. Table 4-2 summarizes the density of each linear feature in the study area.

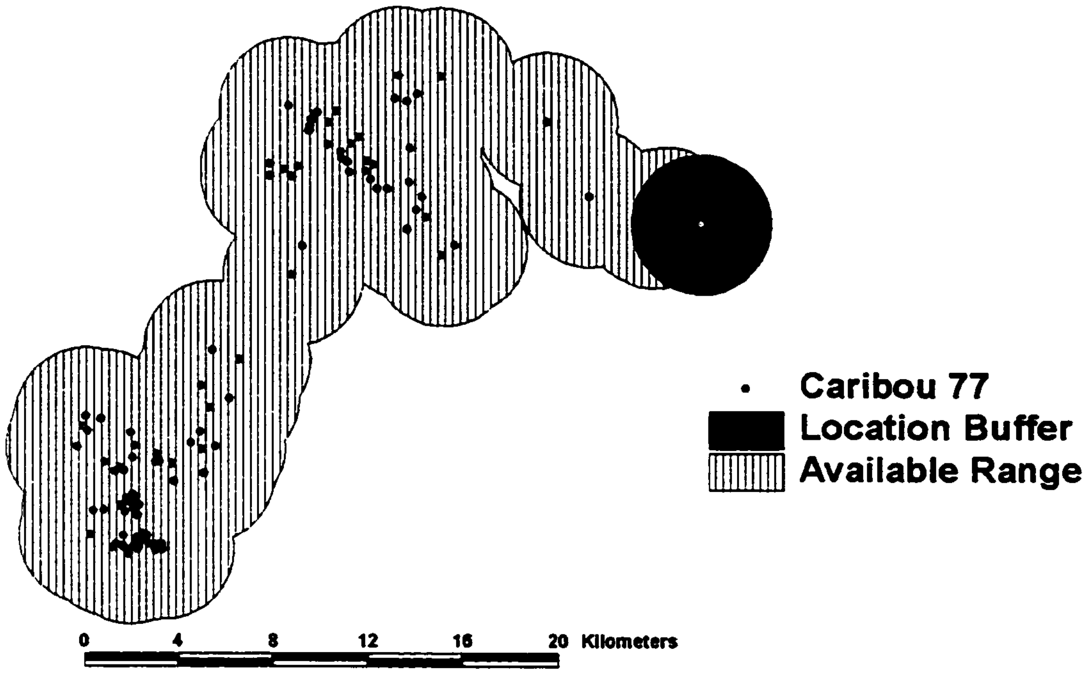


Figure 4-1. Available winter range determination for caribou. GPS locations from 1 December to 30 April, winter 1999/2000, were buffered by a radius equal to the maximum distance traveled per day (90th percentile). The available range was created by joining the GPS location buffers for each individual caribou.

Table 4-1. GPS caribou location data, and associated total available areas, used in the compositional analyses for 12 wintering caribou from the Redrock / Prairie Creek herds during the winters 1998-2000.

Caribou ID	Data Winter	No. Location Days	Daily Travel Distance (90th Percentile) (Km)	Excluded Area (Km^2)	Total Available Area (Km^2)
4c	1998-1999	117	2.7	3	355
51	1998-1999	112	1.6	11	112
52	1998-1999	100	2.5	0	141
5a	1998-1999	144	3.6	47	618
5b	1998-1999	140	1.9	0	192
72	1999-2000	84	1.4	8	42
73	1999-2000	122	3.7	24	522
77	1999-2000	144	2.9	8	347
78	1999-2000	141	3.6	22	544
79	1999-2000	130	4.1	9	507
7a	1999-2000	147	2.4	0	324
7b	1999-2000	146	3.0	0	531

Table 4-2. Density of linear features occurring within the study area. Total study area was 4,200 km^2.

LINEAR FEATURE	Total Length (km)	Density (km/km^2)
Streams	1500	0.36
Roads	1346	0.32
Seismic Lines	2804	0.67

To remove wellsites and cutblocks as potentially confounding variables to caribou distributions around linear features, a buffered area around each of these landscape features were excluded from analysis. I chose a buffer width of 250 m, as there is evidence for this avoidance distance from a study in northeastern Alberta (Dyer 1999). A similar distance may apply to cutblocks in the study area (Rohner and Szkorupa 1999). The total of these excluded buffer areas is summarized for each caribou in Table 4-1. Any caribou locations occurring in these areas were also removed. One caribou (Caribou 71), collared during the 1999/2000 winter, was removed from the analysis due to insufficient locations, resulting primarily from a non-functional collar (approximately 2 weeks data collection total) and exclusions of locations within cutblock areas.

Linear features were buffered by 100 m, 250 m, 500 m, 1000 m, 2000 m and > 2000 m distances (Table 4-3), consistent with Dyer (1999), thus permitting comparisons between caribou ecotypes. Buffer categories were large enough to ensure that all available distance buffer classes contained at least one caribou location if caribou locations occurred at random. No caribou had sufficient pipeline or powerline buffer areas, so these linear landscape features were removed from the analysis.

4.4.3 Statistical Analysis

I used standard techniques to compare use and availability to test for preference or avoidance of linear features by caribou. For a descriptive and graphic illustration of preferences, I used Manly's alpha, a common index of preference (Krebs 1989). Such indices, however, can be biased when data points are not entirely independent. Therefore, for statistical testing, I performed compositional analyses of habitat use as

Table 4-3. Linear features were buffered by specified distances. Each distance buffer acted as a "habitat category", for comparing caribou use to availability in the compositional analyses.

Buffer	Distance to Stream (m)	Distance to Road (m)	Distance to Seismic Line (m)
1	< 100	< 100	< 100
2	101 - 250	101 - 250	101 - 250
3	251 - 500	251 - 500	251 - 500
4	501 - 1000	501 - 1000	501 - 1000
5	1001 - 2000	1001 - 2000	> 1000
6	> 2000	> 2000	-

described by Aebischer *et al.* (1993). For this method, each distance buffer acted as a "habitat category", from which to compare caribou use. The area within each caribou's winter range defined "available habitat." The number of locations occurring in each buffer distance defined "habitat use." Available habitat was defined as the area of each distance buffer over the caribou's winter range area. Used habitat was defined as the number of caribou locations occurring in each buffer distance over the total number of caribou locations. If there was no use of a buffer distance, but the buffer distance was available, the 0% use was replaced by 0.01%, an order of magnitude less than the smallest recorded nonzero percentage (Aebischer *et al.* 1993). See Appendix 4-1 for percent available and percent use mean values for the linear feature distance buffers.

Habitat selection or avoidance occurs when a particular type of habitat is used more or less often than expected at random (Johnson 1980). All distance buffers were examined simultaneously, testing the hypothesis that the log-ratio of "used habitat" (y) equalled the log-ratio of "available habitat" (y_0) (H_0: $d = y - y_0 = 0$). The residual matrix of raw sums of squares (R_2) and the matrix of mean-corrected sums of squares and cross-products (R_1) were calculated from d (Zar 1984) and used to calculate a chi-squared value:

$$\Lambda = | R1 | / | R2 |$$

$$\chi^2_{(\alpha = 0.05;\ df = \text{no. buffers} - 1)} = (-N) \ln \Lambda,$$

where N = the number of caribou used in the analysis.

The null hypothesis of random use was rejected at $\alpha \leq 0.05$.

If caribou use of distance buffers was significantly non-random, the distance buffers were ranked by order of use and any significant selections were identified.

Ranking was achieved by determining the pair-wise differences (t-tests) between distance buffer use and availability log-ratios using the equation:

$$\ln(\chi_{U2}/\chi_{U1}) - \ln(\chi_{A2}/\chi_{A1})$$

If the pairwise difference was less than zero, then use of habitat "1" was assumed greater than habitat "2" and vice versa when the pair-wise difference was greater than zero. A matrix containing all pair-wise differences was created (Appendix 4-2), and the number of positive pair-wise differences was tallied. The total positive differences for each distance buffer determined its ranking for caribou selection.

The outlying buffers (5th for seismic lines and 6th for roads and streams) were used to determine preference or avoidance. If a distance buffer was used significantly less than the outer buffer, I concluded it was avoided by caribou.

Once the compositional analyses were completed, I calculated the power of all chi-squared and paired t-tests, using the *GPower computer program developed by Faul and Erdfelder (1992). Using *post hoc* power analyses, the power of the chi-squared tests were determined setting the effect size to 0.5, alpha to 0.05, and degrees of freedom equal to the number of linear feature distance buffers minus one. The power for paired t-tests (*post hoc*) was calculated using an effect size of *f* (mean/SD), alpha of 0.05, and degrees of freedom equal to the total number of caribou minus one.

To test for differences in habitat compositions, across linear feature distance buffers, single factor ANOVA tests were performed on habitat variables using SPSS 9.0 statistical program (SPSS Inc. 1998) (Appendix 4-3). Habitat variables were chosen based on previous caribou habitat selection research, and the significance of habitat variables to mountain caribou distributions. Tukey HSD *post hoc* tests were performed when an ANOVA F-test was significant; to determine which distance buffers contained significantly different amounts of a habitat variable.

4.4.4 Caribou Independence

An assumption underlying the compositional analysis is that each animal provides an independent measure of habitat use within the population (Aebischer *et al.* 1993). Group sizes for mountain caribou vary, with the largest groups occurring during the rut and in late winter (Edmonds 1988). This gregarious social organization could therefore jeopardize the independence of each animal within the analysis.

To determine if any caribou behaved dependently, the distance between locations, from the same date and approximate time of day, for each possible caribou interaction was determined. To compare locations from the same date, a subset of 19 days for each winter, in which all caribou were observed, was chosen from the caribou location data. The location dates within the subset of data occurred approximately one week apart. Distances < 1 km between caribou locations were considered to have the potential to limit the assumption of animal independence. The total number of possible animal interactions was 10 during winter 1998/1999 and 21 during winter 1999/2000.

4.4.5 Road Activity

Road vehicle activity data were collected through a series of interviews with Land and Forest Service Rangers, and Weyerhaeuser field operators, as well as from one trapper. Roads were considered "active" (i.e. accessible) if they were plowed during the winter. Roads were classified as "inactive" if they were not plowed during the winter.

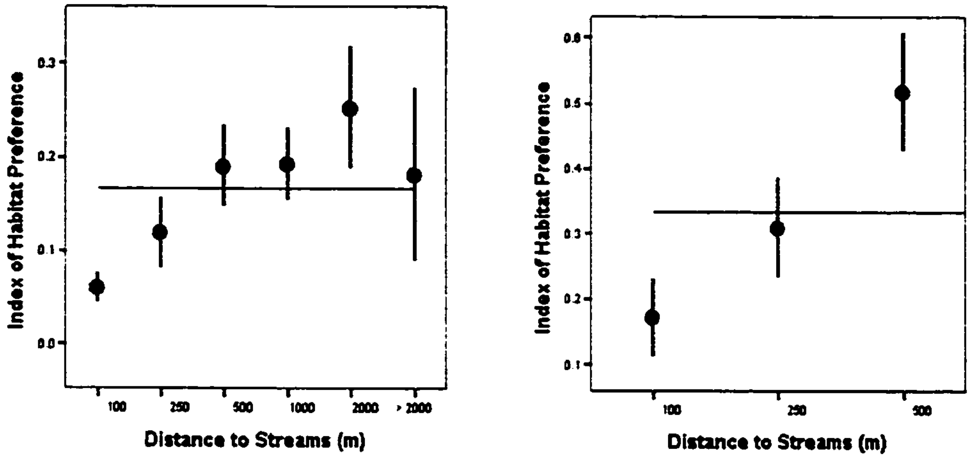
Data were collected separately for the two winters of 1998/99 and 1999/2000. Activity data for cutlines were not collected, however areas of traditional snowmobile use on cutlines were noted. Activity data was added to the attribute table for the road coverage.

Compositional analyses, as outlined in section 4.4.3, were carried out on active and inactive roads separately. However, 11 of the 12 caribou had insufficient active road buffers to expect caribou, if caribou locations were random, and therefore were dropped from the analysis. With only one remaining caribou, the compositional analysis could not be carried out for active roads. One caribou was dropped from the inactive road compositional analysis, due to insufficient road distance buffer areas, prior to analysis.

4.5 Results

4.5.1 Caribou Response to Streams

Caribou locations showed a highly significant deviation from a random distribution in relation to streams ($\chi^2 = 12.09$, df = 5, $p < 0.04$). As illustrated in Figure 4-2, there was a clear trend for increased preference of those portions in the landscape that were further away from streams, with preference indices indicating an avoidance of 250 m. This trend was consistent for coarse and fine scale (< 500 m) analyses. However, an inconsistency occurred at the coarse scale; as the > 2000 m buffer did not follow this trend (Table 4-4; Appendix 4-2 for details). During the compositional analysis, individual comparisons of buffer preferences to the outside buffer did not confirm avoidance of streams (Table 4-4). However, the 0 – 250 meter distance buffers were used significantly less than the 251 – 2000 meter buffers. This suggests that had the outer buffer been determined at > 1000 m, an avoidance claim of 250 m from streams could



a) Coarse Scale

b) Fine Scale

Figure 4-2. Caribou preference indices for distances to streams during winters 1998-1999, and 1999-2000. Index of habitat preference for each distance buffer is the mean of Manly's alpha. Manly's alpha ranges from 0 – 1. a) Coarse scale selection for streams. Random distribution would produce a neutral value of 0.16, higher values indicate preference and smaller values indicate avoidance. b) Fine scale selection for streams. Random distribution over the landscape would produce a neutral value of 0.33, higher values indicate preference and smaller values indicate avoidance.

Table 4-4. Caribou selection and ranking of distance buffers during winters 1998 - 2000, as determined from compositional analysis. If non-random selection of distances from linear features occurred, then ranking matrices were used to rank distance buffers according to their preference by caribou. Significant contrasts between ranks displayed by the symbol '>>>'.

LINEAR FEATURE	Caribou Selection	Chi-Square	df	P	Distance Buffer Ranking	Significant Ranks
Streams	Non – Random	12.09	5	< 0.04	5 > 4 > 3 > 6 > 2 > 1	5 >>> 1, 2 4 >>> 1, 2 3 >>> 1, 2
Streams (< 500 m)	Non - Random	5.92	2	< 0.05	3 > 2 > 1	3 >>> 1, 2
Roads	Non – Random	17.87	5	< 0.004	6 > 5 > 4 > 3 > 2 > 1	6 >>> 1, 2, 3 5 >>> 1, 2 4 >>> 1 3 >>> 1 2 >>> 1
Roads (< 500 m)	Non – Random	10.73	2	< 0.004	3 > 2 > 1	3 >>> 1
In-Active Roads	Non - Random	15.74	5	< 0.005	6 > 4 > 5 > 3 > 2 > 1	6 >>> 1, 2 5 >>> 1 4 >>> 1
Seismic	Random	7.39	4	> 0.12	N/A	N/A
Seismic (< 500 m)	Random	0.19	2	> 0.25	N/A	N/A

have been established. Since the buffer designation for streams was arbitrary, it is possible that the designations should have resembled those for seismic lines, due to the homogenous distribution of streams being more similar to that of seismic lines than to roads. This homogenous distribution may have shifted the outer buffer of > 2000 m into proximity of another stream's influence, or into the proximity of a road. Nevertheless, a fine scale analysis confirmed that when caribou were within 500 m of streams, they avoided streams to a 250 m distance (Table 4-4).

Stream distance buffers had significantly different elevations (Appendix 4-3). The furthest buffers (501 to + 2000 m) from streams had greater elevations than the nearest distance buffers. The < 100 m buffer was composed of less lodgepole pine / spruce spp. forest stands, > 80 years origin, than the 500 – 1000 m buffer. There were no significant differences in amounts of: pure lodgepole pine forest stands, of > 80 years or ≤ 80 years origin; lodgepole pine / spruce spp. forest stands, ≤ 80 years origin; spruce and fir mixed stands, of > 80 years or ≤ 80 years origin; or deciduous dominant and mixed deciduous stands, of > 80 years or ≤ 80 years origin (Appendix 4-3).

In summary, these results provide evidence to reject the hypothesis that caribou move independently of streams: There was significant fine-scale avoidance of streams for caribou within 500 m to these linear features, and an unexplained drop in preference for areas that occurred at distances > 2000 m.

4.5.2 Caribou Response to Roads

Caribou use of roads paralleled their distribution around streams, with more locations than expected as distance from roads increased ($\chi^2 = 17.87$, df = 5, p = 0.004;

Table 4-4). The ranking of distance buffers was consistent, from least preference close to roads to highest preference at distances > 2000 m from roads (Table 4-4, Figure 4-3). Significant contrasts between buffers less than 500 m were found from the outermost buffer (> 2000 m), indicating an avoidance of 500 m from roads (Table 4-4, Appendix 4-2). However, I caution this avoidance level due to the overlap of preference indices confidence intervals on the neutral line at the 250 m and 500 m distances (Figure 4-3).

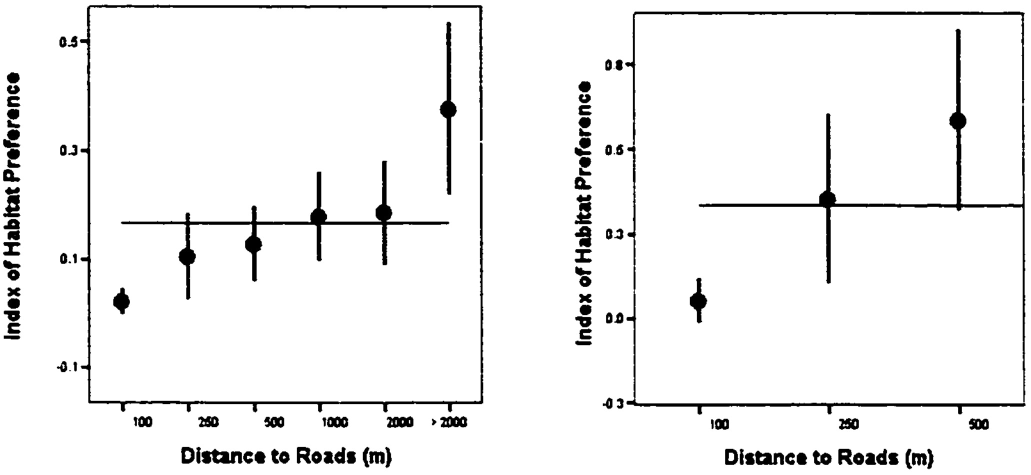
Also, because roads in the study area generally occur along the northern and eastern extent of historical caribou ranges, some caribou included in this analysis had only small proportions of roads available to them along the fringes of their range. In fact, three caribou did not occur at all within 500 m of roads. To examine whether the significance of results was influenced by these caribou, which may have used a different part of the study area due to unrelated factors, I conducted an additional fine scale analysis. For this analysis, only caribou with individual locations occurring within 500 m of roads were analyzed (n = 9). The results also revealed a significant response to roads by these caribou ($\chi^2 = 10.73$, df = 2, p = 0.004, Table 4-4). The ranking remained consistent, showing a clear trend for increased selection of areas further away from roads (Figure 4-3). The closest buffer to roads (within 100 m) was preferred significantly less than areas at distances from 251 – 500 m from roads (Appendix 4-2).

When roads were designated as active or inactive, 10 out of the 12 caribou did not come within 500 m of active roads and 6 out of the 12 caribou did not come within 2 km of active roads. As a result, a compositional analysis could not be performed for active roads due to insufficient active road buffer areas. However, caribou were found to remain non-random around inactive roads ($\chi^2 = 15.74$, df = 5, p = 0.005). Caribou maintained their trend for increased selection of areas further away from roads (Table 4-4). The outer most buffer (> 2000 m) was preferred significantly more than areas within 250 m of inactive roads (Table 4-4). This indicates that even when roads were not used during the winter by vehicular traffic (not plowed), caribou still avoided the structures to a distance of 250 m.

Habitat composition varied across road distance buffers (Appendix 4-3). Mean elevation was greater near roads. The amount of lodgepole pine dominant forest stands, > 80 years origin, was significantly greater within 2000 m of roads than at distances > 2000 m from roads. Amounts of lodgepole pine dominant forest stands, ≤ 80 years origin, increased at distances further than 250 m from roads. Mixed lodgepole pine / spruce spp. forest stands, > 80 years origin, occurred in greater amounts in the < 100m, 251-1000 m, and > 2000 m buffers than within the 1001-2000 m buffer. The > 2000 m buffer also contained greater amounts mixed lodgepole pine / spruce spp. forest stands, > 80 years origin, than distance buffers < 250 m from roads. Caribou are reported to prefer higher elevations (Bjorge 1984), along with pine stands and mixed pine / spruce stands, of > 80 years origin which contain a rich supply of terrestrial lichen (Edmonds and Smith 1991). Therefore, the habitat compositions occurring closer to roads have been documented to be preferred by mountain caribou and would not have confounded the resultant avoidance effect.

4.5.3 Caribou Response to Seismic Lines

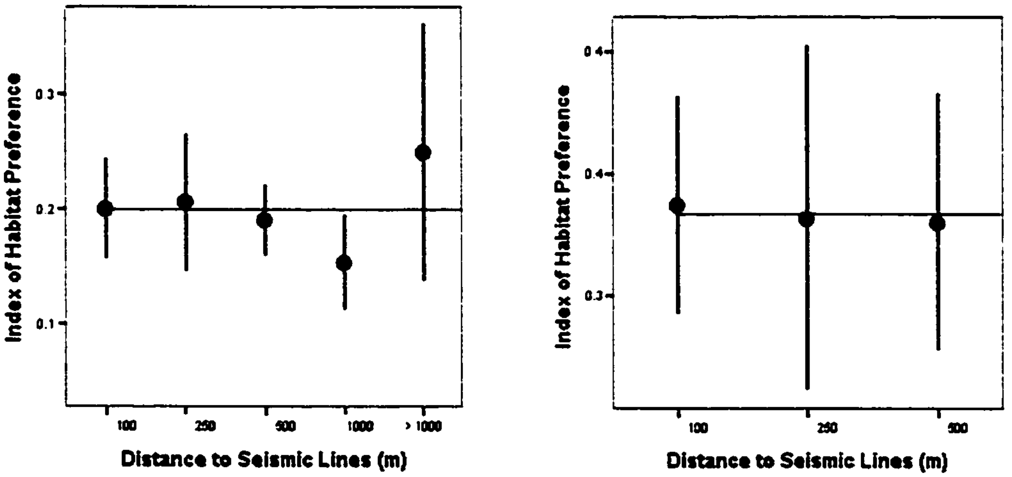
Caribou locations in relation to seismic lines did not differ from random over the two winters studied ($\chi^2 = 7.39$, df = 4, p = 0.12) (Table 4-4). No trends in preferences



a) Coarse Scale

b) Fine Scale

Figure 4-3. Caribou preference indices for distances from roads during winters 1998 - 1999 and 1999 - 2000. Index of habitat preference for each distance buffer is the mean of Manly's alpha. a) Coarse scale selection for 12 caribou around roads. A random distribution would produce a neutral value of 0.17, higher values indicate preference and smaller values indicate avoidance. b) Fine scale selection of 9 caribou for roads. Random distribution would produce a neutral value of 0.33, higher values indicate preference and smaller values indicate avoidance.



a) Coarse Scale

b) Fine Scale

Figure 4-4. Caribou preference indices for distances to seismic lines during winter 1998-1999 and winter 1999-2000. Index of habitat preference for each distance buffer is the mean of Manly's alpha. a) Coarse scale selection for seismic lines. A random distribution over the landscape would produce a neutral value of 0.20, higher values indicate preference and smaller values indicate avoidance. b) Fine scale selection for seismic lines. A random distribution over the landscape would produce a neutral value of 0.33.

for distance buffers from seismic lines were found, as shown in Figure 4-4. Since the overall χ^2 value was not significant, distance buffers were not ranked (Aebischer *et al.*1993). There were no significant differences in amounts of selected habitat variables across seismic line distance buffers (Appendix 4-3).

4.5.4 Caribou Response to Road and Seismic Age

Revel *et al.* (1984) documented that seismic lines exhibit tree revegetation after abandonment. Although the rate of tree growth occurs at a much slower rate on seismic lines than on cutblocks or wildfire areas of the same post-disturbance period, qualitative results have determined that tree density on seismic lines reach similar tree densities to those found after wildfires after 10-20 years (MacFarlane 1999). It is possible, therefore, for seismic lines to revegetate within a forest landscape and become non-existent from the perspective of caribou. To determine if the age of seismic lines and roads influence caribou distributions, aerial photographs from 1975 and 1986 were examined. Each linear development digitized from the 1998 satellite imagery was assigned a relative age. Lines were categorized into 3 post-disturbance age classes: > 23 years (using 1975 series), 13 – 23 years (using 1986 series), and < 13 years (using 1998 IRS) (Table 4-5).

A logistic regression model for binomial counts of caribou locations within distance buffers for roads and seismic lines of both old (≥ 23 years) and new (≤ 22 years) origin was developed using SPSS 9.0 (SPSS Inc. 1998). Methods for model creation followed those outlined in Chapter 21 of Ramsey and Schafer (1996). SPSS was unable to provide an output when all three post-disturbance age classes were used, due to the low occurrence of lines within the 13 – 23, and the < 13 years post-disturbance age classes, so

Table 4-5. Percent of linear feature age classes within the study area.

		Linear Feature	
		Roads	Seismic Lines
Age	> 23 yrs	53%	80%
	12 - 23 yrs	36%	15%
	< 12 yrs	11%	5%

the two classes were joined into one category. Distance to linear feature was treated as a continuous variable. However, the area of distance buffers increased as the distance from a feature increased. The proportional area of distance buffers was therefore included as a variable in the model. Both distance and area variables were log-transformed to meet visual examination for linearity. The best fitting model was determined by using a drop-in-deviance test, working from the most complex model to the most simplistic model. Wald's test was used to determine significance of individual variable terms. A model was adequate when the deviance goodness-of-fit test produced a large p-value ($p > 0.05$), and was moderately adequate when a p-value ranged from 0.01 to 0.05. The best fitting model was moderately adequate ($\chi^2 = 24.12$, df = 12, $p = 0.02$) (Appendix 4-4).

Based on the logistic regression model, at any given distance, the odds of locating caribou around old aged seismic lines were 0.26 times ($= e^{-1.66+0.312\{1-0\}}$) the odds of locating caribou around newer seismic lines. In other words, the odds of locating caribou around seismic lines of older origin were 26% greater than the odds of caribou occurring around newer, and presumably less vegetated, seismic lines. At any given distance, caribou odds around old aged roads were 0.07 times ($= e^{-2.906+0.312\{1-0\}}$) the caribou odds occurring around newer roads. This 7% increase in caribou odds occurring around older origin roads is much less dramatic than the increase determined for seismic lines.

4.5.5 Caribou Movement Independence

Over the course of either winter, none of the caribou traveled together throughout the entire sampling period. However, some caribou did spend a portion of the late winter months together, with distances < 1 km occurring between caribou locations from the end of January to mid March (Table 4-6 and Table 4-7). During the 1998/1999 winter, 2.6% of the location distances calculated were < 1 km apart, with an average distance between locations of 18.2 km. These < 1 km distances occurred strictly between caribou 5a and caribou 51 (Table 4-8). During the 1999/2000 winter, 14% of the location distances calculated were < 1 km, with an average distance between locations of 16.0 km. Seven of the possible 21 caribou interactions resulted in distances < 1 km (Table 4-8).

4.5.6 Influence of Sample Size and Available Range

Additional analyses were carried out to ensure that the number of caribou locations used per day (Appendix 4-5), and the available range (Appendix 4-6) for each caribou did not influence results from the compositional analyses. Table 4-9 outlines the results of the compositional analyses utilizing 4 locations per day for each animal, with the available area determined by buffering only the noon locations by the 90th percentile for maximum daily distance traveled (same available areas as original analysis) (see Appendices 4-7, 4-8, 4-9, and 4-10 for detailed results when the number of caribou locations used were 4 per day). Table 4-10 outlines the results of the compositional analyses utilizing 4 locations per day for each animal, with the available area enlarged by buffering all locations by the 90th percentile for maximum daily distance traveled (versus buffering each location with the maximum distance traveled in a 6 hour period) (see Appendices 4-11, 4-12, 4-13, and 4-14 for detailed results when available area was enlarged).

Tables 4-9 and 4-10 reflect that the compositional analyses results were not influenced by the number of caribou locations, or by an enlarged available area. In fact,

Table 4- 6. Possible caribou interactions during winter 1998/1999. Interactions which resulted in distances between caribou locations of < 1 km are denoted by a checkmark (√).

	Caribou 4C	Caribou 51	Caribou 52	Caribou 5A	Caribou 5B
Caribou 4C		X	X	X	X
Caribou 51			X	√	X
Caribou 52				X	X
Caribou 5A					X
Caribou 5B					

Table 4- 7. Possible caribou interactions during winter 1999/2000. Interactions which resulted in distances between caribou locations of < 1 km are denoted by a checkmark (√).

	Caribou 72	Caribou 73	Caribou 77	Caribou 78	Caribou 79	Caribou 7a	Caribou 7b
Caribou 72		X	X	X	X	X	X
Caribou 73			√	√	√	X	X
Caribou 77				√	√	X	X
Caribou 78					√	X	X
Caribou 79						X	X
Caribou 7a							√
Caribou 7b							

Table 4- 8. Individual caribou interactions that resulted in distances < 1 km, during winters 1998/1999 and 1999/2000. None of the caribou interactions resulted in caribou grouping together (< 1 km) over the entire winter.

Caribou Interaction	% Locations < 1 km	Average Distance Between Locations (km)
5A x 51	25	7.9
73 x 77	42	5.9
73 x 78	37	6.0
73 x 79	42	5.6
77 x 78	26	8.0
77 x 79	32	5.1
78 x 79	42	7.0
7A x 7B	68	2.3

Table 4-9. Caribou selection and ranking of distance buffers during winters 1998-2000, as determined from compositional analyses, utilizing 4 locations per day, one location per day (noon) buffered by 90th percentile for maximum daily travel distance. If non-random selection of distances from linear features occurred, then ranking matrices were used to rank distance buffers according to their preference by caribou. Significant contrasts between ranks are displayed by the symbol '>>>' in the last column.

LINEAR FEATURE	Caribou Selection	Chi-Square	df	P	Distance Buffer Ranking	Significant Ranks
Streams	Non – Random	19.82	5	< 0.001	5 > 4 > 3 > 6 > 2 > 1	5 >>> 1, 2 4 >>> 1, 2 3 >>> 1, 2
Streams (< 500 m)	Non - Random	10.74	2	< 0.005	3 > 2 > 1	3 >>> 1, 2
Roads	Non – Random	14.35	5	< 0.015	6 > 5 > 4 > 2 > 3 > 1	6 >>> 1, 2, 3 5 >>> 1 4 >>> 1
Roads (< 500 m)	Non – Random	7.93	2	< 0.016	3 > 2 > 1	3, 2 >>> 1
Seismic	Random	3.56	4	> 0.25	N/A	N/A
Seismic (< 500 m)	Random	0.82	2	> 0.25	N/A	N/A

Table 4-10. Caribou selection and ranking of distance buffers during winters 1998-2000, as determined from compositional analysis, utilizing 4 locations per day, each location buffered by 90th percentile for maximum daily travel distance (enlarged available area). If non-random selection of distances from linear features occurred, then ranking matrices were used to rank distance buffers according to their preference by caribou. Significant contrasts between ranks are displayed by the symbol '>>>' in the last column.

LINEAR FEATURE	Caribou Selection	Chi-Square	df	P	Distance Buffer Ranking	Significant Ranks
Streams	Non – Random	21.51	5	< 0.0001	5 > 4 > 3 > 6 > 2 > 1	5 >>> 1, 2 4 >>> 1, 2 3 >>> 1, 2
Streams (< 500 m)	Non - Random	10.55	2	< 0.005	3 > 2 > 1	3 >>> 1, 2
Roads	Non – Random	20.38	5	< 0.0001	6 > 5 > 4 > 2 > 3 > 1	6 >>> 1, 2, 3 5 >>> 1 4 >>> 1
Roads (< 500 m)	Non – Random	11.53	2	< 0.0025	3 > 2 > 1	3, 2 >>> 1
Seismic	Random	4.06	4	> 0.25	N/A	N/A
Seismic (< 500 m)	Random	1.37	2	> 0.25	N/A	N/A

the only major difference when more locations and an enlarged available area were analyzed, was a greater response to roads at the fine scale (distances 101 – 500 m were significantly preferred over distances < 100 m).

4.6 Discussion

My results show that caribou avoided perennial streams, a natural linear feature in the study area, at the fine-scale. Consistent with my prediction, caribou also avoided one linear landscape structure of anthropogenic origin: roads were significantly avoided; however no consistent trend was apparent for seismic exploration lines in the study area. This is the second study in Alberta investigating the response of caribou to linear development in forested areas to find an effect of human infrastructure. In the following sections, I will address the reliability and implications of these results.

There are several explanations for the avoidance of streams by mountain caribou in our area. The winter distribution of caribou could be indirectly affected by rivers and creeks, for example, by habitat variables that are associated with elevation. Caribou in the study area have been reported to prefer pine stands with a rich supply of terrestrial lichens, which tend to grow along well drained landforms such as ridges (Edmonds and Bloomfield 1984; Edmonds and Smith 1991). Therefore, one potential explanation for avoidance of streams could be the lack of preferred habitat in the vicinity of these landscape features. If edges along slopes to stream valleys are preferred, then a drop in preference further away from streams on higher plateaus as observed in Figure 4-2 might be expected. Also, related to the increasing elevation as the distance from streams increases, is the evidence that roads were occurring at higher elevations. As a result, the lack of preference by caribou for the > 2000 m buffer may be due to the presence of a road. Alternatively, there may be indirect effects that result in negative responses by wintering caribou. Concentrations of other ungulate species, such as moose and elk, which prefer habitats with ample supply of shrubs and grasses along rivers, and wolves moving on frozen rivers that connect these habitats, may result in attempts by caribou to alleviate predation pressures through spatial separation. The two explanations are not mutually exclusive and could both apply.

This study reinforces findings from northeastern Alberta that caribou avoid roads in forested areas (Dyer 1999). I found a pronounced preference for areas far away from roads, with a significant avoidance of roads by caribou up to 100 m, and a possible avoidance up to 500 m. I consider my results on avoidance up to a 500 m distance as cautionary, because the study area was heterogeneous with respect to roads, and my sample size of collared animals was limited. However, there was also a fine-scale effect on caribou that occurred in the vicinity of roads (100 m avoidance), thus corroborating my conclusion of an avoidance pattern. The exact mechanism for such avoidance is not known. Behavioural avoidance could have similar causes as postulated for streams: caribou may perceive roads as travel corridors for predators, or avoid other ungulates associated with these areas. In addition, caribou may avoid roads due to increased human activity associated with these developments. However, even roads that were not plowed, and thus classified as inactive, were avoided to a distance of 250 m, signalling that the mechanism for avoidance may be more than just a response to increased human activity.

Potential consequences on caribou populations are twofold. It is possible that lead to higher caribou mortality near lines (Stuart-Smith *et al.* 1997; James 1999). Another consequence may be habitat loss, because otherwise suitable habitat is avoided. At present, a fine scale avoidance of 100 m from roads would translate into an area of reduced use of 253 km^2 or 6% of available habitat for caribou in the study area. Depending on the intensity of effects on caribou (e.g., coarse scale avoidance), and the level of development, the area of actual reduced use could be much greater (Dyer 1999).

I did not detect a significant response by caribou to seismic lines. This result is in contrast to Dyer (1999), who found that caribou in northeastern Alberta avoided both roads and seismic lines. This difference may be explained by several factors. First, these differences may be attributed to regional differences, either in habitat and intensity of development of the study area, or in variation among woodland caribou ecotypes due to differing life history characteristics. My study area, in the foothills of the Rocky Mountains, has greater topographic relief and variation than the boreal forest in northeastern Alberta. In addition, 80% of conventional seismic lines analyzed in my study area were of older origin (Table 4.5), implying that they show various stages of reforestation. It is possible that reforestation diminished the biological influence of seismic lines on caribou behaviour, given the odds of caribou occurring around older lines were 26% greater than for newer lines. As well, the density of seismic lines in west-central Alberta is much lower (0.67 km/km^2) than in northeastern Alberta, where Dyer (1999) reported that caribou had an average of 1.15 km/km^2 of seismic lines in their home ranges. Higher landscape variability and lower density of lines may explain a lower influence of seismic lines in my study area. In contrast to the mountain ecotype, boreal woodland caribou are also yearly residents in their home ranges. For these animals, which showed avoidance up to 250 m from seismic lines during the winter period (Dyer 1999), it may be easier to adopt avoidance behaviour in a more familiar home range or there may be a higher selective pressure to avoid natural and anthropogenic linear features in that landscape.

Perhaps more importantly, my sample sizes were small (limited further with possible auto-correlation among caribou), and assuming that potential distance effect is smaller for seismic lines than for roads, the statistical power of my design was very limited (Table 4-11). My results certainly lack the statistical power to conclude unequivocally that seismic lines in my study area do not affect caribou. Continued monitoring of caribou will increase sample size and power, helping to understand caribou distributions in relation to human development.

4.7 Management Implications

Caribou avoidance of roads, and potentially other linear features, increases the importance of minimizing road access into caribou range, if the goal of sustaining both caribou and industrial development is to be attained. This could be achieved in several ways. First, new linear features can be reduced by using existing and common access, and by limiting access. Temporary access structures can be removed, reclaimed and reforested. The current operating guidelines for the area (WCACSC 1996) include such access-reducing strategies, as well as ensuring that winter operations follow an "early in, early out" philosophy, so that activity occurs prior to critical winter periods for caribou.

Second, public access on roads can be controlled and temporarily restricted to reduce disturbance or mortality on caribou winter ranges by gates, signs, education,

Table 4- 11. Power (1-β) of compositional analysis test statistics: chi-squared tests for randomness of distributions around linear features, and average power of paired t-tests used to rank distance buffers. *A priori* calculations using G*Power determined that for the detection of a large effect in the chi-squared tests (Cohen (1988) conventional large effect size = 0.5) would have required 26 independent caribou for seismic lines, and 28 independent caribou for roads and streams.

Linear Feature	**$\chi2$ (1 - β)**	**T-test (1 - β)**
Stream	0.22	0.42
Road	0.22	0.52
Seismic Line	0.24	N/A

temporary rollback, or manned access control. Managing access is difficult, and can be expensive. A pressing challenge will be to engage members of the public who typically resent restrictions on their use of crown land. Frequently, signs, gates and other management measures are ignored, particularly if strong public support for the restrictions cannot be demonstrated (BCRC 1998). As a result, bans on existing roads may not be feasible (Cumming 1996). What is possible, however, is the prevention of new access into important caribou habitat and controlling access on existing linear developments (Cumming 1996).

Third, the structure of new lines can be designed to minimize potential impacts. Since the introduction of operating guidelines in west-central Alberta, several measures have been implemented to reduce the potential effects of seismic lines on caribou. Low Impact Seismic (LIS) is a desirable target for exploration work. LIS are exploration lines cut with a narrow width (4.5 m) compared to conventional seismic lines (8 m), and in a continuously meandering path to reduce line of sight. Heli-portable, envirodrill and hand-cut lines further reduce any potential effects on vegetation changes, new travel corridors for wolves, or increased disturbance by human recreational users. The fact that I did not detect caribou responses to seismic lines may also reflect the success of these measures and the importance of maintaining the current operating guidelines. Another important factor explaining the lack of caribou response to seismic lines in this study area may be the existing forest structure on the older reforested lines. It may be beneficial for managers to accelerate the reestablishment of forest on current seismic lines within the study area by providing planted tree corridors for wildlife cover (Buchanan 1993). Previously, planted travel corridors at various intervals on ROWs have had a beneficial effect on the willingness of deer to cross linear features (Dominske 1997). In addition to providing cover, the planting of tree seedlings along lines would reduce competition from invasive low-lying foliage, and from commercial grass seed mixes, allowing quicker reestablishment and growth of trees (Berkowitz and Canham 1993). Tree growth on seismic lines is inhibited, not only from competition, but also by ATV traffic (Revel *et al.* 1984). Previous research has showed that seismic lines with high regeneration had higher levels of slash or fallen logs as well as lower levels of ATV or bulldozer disturbance than lines with lower tree densities (MacFarlane 1999). The planting of trees on linear features would not only help the reestablishment of the forest on these disturbances and increase wildlife cover, but would also help reduce the amount of ATV use on the lines.

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Chapter 5: General Conclusions

5.1 Thesis Conclusions

I demonstrated that mountain caribou avoid both natural linear features and roads, with caribou avoidance decreasing as the distance from streams and roads increased. In a fine scale investigation, caribou avoided streams up to 250 m. Roads were avoided to a 500 m distance in a coarse scale investigation, but this avoidance level should be interpreted cautiously, due to the small sample size of caribou used in this analysis, and the location of roads in the landscape (i.e. roads occurred on the fringes of caribou ranges). Nevertheless, a 100 m avoidance of roads, when caribou came within 500 m of roads, was unmistakable using both preference indices and compositional analysis. The mechanism for such avoidance is not known, but one theory is that caribou perceive roads in the same way as natural linear features; as travel corridors for predators and other ungulates associated with these areas. Caribou may also avoid roads due to increased human activity associated with these developments (Northcott 1985; Cumming and Hyer 1996). However, in my study, even roads that were classified as inactive were avoided to a distance of 250 m, signalling that the mechanism for avoidance may be more than just a response to increased human activity.

This is the second study investigating the response of woodland caribou to linear development in forested areas that has found an effect of roads. This avoidance of human infrastructure results in effective habitat loss that is greater than the physical disturbance of the development itself (James 1999). An additional consequence is increased access, not only for humans, but also for predators and alternative prey. This increased access could lead to increased mortality from legal and illegal hunting pressure, vehicle collisions, and increased caribou/wolf encounters. However, this study made no attempt to determine demographic consequences from linear feature avoidance or from increased access.

I found no consistent trend in caribou distributions around seismic exploration lines, which may be due to the small sample size of caribou used in this analysis. However, this result was inconsistent with Dyer (1999), who reported that boreal caribou avoided seismic lines. In contrast to the mountain ecotype, boreal caribou are yearly residents in their home ranges and therefore may have greater selective pressure to develop avoidance behaviour towards natural and anthropogenic linear features in that landscape. These contrasting results reaffirm suggestions that the two woodland caribou ecotypes not only have different habitat adaptations, but that the impact of industrial development and the management of development on their habitat may also vary (Edmonds 1991).

The west-central Alberta study area is very rugged, dominated by major drainages with variable topographic relief. In northeastern Alberta there is minimal topographic relief (Dyer 1999; James 1999). Whereas a straight and continuous seismic line in west-central Alberta may have its line of sight intercepted by a steep slope, the same line in northeastern Alberta could provide clear visibility down its entire distance. Secondly, the density of conventional seismic lines in northeastern Alberta was almost double that for my study area. The variable development intensity and caribou responses may be indicative of a threshold density of seismic lines at which caribou abandon usable habitat. Thirdly, only low impact seismic (LIS) lines (width < 4.5 m) have been approved in west-central Alberta over the past 10 years (D. Hervieux, pers. comm.), whereas conventional seismic lines (8 – 10 m width) are the norm in northeastern Alberta (S. Dyer, pers. comm.). Unfortunately, the LIS could not be mapped in my study area, so their comparative effect on caribou response was not determined. However, for the conventional seismic lines in the study area that were mapped, 80% of the lines were greater than 23 years of age. A moderately adequate statistical model developed in this study found that caribou were more likely to occur around these older seismic lines than around younger lines, indicating that not all seismic lines are equal in their influence on caribou distributions. This response to post-disturbance age of seismic lines may also have contributed to the differential responses observed in the two regions.

As well as determining mountain caribou response to linear features, this study also developed a method for creating an accurate base map that can be used within a GIS for further wildlife studies investigating human disturbances. Managers have been adopting GIS as a decision making tool, as it has the ability to provide fast and extensive spatial information. However, GIS applications do not come without limitations. For wildlife studies, researchers must ensure not only that GPS animal location data are of sufficient accuracy, but also that base maps used within the GIS have an appropriate source and scale of landscape information (Walker *et al.* 1986).

5.2 Management Implications

This study verifies that access management should remain a primary mitigative measure for industrial development to be sustained within caribou ranges. The current Operating Guidelines for Industrial Activity in Caribou Ranges in West-central Alberta (WCACSC 1996) outline specific actions for reducing access, which need to be reemphasized and enforced, given the demonstrated response of caribou to roads. Within the current guidelines, mitigation measures for reducing access include: use of existing access, use of shared/common access, primary use of temporary access (< 2 years) which can be removed, reclaimed and reforested after use, reclamation and/or reforestation of abandoned existing access, remotely-operated production operations without surface access, completing work early to avoid critical winter periods, and placing effective forms of public access controls on both temporary and permanent access (e.g., signs, gates, temporary rollback). However, managing existing access is difficult and can be expensive. What may be more feasible, and potentially more beneficial for woodland caribou, is the prevention of new access into important caribou habitat (Cumming 1996).

In addition to preventing and minimizing new access into caribou range, the structure of new linear features, including seismic lines, pipeline ROWs, and powerlines, should be designed to minimize potential impacts. For example, since the introduction of operating guidelines in west-central Alberta, several measures have been implemented to reduce the potential effects of seismic lines on caribou. LIS is the desirable target for exploration work, as it may reduce potential effects on vegetation changes, new travel corridors for wolves, and disturbance by human recreational users. Although LIS activities were not analyzed, due to limitations in data resolution, the lack of caribou response to seismic lines may reflect the success of these measures, particularly if cumulative levels are important in mediating response.

Based on the seismic line post-disturbance age results, it may also be beneficial for managers to accelerate the re-establishment of forest along seismic lines and other linear developments by planting tree corridors for wildlife cover (Buchanan 1993). In addition to providing cover, the planting of tree seedlings along lines would reduce competition from commercial grass seed mixes, allowing quicker re-establishment and growth of trees (Berkowitz and Canham 1993). The planting of trees on linear features would not only increase wildlife cover and reduce the life span of linear disturbances within the landscape, but would also help reduce the amount of recreational use on the lines. Other mitigative measures that managers could implement to reduce the impact of linear developments include the complete roll-back of trees and debris onto new ROWs, reclamation of abandoned ROWs, and the replanting or obstruction of unused or unnecessary corridors (James and Stuart-Smith 2000).

Although the current guidelines address minimization of access and linear feature impacts, ultimately they are limited in their ability to achieve caribou conservation. One problem is that standing committees are strictly advisory bodies with no power to enforce compliance. Furthermore, neither the guidelines or policies created are enforceable by government; they are merely "legitimate expectations" (A. Kwasniak, pers. comm.). As a result, peer pressure and cooperation are relied upon to achieve compliance (Hamilton and Edey 1998). Finally, the guidelines provide no direction to manage the amount, or intensity of cumulative industrial development on caribou range (Dyer 1999).

Despite the inherent weaknesses in the current operating guidelines, the guidelines can evolve using an adaptive management approach. Further research is needed to address the effectiveness of mitigation guidelines as they are applied to industrial development on caribou ranges (Edmonds 1998), and identify additional mitigation measures that might be employed. In the meantime, managers must ensure that approved developments are conducted as conservatively, and with as little impact, as possible.

5.3 Future Research

Future research must address the seemingly contradictory evidence regarding caribou responses to seismic lines. Dyer's (1999) results, from the boreal ecotype in northeastern Alberta, implicate seismic lines as one of the most significant developments affecting caribou behaviour, due to the dominance of these lines, and the increasing intensity of seismic line creation in the boreal landscape. Although our studies addressed different ecotypes of woodland caribou, in areas with substantial regional differences in topography, and level of development, it is also important to note that my study included a much smaller sample size of animals (some occurring dependently during short intervals of the winter), and was therefore hindered by low statistical power. In addition, the short temporal scale of this research needs to be recognized. The winters of investigation may not have been representative of longer-term patterns of caribou distributions around seismic lines. Future research should also address whether threshold levels of seismic development exist, at which caribou begin to avoid lines.

Currently only LIS are approved on the Redrock / Prairie Creek caribou range (D. Hervieux, pers. comm.). Unfortunately, these lines could not be analyzed in this study. Although LIS are hypothesized to have minimal effects, due to the reduction in line width and increased landscape variability from conventional seismic lines, these lines need to be examined to determine their overall effects. In particular, the initial phase of exploration and creation of the lines is considered perhaps the most disturbing phase to woodland caribou, because it involves an unpredictable series of events and loud noise (Bradshaw *et al.* 1997). It may therefore not be the physical presence of the LIS that disturbs caribou, but the activities required to create the line. It is also unknown whether there is a threshold density of LIS at which point caribou will avoid this development (e.g., intensive 3-D seismic grids).

A primary argument in caribou research is that predator avoidance drives caribou behavior (Rettie and Messier 2000). The compelling evidence provided by James and Stuart-Smith (2000), that linear features increase wolf mobility and that wolves use linear features as travel corridors in the boreal forest, is cause for concern. Future research in west-central Alberta should address predator movements to determine if mountain caribou are also at risk of increased predation near linear features.

Woodland caribou distributions have been found to decline near linear features (Dyer 1999; James 1999), but it has not been determined if these features affect both males and females in the same way, or if this response affects caribou demographics. As well, linear feature developments are only one of many human-induced changes in woodland caribou habitats. Cumulative impacts are poorly understood, yet numerous industrial activities are occurring on the landscape simultaneously (Edmonds 1998). Future research must address the cumulative effects that linear features (including pipeline and powerline ROWs), forest harvesting, coal mining, oil/gas production facilities, recreational activities, and other human activities are placing on already threatened woodland caribou populations (Dyer 1999; James 1999; Smith *et al.* 2000). Assessing cumulative effects of industrial expansion should include estimates of habitat loss due to avoidance (James 1999). Where caribou populations decline, critical thresholds in habitat availability will be particularly important to determine, and these may vary between landscapes and ecotypes (e.g., Andren 1999). If present, these thresholds should be used to place caps on cumulative development which should be implemented in the operating guidelines for industrial development on caribou ranges to ensure that the integrity and supply of caribou habitat, as demonstrated through viable populations, is maintained.

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Appendix 4-1. Distribution of caribou locations in buffers of increasing distance to each type of linear feature in the study area. The data are given as percentage (mean and standard error), for both use and availability. The analysis was performed on the complete set of distance buffers (all), and within close range (< 500 m) of these linear features (fine scale).

LINEAR FEATURE		DISTANCE BUFFERS 1 used	1 avail.	2 used	2 avail.	3 used	3 avail.	4 used	4 avail.	5 used	5 avail.	6 used	6 avail.
Streams (all)	Mean	1.85	6.04	5.03	8.10	12.15	12.44	21.44	22.40	38.75	31.29	20.78	19.72
	SE	0.27	0.34	0.91	0.47	1.83	0.74	2.34	1.27	4.13	1.09	6.29	3.39
Streams (fine-scale)	Mean	10.74	22.75	25.64	30.51	63.62	46.74	-	-	-	-	-	-
	SE	1.72	0.22	2.95	0.15	3.29	0.36	-	-	-	-	-	-
Roads (all)	Mean	0.39	1.48	1.84	2.19	3.25	3.71	7.88	7.75	10.95	14.46	75.69	70.42
	SE	0.22	0.33	0.74	0.50	1.24	0.87	3.01	1.84	2.59	2.53	7.41	6.05
Roads (fine-scale)	Mean	2.89	20.15	30.28	29.80	66.83	50.05	-	-	-	-	-	-
	SE	1.52	0.21	10.48	0.19	10.69	0.37	-	-	-	-	-	-
Seismic Lines (all)	Mean	12.45	12.20	16.17	15.29	19.24	19.81	18.17	23.45	33.98	29.25	-	-
	SE	1.70	0.67	2.53	0.88	2.24	1.05	2.84	1.09	6.33	3.10	-	-
Seismic Lines (fine-scale)	Mean	26.25	25.79	32.32	32.28	41.43	41.94	-	-	-	-	-	-
	SE	1.71	0.16	3.17	0.15	2.69	0.25	-	-	-	-	-	-

Appendix 4-2. Ranking matrices identifying selection of linear feature distance buffers by caribou, winters 1998-1999 and 1999-2000. Reported are t-test statistics for pair-wise comparisons of buffers, count of positive differences, and resulting ranks. Bold values indicate significant differences in selection ($p \leq 0.05$).

Streams Winters 1998–2000, df = 11, α = 0.05(2)

	1	2	3	4	5	6	No. Positives	Rank
1	-----	- 2.0	**- 2.2**	**- 2.4**	**- 2.9**	- 2.0	0	6
2	+	-----	**- 2.2**	**- 2.2**	**- 4.0**	- 0.6	1	5
3	+	+	-----	- 0.6	- 1.9	+ 1.1	3	3
4	+	+	+	-----	- 1.0	+ 1.0	4	2
5	+	+	+	+	-----	+ 1.9	5	1
6	+	+	–	–	–	-----	2	4

Streams within 500 m, Winters 1998-2000, df = 11, α = 0.05(2)

	1	2	3	No. Positives	Rank
1	-----	- 1.9	**- 2.2**	0	3
2	+	-----	**- 2.6**	1	2
3	+	+	-----	2	1

Roads Winters 1998 - 2000, df = 11, α = 0.05(2)

	1	2	3	4	5	6	No. Positives	Rank
1	-----	**- 2.2**	**- 2.7**	**- 3.4**	**- 4.0**	**- 6.0**	0	6
2	+	-----	- 0.8	- 1.8	**- 2.3**	**- 3.4**	1	5
3	+	+	-----	- 1.2	- 1.5	**- 2.5**	2	4
4	+	+	+	-----	- 0.5	- 1.8	3	3
5	+	+	+	+	-----	- 1.5	4	2
6	+	+	+	+	+	-----	5	1

Roads within 500 m, Winters 1998 – 2000, df = 8, α = 0.05(2)

	1	2	3	No. Positives	Rank
1	-----	- 2.1	**- 3.5**	0	3
2	+	-----	- 0.9	1	2
3	+	+	-----	2	1

Appendix 4-3 Comparison of habitat variables, using single factor ANOVAs, across linear feature distance buffers. When significant differences found (p ≤ 0.05), Tukey HSD (unplanned comparisons) outputs were used to determine which of the distance buffers contained significantly different levels of the habitat variable.

HABITAT VARIABLE	Streams		Roads		Seismic
	ANOVA	*Tukey HSD*	*ANOVA*	*Tukey HSD*	*ANOVA*
Elevation	F = 10.09, df = 5 p < 0.001*	Buffer 6 >>> 1, 2, 3 Buffer 5 >>> 1,2 Buffer 4 >>> 1	F = 10.09, df = 5 p < 0.001*	Buffer 1 >>> 4, 5, 6 Buffer 2 >>> 4 Buffer 3 >>> 4	F = 0.251, df = 4 p = 0.908
LP Dominant > 80 years	F = 1.18, df = 5 p = 0.329		F = 83.37, df = 5 p < 0.001*	Buffer 1 >>> 4,6 Buffer 2 >>> 3,4,5,6 Buffer 3 >>> 6 Buffer 4 >>> 6 Buffer 5 >>> 4,6	F = 0.099, df = 4 p = 0.982
LP Dominant ≤ 80 years	F = 0.59, df = 5 p = 0.708		F = 32.27, df = 5 p < 0.001*	Buffer 4 >>> 1,2 Buffer 5 >>> 1,2 Buffer 6 >>> 1,2,3,4,5	F = 0.941, df = 4 p = 0.447
LP / Spruce Sp. > 80 years	F = 2.63, df = 5 p = 0.032*	Buffer 1 >>> 4	F = 17.20, df = 5 p = 0.002*	Buffer 1 >>> 5 Buffer 3 >>> 5 Buffer 4 >>> 5 Buffer 6 >>> 1,2,5	F = 1.958, df = 4 p = 0.114
LP / Spruce Sp. ≤ 80 years	F = 0.28, df = 5 p = 0.925		F = 1.65, df = 5 p = 0.279		F = 0.484, df = 4 p = 0.685
Spruce / Fir Mixed > 80 years	F = 1.90, df = 5 p = 0.107		F = 2.00, df = 5 p = 0.212		F = 2.000, df = 4 p = 0.107
Spruce / Fir Mixed ≤ 80 years	F = 0.84, df = 5 p = 0.529		F = 0.27, df = 5 p = 0.916		F = 0.302, df = 4 p = 0.876
Deciduous Dom. / Mixed > 80 years	F = 1.55, df = 5 p = 0.186		F = 1.13, df = 5 p = 0.434		F = 1.946, df = 4 p = 0.116
Deciduous Dom. / Mixed ≤ 80 years	F = 0.46, df = 5 p = 0.805		F = 2.59, df = 5 p = 0.139		F = 0.171, df = 4 p = 0.952

Appendix 4-4. Logistic regression model creation, for binomial counts of caribou locations within distance buffers for roads and seismic lines, of both old (≥ 23 years) and new (≤ 22 years) origin. The best fitting model was determined by using the drop-in-deviance test, working from the most complex model (included all interaction terms) to the most simplistic model. A model was deemed adequate when the deviance goodness-of-fit test produced a large p-value ($p \geq 0.05$), and was moderately adequate when a p-value ranged from 0.01 to 0.05. All outputs generated using SPSS 9.0 statistical program. Model 2 was best fitting model:

Logit = -1.66 – 2.91(Road) + 0.31(Age) + [1.25*(LNarea)] – [0.17*(LNarea)*(LNdistance)] + [0.18(Road)*(Lndistance)]

	Variable	Regression Coeff.	S.E.	Z-Stat	$P_{(2)}$	Goodness-of-Fit χ^2	Drop In Deviance χ^2
MODEL 1	Road (1=Road, 0=Seismic)	1.26	2.48	0.51	0.610	44.87, df = 10, p < 0.001 Inadequate model.	N/A
	LNdistance	0.10	0.12	0.81	0.418		
	Age (1=old, 0=new)	0.33	0.10	3.17	0.002		
	LNarea	1.05	0.29	3.63	< 0.001		
	Road x LNdistance	-0.26	0.24	-1.09	0.260		
	Road x LNarea	0.33	0.28	1.19	0.234		
	LNarea x LNdistance	-0.14	0.05	-3.16	0.002		
	Intercept	0.83	0.83	-2.77	0.006		
MODEL 2	Road	-2.91	0.71	-4.11	< 0.001	24.12, df = 12, p = 0.020 Moderately adequate model.	-20.76, df = 2, p > 0.25 Reduced model (Model 2) fits data better than full model (Model 1).
	Age	0.31	0.11	2.82	0.005		
	LNarea	1.25	0.94	13.33	< 0.001		
	LNarea x LNdistance	-0.17	0.17	-10.36	< 0.001		
	Road x Lndistance	0.18	0.10	1.88	0.060		
	Intercept	-1.66	0.28	-6.03	< 0.001		
MODEL 3	Road	-1.63	0.11	-14.31	< 0.001	30.19, df = 13, p = 0.004 Inadequate model.	6.08, df = 1, p = 0.015 Reduced model (Model 3) does not fit data better than full model (Model 2)
	Age	0.24	0.10	2.42	0.016		
	LNarea	1.41	0.07	19.13	< 0.001		
	LNarea x LNdistance	-0.19	0.17	-11.25	< 0.001		
	Intercept	-1.44	0.24	-5.99	0.004		

Appendix 4-5. GPS data were collected on 12 female wintering caribou, at a rate of 4 locations per day, in the Redrock / Prairie Creek herd ranges, winters 1998-2000 (increased sample size). Total available area for each caribou was determined by buffering noon locations (1 location per day) by a radius equal to the 90th percentile for maximum daily travel distance. Buffers of 250 m around wellsites and cutblocks were excluded from the total available areas to avoid confounding effects on the analysis of responses to linear features.

Caribou ID	Data Winter	N Location Days	% Days @ 4 Loc./day	N Total Locations	Daily Travel Distance (90th Percentile) (km)	Excluded Area (km^2)	Total Available Area (km^2)
4c	1998-1999	151	100	460	2.7	3	355
51	1998-1999	119	43	338	1.6	11	112
52	1998-1999	149	90	359	2.5	0	141
5a	1998-1999	151	97	575	3.6	47	618
5b	1998-1999	151	86	541	1.9	0	192
72	1999-2000	94	62	298	1.4	8	42
73	1999-2000	122	80	300	3.7	24	522
77	1999-2000	131	91	293	2.9	8	347
78	1999-2000	131	87	346	3.6	22	544
79	1999-2000	131	87	367	4.1	9	507
7a	1999-2000	131	88	474	2.4	0	324
7b	1999-2000	149	88	515	3.0	0	531

Appendix 4-6. GPS data were collected on 12 female wintering caribou in the Redrock/Priarie Creek herd ranges, winters 1998-1999. Total available area was enlarged by buffering 4 locations per day by a radius equal to the 90th maximum daily travel distance (enlarged available area). Buffers of 250 m around wellsites and cutblocks were excluded from the total available areas to avoid confounding effects on the analysis of responses to linear features.

Caribou ID	Data Winter	N Location Days	% Days @ 4 Loc./day	N Total Locations	Daily Travel Distance (90th Percentile) (km)	Excluded Area (km^2)	Total Available Area (km^2)
4c	1998-1999	151	100	460	2.7	7	409
51	1998-1999	119	43	338	1.6	12	127
52	1998-1999	149	90	359	2.5	0	175
5a	1998-1999	151	97	575	3.6	48	663
5b	1998-1999	151	86	541	1.9	0	263
72	1999-2000	94	62	298	1.4	10	46
73	1999-2000	122	80	300	3.7	27	532
77	1999-2000	131	91	293	2.9	8	377
78	1999-2000	131	87	346	3.6	24	585
79	1999-2000	131	87	367	4.1	9	495
7a	1999-2000	131	88	474	2.4	0	345
7b	1999-2000	149	88	515	3.0	0	617

Appendix 4-7. Ranking matrices identifying selection of linear feature distance buffers by caribou, winters 1998-1999, and 1999-2000, using 4 locations per day per animal. Reported are t-test statistics for multiple comparisons of buffers, count of positive differences, and resulting ranks. Bold values indicate significant differences in selection ($p \leq 0.05$).

Streams Winters 1998–2000, df = 11, α = 0.05(2)

	1	2	3	4	5	6	No. Positives	Rank
1	------	- 1.7	**- 2.3**	**- 2.3**	**- 2.5**	- 1.8	0	6
2	+	------	**- 2.9**	**- 3.0**	**- 3.5**	- 0.5	1	5
3	+	+	------	- 0.3	- 1.2	+ 0.8	3	3
4	+	+	+	------	- 1.0	+ 1.1	4	2
5	+	+	+	+	------	+ 1.2	5	1
6	+	+	–	–	–	------	2	4

Streams within 500 m, Winters 1998-2000, df = 11, α = 0.05(2)

	1	2	3	No. Positives	Rank
1	------	- 1.6	**- 2.2**	0	3
2	+	------	**- 2.9**	1	2
3	+	+	------	2	1

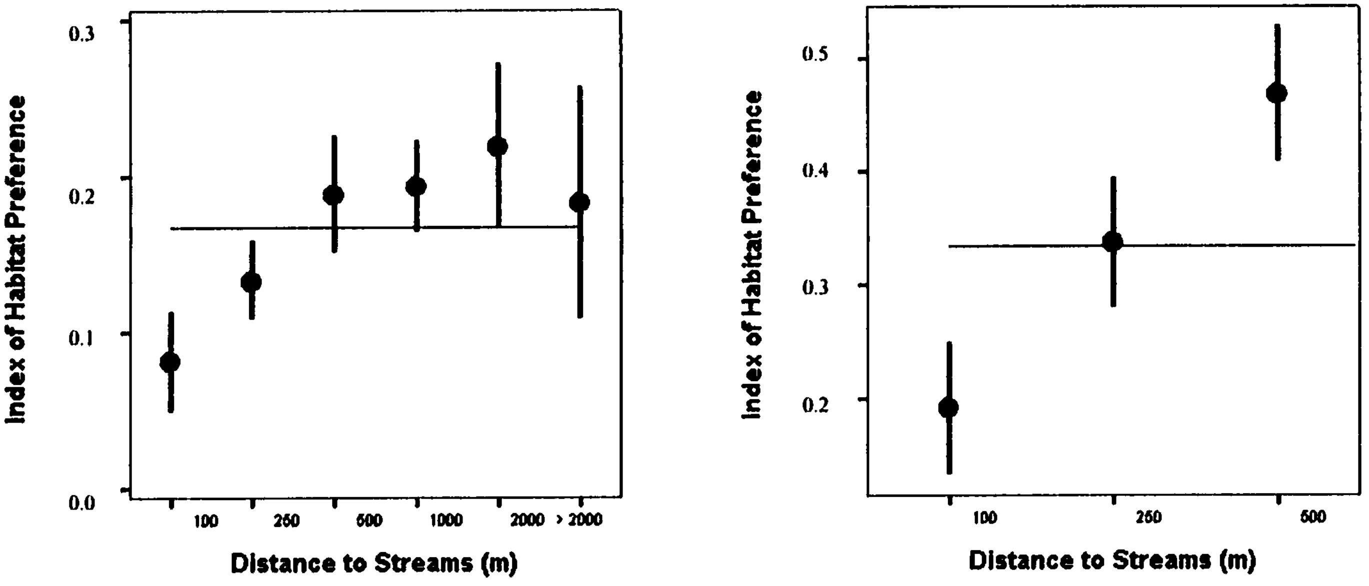
Roads Winters 1998 - 2000, df = 11, α = 0.05(2)

	1	2	3	4	5	6	No. Positives	Rank
1	------	- 1.3	- 1.2	**- 2.8**	**- 2.5**	**- 3.7**	0	6
2	+	------	+ 0.8	- 1.5	- 1.3	**- 2.4**	2	4
3	+	-	------	- 1.6	- 1.4	**- 2.3**	1	5
4	+	+	+	------	- 0.3	- 1.5	3	3
5	+	+	+	+	------	- 1.3	4	2
6	+	+	+	+	+	------	5	1

Roads within 500 m, Winters 1998 – 2000, df = 8, α = 0.05(2)

	1	2	3	No. Positives	Rank
1	------	**- 2.7**	**- 3.1**	0	3
2	+	------	- 0.01	1	2
3	+	+	------	2	1

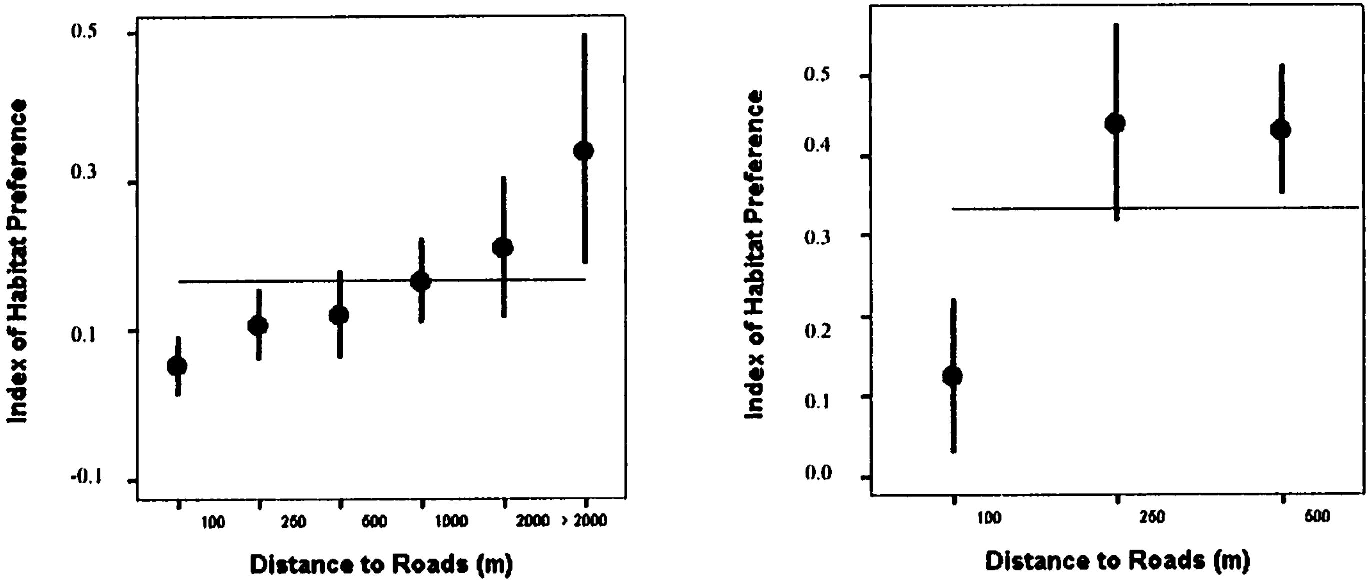
Appendix 4-8. Preference indices for 12 female caribou based on 4 locations per day (increased sample size), from distances to streams during winters 1998-1999, and 1999-2000. Index of habitat preference for each distance buffer is the mean of Manly's alpha. Manly's alpha ranges from 0 – 1. a) Coarse scale selection for streams. A random distribution over the landscape would produce a neutral value of 0.17, higher values indicate preference and smaller values indicate avoidance. b) Fine scale selection for streams. A random distribution over the landscape would produce a neutral value of 0.33, higher values indicate preference and smaller values indicate avoidance.



A) Coarse Scale

B) Fine Scale

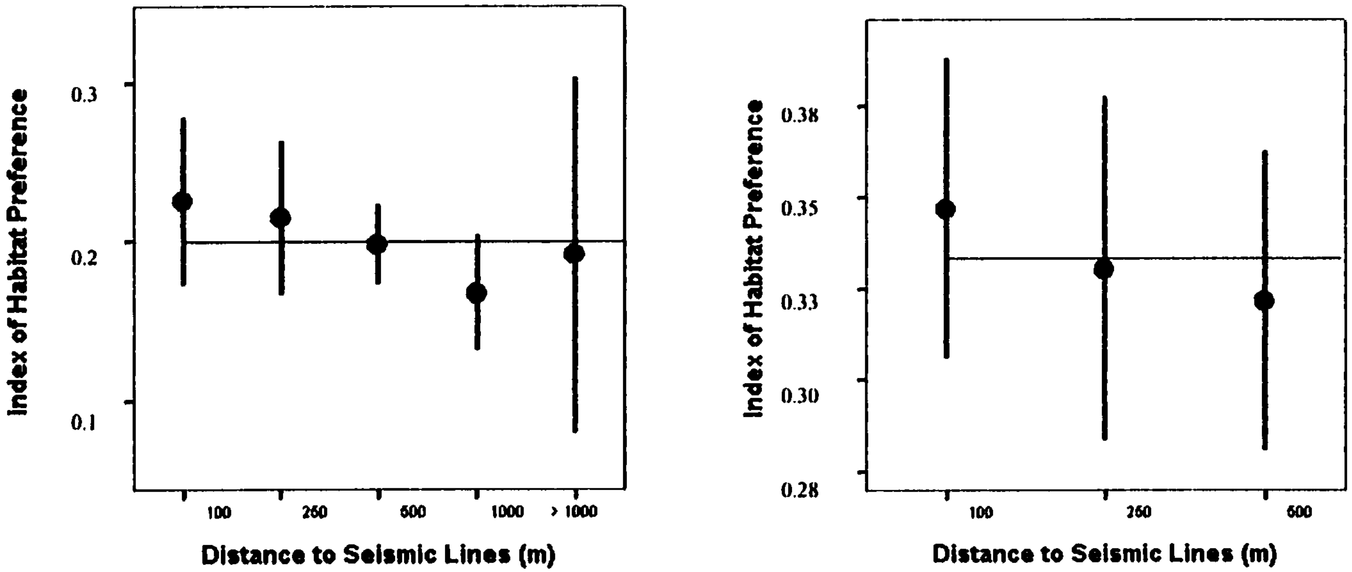
Appendix 4-9. Preference indices for 12 female caribou based on 4 locations per day (increased sample size), from distances to roads during winters 1998-1999, and 1999-2000. Index of habitat preference for each distance buffer is the mean of Manly's alpha. Manly's alpha ranges from 0 – 1. a) Coarse-scale selection for roads. A random distribution over the landscape would produce a neutral value of 0.17, higher values indicate preference and smaller values indicate avoidance. b) Fine scale selection for roads. A random distribution over the landscape would produce a neutral value of 0.33, higher values indicate preference and smaller values indicate avoidance.



A) Coarse Scale

B) Fine Scale

Appendix 4-10. Preference indices for 12 female caribou, based on 4 locations per day (increased sample size), from distances to seismic lines during winters 1998-1999, and 1999-2000. Index of habitat preference for each distance buffer is the mean of Manly's alpha. Manly's alpha ranges from 0 – 1. a) Coarse scale selection for seismic lines. A random distribution over the landscape would produce a neutral value of 0.20, higher values indicate preference and smaller values indicate avoidance. b) Fine scale selection for seismic lines. A random distribution over the landscape would produce a neutral value of 0.33, higher values indicate preference and smaller values indicate avoidance.



A) Coarse Scale

B) Fine Scale

Appendix 4-11. Ranking matrices identifying selection of linear feature distance buffers by caribou, with enlarged available ranges, winters 1998-1999 and 1999-2000. Reported are t-test statistics for pair-wise comparisons of buffers, count of positive differences, and resulting ranks. Bold values indicate significant differences in selection ($p \leq 0.05$).

Streams Winters 1998–2000, df = 11, $\alpha = 0.05(2)$

	1	2	3	4	5	6	No. Positives	Rank
1	-----	- 1.9	**- 2.8**	**- 2.8**	**- 3.0**	- 1.8	0	6
2	+	-----	**- 2.8**	**- 2.9**	**- 3.5**	- 0.4	1	5
3	+	+	-----	- 0.3	- 1.0	+ 0.8	3	3
4	+	+	+	-----	- 1.0	+ 1.1	4	2
5	+	+	+	+	-----	+ 1.2	5	1
6	+	+	-	-	-	-----	2	4

Streams within 500 m, Winters 1998-2000, df = 11, $\alpha = 0.05(2)$

	1	2	3	No. Positives	Rank
1	-----	- 1.6	**- 2.2**	0	3
2	+	-----	**- 2.8**	1	2
3	+	+	-----	2	1

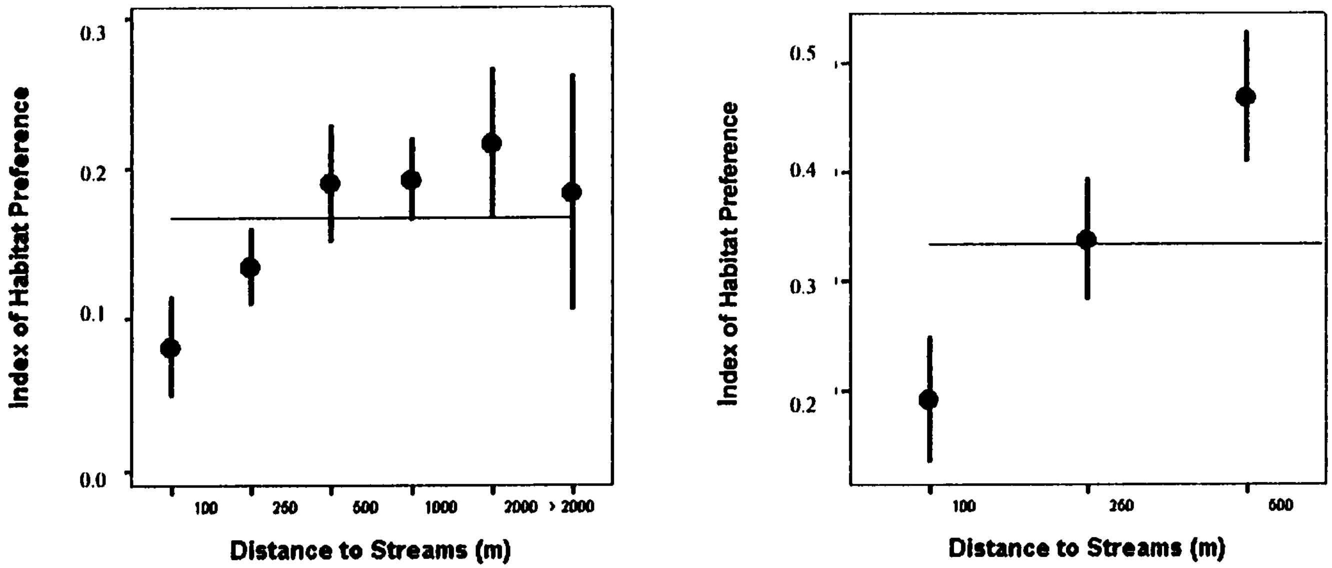
Roads Winters 1998 - 2000, df = 11, $\alpha = 0.05(2)$

	1	2	3	4	5	6	No. Positives	Rank
1	-----	- 1.4	- 1.2	**- 3.0**	**- 2.5**	**- 3.9**	0	6
2	+	-----	+ 0.9	- 1.5	- 1.3	**- 2.8**	2	4
3	+	-	-----	- 1.6	- 1.3	**- 2.6**	1	5
4	+	+	+	-----	- 0.2	- 1.9	3	3
5	+	+	+	+	-----	- 1.5	4	2
6	+	+	+	+	+	-----	5	1

Roads within 500 m, Winters 1998 – 2000, df = 8, $\alpha = 0.05(2)$

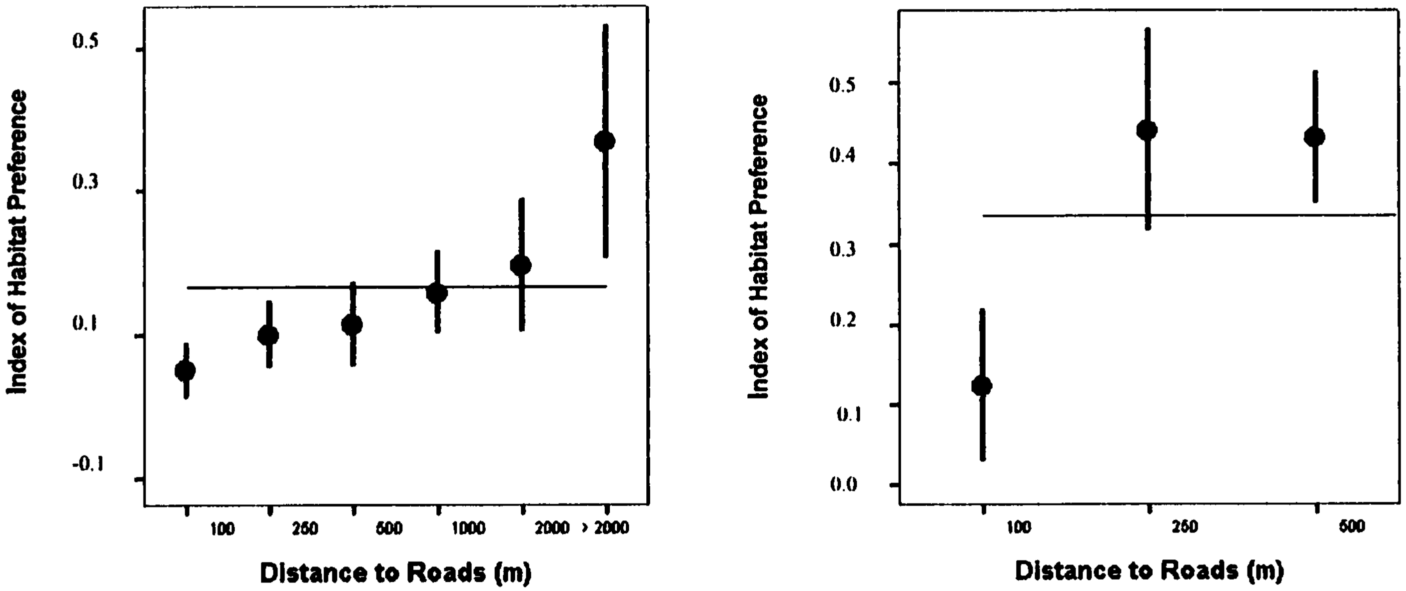
	1	2	3	No. Positives	Rank
1	-----	**- 2.7**	**- 3.1**	0	3
2	+	-----	- 0.01	1	2
3	+	+	-----	2	1

Appendix 4-12. Preference indices for 12 female caribou with enlarged available range areas, from distances to streams during winters 1998-1999, and 1999-2000. Index of habitat preference for each distance buffer is the mean of Manly's alpha. Manly's alpha ranges from 0 – 1. a) Coarse scale selection for streams. A random distribution over the landscape would produce a neutral value of 0.17, higher values indicate preference and smaller values indicate avoidance. b) Fine scale selection for streams. A random distribution over the landscape would produce a neutral value of 0.33, higher values indicate preference and smaller values indicate avoidance.


A) Coarse Scale

B) Fine Scale

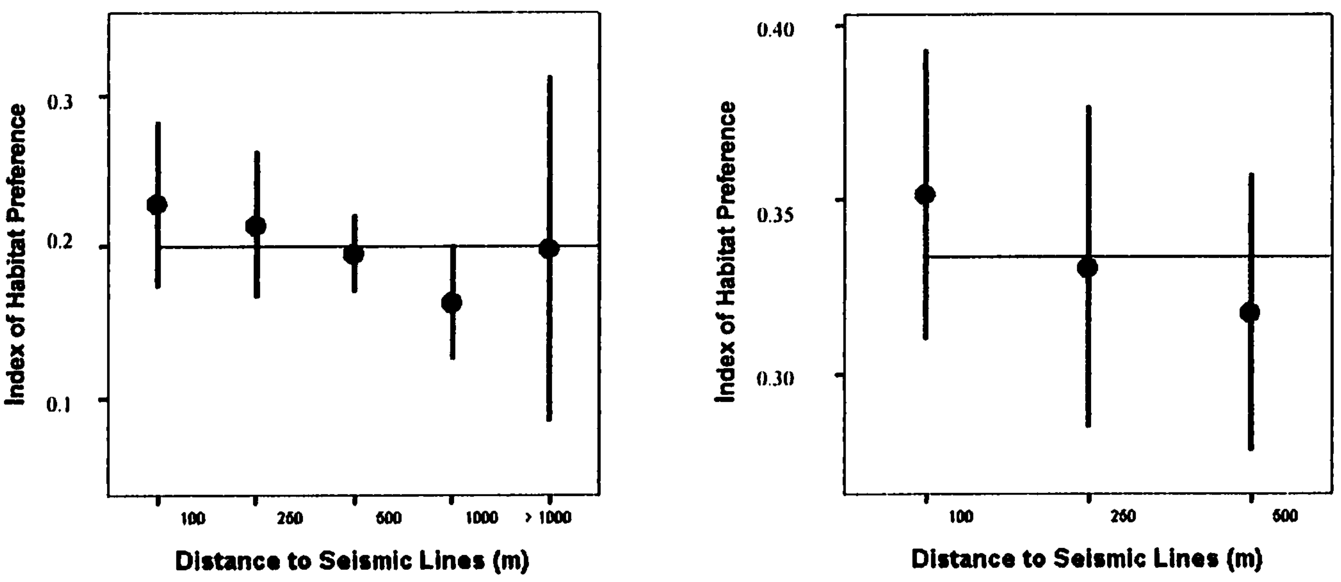
Appendix 4-13. Preference indices for 12 female caribou with enlarged available range areas, from distances to roads during winters 1998-1999, and 1999-2000. Index of habitat preference for each distance buffer is the mean of Manly's alpha. Manly's alpha ranges from 0 – 1. a) Coarse scale selection for roads. A random distribution over the landscape would produce a neutral value of 0.17, higher values indicate preference and smaller values indicate avoidance. b) Fine scale selection for roads. A random distribution over the landscape would produce a neutral value of 0.33, higher values indicate preference and smaller values indicate avoidance.



A) Coarse Scale

B) Fine Scale

Appendix 4-14. Preference indices for 12 female caribou, with enlarged available range areas, for distances to seismic lines during winters 1998-1999, and 1999-2000. Index of habitat preference for each distance buffer is the mean of Manly's alpha. Manly's alpha ranges from 0 – 1. a) Coarse scale selection for seismic lines. A random distribution over the landscape would produce a neutral value of 0.20, higher values indicate preference and smaller values indicate avoidance. b) Fine scale selection for seismic lines. A random distribution over the landscape would produce a neutral value of 0.33, higher values indicate preference and smaller values indicate avoidance.



A) Coarse Scale

B) Fine Scale