Distribution and Movements of Woodland Caribou on Disturbed Landscapes in West-Central Manitoba: Implications for Forestry

By

Carrie-Anne Lander

A Thesis submitted to the Faculty of Graduate Studies of

The University of Manitoba

in partial fulfillment of the requirements for the degree of

MASTER OF NATURAL RESOURCES MANAGEMENT

Natural Resources Institute

University of Manitoba

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THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

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Abstract

Forest operations have been implicated in adversely impacting woodland caribou populations. In order to improve on existing forestry mitigation plans on caribou ranges, the distribution and movements of the Kississing-Naosap herd on disturbed landscapes in west-central Manitoba was examined across a variety of scales. The results indicate a hierarchical pattern of selection by woodland caribou, with seasonal differences. Caribou avoided disturbance across all scales, and selected for mature coniferous habitat types. At a finer scale they selected for summer paths with greater arboreal lichen cover and winter paths with greater visibility. Caribou also selected areas further into cover, away from forest edges. Based on these results, I recommend that leave areas within operating areas be composed of a mosaic of mature jack pine, treed muskeg, and spruce cover types, and at least 1 km in width. I also recommend harvesting larger blocks, obliterating roads post-harvest, and encouraging the regeneration of coniferous stands.

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Table of Contents

List of Figures

List of Tables

List of Plates

Chapter 1: Introduction

1.1 Introduction

The boreal ecotype of woodland caribou (*Rangifer tarandus caribou*) is listed as "threatened" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC, 2002). Human activity and development are largely implicated in the decline in numbers of woodland caribou, especially in more southern regions (Bergerud, 1974; Rebizant et al., 2000). Forest harvesting in particular has been implicated in adversely impacting caribou populations across the country (Cumming and Beange, 1993), despite attempts by forest companies to reduce the impacts. Since arboreal and terrestrial lichens are a major food source for most woodland caribou populations (Rebizant et al., 2000), they tend to occupy areas of the boreal forest which are lichen-rich (mature coniferous stands) (Hristienko, 1985). Mature forests are also most valuable to forest companies, thus posing a conflict. In addition to creating widespread habitat loss, clear-cutting creates further problems with respect to increased predation, decreased food availability, increased snow accumulation that decreases the accessibility of those food sources (Johnson et al., 2004), increased displacement (Chubbs et al., 1993), and loss of security cover (Bolen and Robinson, 2003:332). Consequently, as the demand for timber increases in Canada, so too has the awareness of the impacts that forestry activities have on woodland caribou and their habitat, and thus management for this species has become a high priority (Cumming, 1992; Johnson et al., 2003). In order for mitigation plans to be effective, information on the habitat requirements of specific herds is necessary. In places where mitigation plans already exist, it is essential to monitor their effectiveness. This study seeks to address the information gaps as outlined in Tolko

Industries Ltd.'s (1999) "Forest Management/Woodland Caribou Mitigation Plan" for the Naosap and Peterson Operating Areas, with respect to habitat use of the Kississing-Naosap woodland caribou herd. This was accomplished by conducting a multi-scale analysis of habitat selection by this herd across three spatial scales and for the snow-covered and snow-free seasons.

1.2 Problem Statement

Several of the ten woodland caribou ranges identified in the province overlap with Tolko Industries Ltd.'s (Tolko) Forest Management License Areas, three of which are currently considered to be at high risk due to the occurrence of industrial activity in the area (Manitoba Conservation, 2005). One of these ranges – the Kississing-Naosap range – overlaps with the Naosap and Peterson Operating Areas, where Tolko has been harvesting since the late 1990's. All harvest and renewal should be completed by spring of 2007 in the Naosap area, and then operations will commence in the Peterson area, where they have identified mature forest stands targeted for harvest over the next 5 years as indicated in their forest harvest plans (D. Cross, pers. comm., 2006). This overlap of forestry activities and important woodland caribou habitat is challenging to managers who want to preserve woodland caribou values without compromising their wood supply (Tolko Industries Ltd., 1999). These concerns prompted Tolko to develop a mitigation plan for these operating areas. However, since habitat use data for the Kississing-Naosap woodland caribou herd is limited, a determination of seasonal habitat use patterns is essential in developing a better understanding of their habitat requirements, from which the mitigation plans can evolve. Furthermore, it will be important to assess whether

Tolko's current forest management practices are meeting the objectives outlined in their woodland caribou-forest management mitigation plans. These plans are designed to provide for future contiguous habitat for caribou, avoid increased predation by reducing favorable habitat conditions for alternate prey species such as moose (*Alces alces*), maintain contiguous blocks of undisturbed habitat represented by a mosaic of habitats of known importance to caribou, maintain undisturbed travel corridors and leave areas, and the development of special management prescriptions (such as buffers, altering road locations, restricting activity during certain seasons, minimizing ground disturbance, and emphasizing natural regeneration) (Tolko Industries Ltd., 1999). In particular, this research will assess the effectiveness of the mitigation measures relating to the leave areas.

1.3 Objectives

The focus of this research is to determine the variables that influence seasonal movements and distribution of woodland caribou at different spatial scales, in order to improve upon existing forest mitigation plans for the Kississing-Naosap caribou range. The main spatial scales will consist of the path or movement scale, and distribution scales within harvested areas and within the home range. The main seasons are defined as the "snow-covered" and "snow-free" seasons.

The specific objectives are:

- To identify factors explaining the distribution of woodland caribou within their home range in the snow-covered and snow-free seasons.

- To identify factors explaining the distribution of woodland caribou within the Naosap Operating Area in the snow-covered and snow-free seasons.
- To identify factors explaining the location of movement paths within harvested areas in the snow-covered season.
- To identify factors explaining the locations of woodland caribou within harvested areas in the snow-free season.

1.4 Thesis Organization

I began in Chapter 1 with a general introduction to the issues surrounding forest management in woodland caribou habitat, and in particular those in my study area, followed by the objectives of this particular study. Chapter 2 involves a characterization of woodland caribou, including their status provincially and nationally. In this chapter I also review the literature on the impacts of forestry to woodland caribou. I then go on to discuss the role of the forest industry in adaptive management, with a review of current recommendations for harvesting on woodland caribou range. I end the chapter with a review of the current management efforts across Canada. In Chapter 3 I introduce the research that forms the basis of this thesis, as well as the study area and subjects. I then highlight the results of this research followed by an interpretation of the findings. I conclude in Chapter 4 with a review of the key findings, management implications stemming from these findings, and recommendations for future research.

Chapter 2: Background

To set the stage for this research, it is necessary to first discuss some background information on woodland caribou, the forest industry, and the relationship between the two. Hence in this chapter, I give an overview of the species including a physical description, and information on reproduction, diet, habitat, population limiting factors, and behaviors. I introduce the Federal Species at Risk Act (SARA) and the status of woodland caribou under this Act, and in the province of Manitoba. I then continue with a discussion on the direct and indirect impacts that forest harvesting has on this species with respect to various habitat, behavioral, and mortality factors. The following section involves a discussion of how these impacts can be avoided or reduced, utilizing a variety of forest management practices. The chapter is concluded with a look at some of the current management efforts across Canada, with respect to recovery and forest management guidelines in woodland caribou range.

2.1 Biology and Ecology of Woodland Caribou

2.1.1 Physical Description

Woodland caribou are an even-toed hoofed mammal of the deer family (*Cervidae*), and a ruminant with a four-chambered stomach (Hristienko, 1985; Whitaker, 1996:815). They are mid-sized cervids, slightly larger than white-tailed deer (*Odocoileus virginianus*), but much smaller than elk (*Cervus elaphus*) and moose (Banfield, 1974; Beacham and Castronova, 2001:138). Adult males may reach up to 8 feet long, 4 feet high (at the shoulder), and 600 pounds in weight, while adult females usually weigh no more than 300 pounds (Whitaker, 1996:842; Beacham and Castronova, 2001:138).

Caribou have larger hooves and wider muzzles than other members of the deer family (Beacham and Castronova, 2001:138). The large concave hooves are a morphological adaptation to deep snow or icy conditions (Whitaker, 1996:844; Geist, 1998:319) and act as paddles for swimming (CPAWS, 2004). The hollow air-filled hairs of their coats also keep caribou dry (Geist, 1998:319), and give them buoyancy when swimming (Whitaker, 1996:845).

They are also distinguished from other members of the deer family by their large, distinctive antlers that are somewhat flat and have several tines, in addition to one that protrudes down the snout (Whitaker, 1996:842; Beacham and Castronova, 2001:138). Unlike other members of the deer family, both sexes of woodland caribou grow antlers (Cumming, 1992; Whitaker, 1996); however, those of females are somewhat skimpy (Whitaker, 1996), and may be inconspicuous (Beacham and Castronova, 2001:138). Woodland caribou are brownish in color, with a white rump and shaggy mane below a whitish neck (Whitaker, 1996; Beacham and Castronova, 2001:138).

2.1.2 Reproduction

Woodland caribou breed in the fall, with each mature bull attracting a rutting group of several cows and juveniles, which he strongly defends from other males (Whitaker, 1996; Beacham and Castronova, 2001:139). After 7½-8 months gestation, 1 or (rarely) 2 calves are born between May and July (Whitaker, 1996). Because females do not start breeding until about 3 or 4 years of age (Beacham and Castronova, 2001:139), and usually only one calf is born each year (Hristienko, 1985), woodland caribou have a relatively low reproductive rate (Cumming, 1992). Birth rates average around 80% per year, and 40-70% of calves may succumb to predation, severe weather, or malnutrition (Beacham and Castronova, 2001:139). As an adaptation for predator avoidance, females usually disperse widely (Cumming, 1992) and choose the most isolated habitats for calving (Beacham and Castronova, 2001:139).

2.1.3 Diet

It is a well-known fact that lichens form a very important part of woodland caribou diets (Rebizant et al., 2000), especially during winter when they are the principal food source (Whitaker, 1996:845). Holleman et al. (1979) found that in winter nearly 5 kg of lichens per day were consumed by an 80 kg caribou. Some populations of woodland caribou, such as the mountain sub-populations, subsist mainly on arboreal species of lichen during winter (Terry et al., 2000; Kinley et al., 2003). Terrestrial lichens, located by sight and smell through the snow, are used by woodland caribou in most other parts of Canada (Cumming, 1992). The terrestrial reindeer lichens (such as *Cladina stellaris, C. rangiferina,* and *C. Mitis*) are the primary late winter food of woodland caribou (Bergerud, 1972).

Despite their relatively low protein content (2-5%) (Johnson et al., 2001), lichens are high in digestible carbohydrates, which are a good source of energy for cold weather conditions (Nellemann et al., 2000). Caribou will also supplement their winter diet with green wintering plants (Bergerud, 1971; Darby and Pruitt, 1984; Rominger and Oldemeyer, 1990), which are higher in nutrients and protein (Thomas and Armbruster, 1996).

Summer diets may include various ground forbs, deciduous shrubs, and arboreal and ground lichens (Bergerud, 1972; Darby and Pruitt, 1984; Thomas and Armbruster, 1996). However, it is inappropriate to generalize caribou food habits across geographical regions (Rominger and Oldemeyer, 1990), and it is important to note that even though caribou are adapted to a diet of lichens, they are not essential to their survival (Bergerud, 1972). Instead these animals are highly plastic in the type of foods they will eat (Hristienko, 1985). Bergerud (1977) catalogued an extensive list of the food types eaten by woodland caribou: 62 lichen species and 282 seed plants (qtd. in Johnson, 1993). Ahti and Hepburn (1967) also provided a thorough list of woodland caribou plant foods.

2.1.4 Habitat

Woodland caribou generally inhabit mature lichen-rich forests within the boreal ecotype (Hristienko, 1985). Extensive stands (1000s of square kilometers) of these mature forests are required to maintain viable populations (Rebizant et al., 2000). Previous studies on woodland caribou habitat use have shown trends in habitat selection, with variation among scales examined. At the finest scale caribou often select for sites that have heavier lichen loads than unused sites (Terry et al., 2000; Johnson et al., 2001; Mosnier et al., 2003). They also may choose sites with specific lichen species, such as in northern B.C. where they frequently selected feeding sites across pine terraces with *Cladonia spp.* and *Cladina mitis* (Johnson et al., 2001). However, access to ground lichens may be limited by snow conditions, and woodland caribou may respond to this by moving to sites with less deep snow. Mosnier et al.'s (2003) results indicate sinking depth as one of the main influences over caribou microhabitat selection. In this case, they may choose sites with greater canopy cover, where snow is less dense and thick, and less energetically costly to crater or move in (Schaefer, 1996).

At a coarser scale of selection, caribou may be selecting those cover types associated with the preferred forage types. Furthermore, coarser scale selection may relate to more limiting factors, such as avoiding predation (Rettie and Messier, 2000). Woodland caribou are reported to select more open habitats in order to reduce the risk of contact with predators (Bergerud and Page, 1987). For example, Darby and Pruitt (1984) reported the Aikens Lake herd of woodland caribou chose semi-open and open bogs in early autumn, with the onset of the rut. They used these open bogs until about mid-February when snow restricted their travel, at which point they moved up to jack pine-rock ridges. At all other times of the year besides October and early winter, they selected mature coniferous uplands.

During spring and summer, woodland caribou have been reported to use islands and lakeshores in order to escape predation (Bergerud, 1985). For example, woodland caribou on Lake Nipigon islands in Ontario spent 8-9 months of the year on smaller islands with relatively low habitat quality, presumably because there were no predators present there (Cumming and Beange, 1987). They avoided the larger islands where moose and wolves (*Canis lupus*) were found (Cumming and Beange, 1987). During summer, other herds tend to use a greater diversity of habitats than in other seasons (e.g. Darby and Pruitt, 1984).

In sum, woodland caribou have been reported to choose particular cover types across a number of spatial scales, which may correspond to forage preferences, forage availability and accessibility, and in particular, limiting factors such as predation. Just as they are versatile in the food types they choose, woodland caribou will also use a wide variety of habitats throughout their range (Rominger et al., 1994), and this can depend on various factors as outlined below.

2.1.5 Population Limiting Factors

Food has been reported to be the limiting factor for migratory populations and where predation is absent (e.g. Adamczewski et al., 1988), however for the boreal ecotype of woodland caribou, predation is the primary limiting factor (Bergerud and Elliot, 1986; Rettie and Messier, 1998). For example, an 8-year study by Bergerud and Page (1987) found the chief cause of caribou mortality was predation by wolves and grizzly bears (*Ursus arctos*). Furthermore, after controlling for predators, they concluded that weather had little effect on the survival of calves. This contradicted their hypothesis that maternal nutritional condition, affected by severe winter conditions, would influence the viability of calves (Bergerud and Page, 1987).

Furthermore, in an experimental wolf reduction in northern British Columbia (B.C.), Bergerud and Elliot (1986) reported calf survival increased significantly in the 3 years that wolves were reduced. In fact, caribou densities may approach up to 8.9 km^{-2} in the absence of predators (Edmonds, 1987, Fong et al., 1991, Seip, 1991; qtd. in Johnson, 1993). Where wolves do exist in caribou range, caribou densities can still increase, if they can maintain a spatial separation from the wolves' other prey species (Rettie and Messier, 2000). Normally, wolves rely on moose as their primary prey with caribou and other species as their secondary prey (Bergerud, 1983; qtd. in Johnson, 1993). Wolf densities of >.007 km^{-2} are usually too high for caribou to maintain their numbers, but if they have sufficient habitat to accommodate their anti-predator dispersal strategy, moderate densities of <.014 km^{-2} may be tolerated (Bergerud and Elliot, 1986).

The spacing technique used by caribou is an anti-predator strategy which may decrease encounter rates with predators and increase searching time for predators (Bergerud and Elliot, 1986; Ouellet et al., 1996), making caribou less profitable to search for, and thus less likely to be captured (Bergerud and Page, 1987). For example, cows often disperse widely into small groups or individually to bear their calves in isolation (Brown and Theberge, 1990), such as on islands or lakeshores (Bergerud, 1985).

The ultimate cause of woodland caribou population declines then is presumably influenced by long-term habitat alteration (Rettie and Messier, 1998; Schaefer, 2003). If habitat changes to early seral stage forests, abundance of wolves' primary prey (e.g. moose, elk, or deer) may increase, leading to an increase in wolves (Rettie and Messier, 1998; Seip, 1998). Subsequently, this higher number of wolves results in increased predation on woodland caribou, whereas previously the two may have co-existed with no major declines in caribou. This scenario occurred in northwestern B.C. in the 1930's and 1940's where caribou were reported to have co-existed with a relatively low density of wolves, until moose moved into the region and woodland caribou populations suffered major declines (Bergerud and Elliot, 1986). Furthermore, the animals may be forced into sub-optimal habitats as they try to escape this heightened predation risk, resulting in reduced forage efficiency and increased competition for food (Kotler et al., 1994; Ouellet et al., 1996). In this case, predation may indirectly be causing declines through compromised nutrition and its effects on body condition and reproductive potential.

Other factors aside from predation and insufficient forage need to be credited for causing deaths. For caribou calves these include stillbirths, birth defects, weather, drowning, accidents, and social interactions like trampling (Hristienko, 1985). For adults these include drowning, fighting between males, deaths in parturition, disease/parasites, accidents, and predation (Hristienko, 1985). Simpson et al. (1985) found that in the Columbia Mountains of B.C., 8 caribou died in snow avalanches, 2 bulls died after locking antlers, 1 died from starvation after injuring their neck, and 2 calves died from poor maternal nutrition. These are all examples of how some of the other factors aside from predation had to be influencing mortality. Moreover, population limiting factors may differ spatially and temporally (Leopold, 1933), so it is important to examine each local population. In any case, woodland caribou are very vulnerable to population decline, because they lack the reproductive elasticity of other cervids (Cumming, 1992).

2.1.6 Sociality and Movements

Woodland caribou are more mobile than other ungulates found in the boreal forest (Cumming, 1992; Johnson et al., 2002). They are not as gregarious as barren-ground caribou, usually only congregating in small herds of three to ten animals (Beacham and Castronova, 2001:138). In southeastern Manitoba mean group size was found to be between 5.5 and 6.2 animals for all seasons except late spring-summer, which was 1.2 (Darby and Pruitt, 1984). This reflects the fact that caribou cows will split up and disperse widely into small groups or singly at calving time. The adult bulls are generally solitary for most of the year, except for during breeding (Fuller and Keith, 1981; Beacham and Castronova, 2001:139). In the fall they move to particular locations for mating, in order to increase encounters between bulls and cows (Fuller and Keith, 1981). After the rut, the males and females separate, and they all start moving towards the wintering grounds (Whitaker, 1996). However, woodland caribou are not as migratory as the barren-ground caribou, and in fact some herds show no seasonal movements (e.g. Darby and Pruitt, 1984). Snow conditions are what usually influences winter movements (Darby and Pruitt, 1984). In the spring, female caribou separate from their group to move to relatively isolated habitat in order to bear their calves (Beachman and Castronova, 2001). New calves are easy prey, and this is an effort to reduce the chances of encountering predators as mentioned earlier. Other movements may be in response to insect harassment (Klein, 1980; Whitaker, 1996). In sum, movements of woodland caribou may be for reproduction (rutting and calving), a response to predation risk, forage limitations as influenced by snow, or avoidance of insects.

2.2 Status of Woodland Caribou

2.2.1 Species at Risk Act (SARA)

The Species at Risk Act was passed by Parliament in 2002, with the goal of ensuring that wildlife species survive, and biodiversity is maintained (Government of Canada, 2003). SARA provides a framework for deciding which species are a priority for action, and what to do to protect those species. COSEWIC provides scientific assessments of the status of a species based on the best available information on the biological status of that species, which is then used in the process of listing that species under the Act. There are currently 233 species listed as species at risk under SARA: 17 extirpated species [those that no longer exist in the wild in Canada, but do exist elsewhere in the wild]; 105 endangered species [species that are facing imminent extirpation or extinction]; 68 threatened species [species that are likely to become endangered if nothing is done to reverse the factors which may lead to this]; and 43 species of special concern [species that may become threatened or endangered because of a combination of biological characteristics and identified threats].

2.2.2 Status of Woodland Caribou

Woodland caribou have disappeared from Nova Scotia and New Brunswick, however they can still be found in the rest of the Canadian provinces and territories, except for Prince Edward Island where they never existed (Cumming, 1992). However, due to human activity and development, the numbers of woodland caribou have decreased in many places, especially in more southern regions (Cumming, 1992). Consequently, several Canadian populations of woodland caribou are listed under SARA. The Atlantic-Gaspé population is listed as endangered, the Boreal and Southern Mountain populations are listed as threatened, and the Northern Mountain population is listed as special concern (COSEWIC, 2002).

In Manitoba, the woodland caribou were once found throughout the entire boreal forest, but now they have been largely decimated from the southern parts of their range (Rebizant et al., 2000). The population is thought to have declined from over 4,000 animals, to an estimated current population of 1821-3135 (Manitoba Conservation, 2005). Manitoba's boreal woodland caribou was listed as threatened under the Endangered Species Act (ESA) in June 2006. By being listed under this Act, they are now afforded the legal protection which could result in more resources being devoted to habitat protection (Martin Cash citing Ron Thiessen in the Winnipeg Free Press, April 15, 2006). This effort will only strengthen the steps already taken by listing them under SARA.

There are presently 10 identified woodland caribou ranges in Manitoba, two of which are considered to be low risk of being negatively impacted from human disturbance, five of medium risk, and three at high risk (Manitoba Conservation, 2005). The subject of this research will concern one of these high risk ranges – the Kississing-Naosap range, as discussed in more detail elsewhere in this document.

2.3 Impacts of Forestry on Woodland Caribou

Habitat loss and increases in hunting and predation are the main factors implicated in the decline of woodland caribou numbers across North America (Bergerud, 1974). Forest harvesting potentially assists in this decline directly through habitat loss and alteration, and by increasing human and predator access into caribou habitat (Cumming, 1992). The various direct and indirect impacts that forest operations have on woodland caribou are discussed in detail below.

2.3.1 Forage Availability

Because lichen establishment is mostly associated with older forests (Rebizant et al., 2000), removal of mature timber and disturbance of the forest floor results in loss of forage resources for woodland caribou. Terrestrial lichen resources may decline when harvesting activities such as log skidding are practiced (Johnson et al., 2004), as this is destructive to the forest floor. The actual removal of trees also reduces the amount of arboreal lichens available to caribou, and because of the desiccating effect of this canopy loss on the micro-environment (M. Manseau, pers. comm., 2005), it may limit the growth of terrestrial lichens as well. Logging activities such as stem-only harvesting, which leave behind woody debris, may leave important sources of arboreal lichen forage on-site, thus reducing the amount of forage lost. However, the boreal ecotype of woodland caribou feed predominantly on terrestrial lichens; so for some populations, leaving arboreal lichens may not be as important as protecting the terrestrial species (M. Manseau, pers. comm., 2006).

In comparison to forest fires, harvesting may not always lead to as much reduction in lichen resources. For example, Coxson and Marsh (2001) found that when winter harvesting did not disturb the forest floor, the lichen cover exceeded that on burned sites of the same age after 15 years. The same effects could not be seen with summer harvesting, due to the greater level of disturbance to the forest floor in the snow-free season. Therefore, the level of disturbance to the forest floor may dictate how much lichen forage remains on-site. Furthermore, post-harvest treatments such as herbicides or scarification may remove much of the existing lichen reserves, as was suspected to be the case in the Cliff Lake area of Ontario after logging in the 1980s (Cumming and Beange, 1993). Moreover, the amount of debris that logging leaves behind influences forage availability as well. Webb (1996) notes that leaving behind debris may be an important aspect of forage availability, as she found reindeer lichens growing on substrates such as slash and stumps, created by logging activities like stem-only harvesting. This type of fragment growth occurred more frequently on logged, rather than burned sites (Webb, 1996). However, this type of growth is not expected to provide much forage for woodland caribou (M. Manseau, pers. comm., 2005).

Furthermore, not all species of lichen thrive after logging – Webb (1996) noted that *Cladina stellaris* declines after logging, as they are not as well suited to high light levels, and they are rather slow-growing. Alternatively, *C. rangiferina* is the fastest growing, and *C. mitis* may be ecologically suited to disturbed sites (Ahti, 1961; qtd. in Webb, 1996). However, it may take several years (over 120) to re-establish sufficient arboreal lichen biomass (Armleder and Stevenson, 1996), and there may be other factors aside from time, involved in lichen recovery (Webb, 1996).

But fortunately, good lichen sources are often found on poor growing sites for trees (Coxson and Marsh, 2001), thus the potential for conflict with harvesting can be reduced. Spring habitat may even be improved through winter harvesting, because the open canopy accelerates green-up of forbs and shrubs which are important to caribou coming off a winter diet (Servheen and Lyon, 1989). However, cutting on a winter range in summer time may have devastating effects, as more damage is done to the terrestrial lichen cover which is so important to the boreal woodland caribou winter diet. Compromised nutrition in winter may lead to a decrease in reproductive success (Gates et al., 1986). Thus, in addition to type of harvesting and post-harvest treatments, the timing of harvesting also has an important influence on forage availability.

2.3.2 Forage Accessibility

Whether or not harvesting activities may favor the retention of forage lichens, the harvested landscape may create conditions in which those lichens are not easily accessible to caribou. Canopy closure increases snow interception and subsequently reduces snow depth (Pruitt, 1957). Loss of canopy through harvesting may lead to deeper snow, making terrestrial lichens less accessible to caribou (Johnson et al., 2004). Although woodland caribou are well adapted to deep snow conditions (Telfer and Kelsall, 1984), they do have snow depth and hardness thresholds after which they will no longer crater, and at which point they may switch to arboreal lichens (Johnson et al., 2004). The threshold depth for cratering by woodland caribou is about 65 cm (Stardom, 1977), although Johnson et al. (2004) and Brown and Theberge (1990) have reported craters as deep as 97 cm and 123 cm, respectively.

Thicker and harder snow increases the difficulty in detecting terrestrial lichens and increases the energy expenditure required to reach them (Fancy and White, 1985). LaPerriere and Lent (1977) reported that caribou chose feeding sites with less hard snow, and Johnson et al. (2000) found they selected feeding sites with less deep snow. Moreover, deep snow may cause caribou to sink, making locomotion difficult and causing caribou to move to higher, more exposed terrain (Adamczewski et al., 1988). These movement choices may actually increase energy expenditure for the animals, as they have to search out other, more favorable snow conditions from which to forage – and as a result are sometimes forced to choose less abundant and less nutritious food resources (Adamczewski et al., 1988; Schaefer, 1996). Alternatively, if they choose to forage in areas of thicker and harder snow where forage abundance is greater, then energy expenditure will also be greater, as it is harder to crater in these conditions (Schaefer, 1996).

However, some suggest that open canopies may in fact be more productive for lichen growth (Coxson and Marsh, 2001). In fact, Lance and Mills (1996) found that caribou most often selected sites in those areas of the forest having more open canopies. Furthermore, the arboreal lichen available on felled trees in logged areas may be a food source for caribou (Simpson et al., 1985). Moreover, the climatic conditions of harvested sites (such as increased wind turbulence and solar radiation) may create a more supportive snowpack, making locomotion, and the ability of animals to reach arboreal lichens easier (Servheen and Lyon, 1989), as was found in the Selkirk Mountain caribou range (Johnson et al., 2004). However, as mentioned before, the boreal ecotype of woodland caribou feed primarily on terrestrial lichen species in winter, thus possibly negating these advantages of increased accessibility to arboreal lichen species.

2.3.3 Increased Predation

Some argue that it is not habitat loss or starvation through lack of lichens which cause the declines of caribou, but that direct mortality from predation is most influential (Bergerud, 1974). For example, Wittmer et al. (2005) found that in a caribou population in B.C., mortality was more likely during summer, a season which also corresponds to greater food abundance. Predation risk on harvested landscapes can increase because post-logging succession often creates habitat attractive to species like moose or deer, whose numbers may subsequently increase (Edmonds and Bloomfield, 1984; Johnson et al., 2004). Consequently, the density of predators such as wolves may also increase in response to this increase in abundance of alternate prey species (Edmonds and Bloomfield, 1984; Johnson et al., 2004). Cumming and Beange (1993) speculate that wolf densities may have increased following cutting in the Cliff Lake Area in northern Ontario after harvesting, contributing to the decline in number of caribou found in the area. When caribou are abundant, wolves may switch from preying on moose to caribou (Holleman and Stephenson, 1981).

Furthermore, the logging roads associated with timber harvesting may enhance the ability of wolves to access woodland caribou which were previously inaccessible (Dyer et al., 2001). As roads make traveling easier, they may contribute to an increase in wolves' search rates, making their predation on caribou more efficient (James and Stuart-Smith, 2000). An example of this impact was found in a study by James and Stuart-Smith (2000) who reported an increase in wolf-caused mortalities on woodland caribou closer to linear features in northeastern Alberta. Moreover, the adverse effects associated with logging roads may be greater than those of the actual cut-blocks because they create more edge habitat, thus contributing more to fragmentation (Reed et al., 1996).

The influx of predators into caribou habitat may severely compromise their anti-predator strategies of spacing away and existing at low densities. This can be devastating to caribou populations as wolves are their primary limiting factor (Bergerud and Elliot, 1986; Rettie and Messier, 1998), and the increased predation could result in population reduction, and possibly eradication. For example, after years of extensive timber harvesting in Sleeping Giant Provincial Park in Ontario, caribou were eradicated, while moose, deer, bears, and wolves increased (Cumming and Beange, 1993).

In addition to attracting predators to the area, white-tailed deer may also bring with them brain worm (*Parelaphostrongylus tenuis*), a fatal disease to woodland caribou (Anderson and Strelive, 1968). Furthermore, logging roads may increase human access to the area, leading to an increase in caribou hunting (Edmonds and Bloomfield, 1984; James and Stuart-Smith, 2000), poaching, or death caused by caribou-vehicle accidents. For example, the mortality of a woodland caribou population in Ontario increased after harvesting, due to deaths from logging trucks, aboriginal hunting, and poaching (Cumming and Beange, 1993).

2.3.4 Avoidance and Displacement

Caribou have been reported to abandon or avoid harvested areas for many years after the initial disturbance. In a study on woodland caribou in east-central Newfoundland, 3 males and 12 females of 35 caribou in total were found farther away from areas that had been clear-cut, than before the harvesting occurred (Chubbs et al., 1993). Of these, the females were found to be 2-3 times farther than the males. This is a similar finding to Nellemann and Cameron's (1998) study on the distribution of calving caribou in an oil-field region near Prudhoe Bay, Alaska. Darby and Duquette (1986) found similar patterns of displacement, where woodland caribou disappeared from parts of their winter range while avoiding clear-cuts. Cumming and Beange (1993) found that caribou at Armstrong and Springwater Lake areas in Ontario continued to use their wintering area, but abandoned the cut portions.

Smith et al. (2000) also found that woodland caribou in west-central Alberta avoided using recently harvested cut-blocks, staying an average distance of 1.2 km farther away from them than random locations. Very few radio-locations were recorded in cut-blocks (0.6%, 4/701) in the final stages of logging. Furthermore, Schaefer and Mahoney (2006) discovered cut-block avoidance in the migratory Middle Ridge herd of Newfoundland, where females maintained an average distance of 9.2 km from active cut-blocks, in addition to pre- and post-harvest avoidance. Males in this study occurred closer (7.78 km) to cut-blocks and did not show any change in proximity as logging progressed.

Avoidance may be influenced by season, as demonstrated in Dyer et al.'s (2001) study, where maximum avoidance of cut-blocks by caribou occurred during late winter, corresponding to the highest level of traffic on the roads. However, in numerous other studies caribou have also been reported to avoid roads despite low traffic levels (Cameron et al., 1992; Nellemann and Cameron, 1996, 1998).

This avoidance by woodland caribou of logged habitats may be displacing them into less suitable habitat, with less forage and deeper snows, putting them at greater risk of mortality in their new range (Cumming and Beange, 1993). This is because they may have chosen those original habitats because of the low risk of predation or greater abundance of forage resources to begin with; so when forced to leave, they may lose those benefits (Cumming and Beange, 1987).

Furthermore, this avoidance may cause carrying capacity on alternate ranges to be exceeded (Nellemann et al., 2000), leading to poorer nutrition and possibly reduced reproductive success of lactating females (Nellemann and Cameron, 1996). Moreover, their spacing-out strategy in order to avoid detection by predators (Stuart-Smith et al., 1997) may be compromised by this forced aggregation, by making the animals easier to find and capture (Dyer et al., 2001).

Aside from the avoidance of the actual cut-blocks in harvest areas, caribou have also frequently been found to avoid linear features such as roads associated with logging as well (Nellemann and Cameron, 1998), possibly due to the perceived threat of mortality associated with them. This is also a type of functional habitat loss when optimal habitats are abandoned and range size is reduced. Similar to cut-block avoidance, many factors influence an animal's reaction to obstructions like roads, such as level of traffic and human activities, season of year, sex and age of animal, etc. (Klein, 1980). Also, if an animal encounters the obstruction year-round instead of only seasonally, they may be less disturbed as they habituate to it (Klein, 1980). Road-building and other forestry activities can also fragment populations of caribou, as is reported for populations found in Saskatchewan (Rettie and Messier, 1998). Such barriers may decrease the amount of gene flow between two groups, affecting their genetic viability.

2.3.5 Altered movements

Movement rates of woodland caribou may be affected by logging disturbances, such as the case in west-central Alberta where a migratory herd of 350 experienced a significant decrease in daily movement rates with progression of timber harvesting (Smith et al., 2000). Reduction in movement rates may compromise the anti-predator strategy of spacing out (Seip, 1991), or lessen the chances of finding forage. Altered movements may also alter the extent of the animals' home ranges, as in west-central Alberta where Smith et al. (2000) found the herd's home range significantly decreased. Smaller home ranges also affect the woodland caribou spacing-out and spacing-away strategies (Seip, 1991), because the animals are aggregated and less energetically costly to find.

2.3.6 Summary of Impacts

Several impacts to woodland caribou may occur as a result of forest harvesting. The impacts may be direct, through mortality caused by an increase in predators or humans in their range. Post-logging succession may create conditions favorable to other ungulates, which may bring with them disease and/or predators. Roads may also result in easier travel routes for these alternate prey species and their predators, as well as increasing the numbers of caribou killed through hunting, poaching or vehicle collisions. The impacts may also be indirect, through a decrease in body condition caused by a reduction in forage availability or accessibility and/or an increase in energy expenditure. Forage resources may be lost directly through removal of trees and damage to the terrestrial lichen mats, or indirectly through the avoidance by caribou of optimal feeding areas. Forage may also be limited if overgrazing occurs on the undisturbed areas that the animals retreat to. However food may seldom be a limiting factor for caribou (Telfer, 1974) so this may not be as important an impact as the increase in predation. Harvesting may also create unfavorable snow conditions leading to a decrease in the accessibility of food resources and/or an increase in the energy expended in reaching these resources. Energy expenditure may also be a result of increased vigilance of the animals when near disturbances such as logging or roads. Ultimately, poor body condition may result, and subsequently pregnancy rates, birth rates, and calf survival may decline, possibly leading to widespread demographic consequences for herds. Because these animals are long-lived and highly mobile, these effects on survival and productivity are difficult to assess (Schaefer and Mahoney, 2006).

2.4 Forestry in Canada

2.4.1 Adaptive Management in the Forestry Industry

Forestry is a major industry in Canada, with about 1 million hectares harvested annually (FPAC, 2006). In order to ensure this large-scale removal of timber remains sustainable, forest companies have incorporated many concepts into their management policies (Nguyen-Xuan et al., 2000) such as biodiversity preservation, landscape management, and forest certification (Potvin et al., 1999). Despite the sometimes large-scale habitat loss and destruction in the short term, it is postulated that clear-cut logging may emulate fire in its ability to renew ecosystems (Racey et al., 1999). It is also this type of ecological cycling that many wildlife species depend on (Bolen and Robinson, 2003:337), and in the absence of natural fire or insect outbreaks, logging may fill this role. For example, in more northern regions, surface lichen mats in mature forests start to decrease after about 70-100 years (Foster, 1985), being replaced by feather-mosses, due to progressive canopy closure and subsequent shading of the forest floor (Kershaw, 1978). As ground lichens are an important source of food for animals such as woodland caribou, it is crucial for this type of forest succession to be limited, which can be done by removal of the over-story canopy (Coxson and Marsh, 2001) through either fire, or logging, if it does indeed mimic fire. Furthermore, harvesting of trees may also prevent more destructive fires from occurring, because if left to accumulate for many years, ground litter can act as fuel for larger flames (Bolen and Robinson, 2003:337).

However, despite claims that logging mimics fire, there may in fact be important differences between the two, with respect to the persisting vegetation. For example, Nguyen-Xuan et al. (2000) claim that lichens do not as successfully colonize the type of substrates left after logging than those left after fire, and that feather-mosses are actually more frequent after logging. In contrast, Webb's (1996) study in northwestern Ontario found no significant differences in the frequency of such colonization between the two disturbance types; although it did find that there were more undisturbed reindeer lichens remaining on the logged sites than on the burned sites, which had virtually none. These claims show how highly variable the fate of lichens is after disturbance. Furthermore, there may be many other factors following logging aside from forage availability, which affect animals such as woodland caribou. For instance, Rettie and Messier (1998) note that succession often results in early seral stage stands after logging. This is an undesirable outcome when the objective is to produce caribou-friendly habitat. Other important consequences include fragmentation of travel corridors, increased predation, and disturbance.

Therefore depending on the management objectives and which species is targeted for protection/mitigation, the type of silvicultural techniques (harvest and post-harvest) used will influence the potential of being able to address sustainable and adaptive forest management (Nguyen-Xuan et al., 2000), as well as whether or not harvesting is more or less destructive than a natural disturbance like fire. A discussion on the range of silvicultural practices and what is recommended when managing for woodland caribou on forested landscapes will follow.

2.4.2 Recommended Silvicultural Practices

The methods used in harvesting and post-harvest treatment can influence the character of the remaining landscape and future forest, thus making certain practices more suitable for various objectives. As forest managers have become more aware of the impacts forest activities have on different wildlife species, they have tried to prescribe silvicultural treatments as per their objectives, although outcomes are still often uncertain.

Forests can be managed as even-aged or uneven-aged, and the former involves harvest methods such as clear-cutting, shelterwood, or seed-tree, while the latter involves single-tree selection or group selection (Castillon, 1996:190; Bolen and Robinson, 2003:331). Those techniques used in even-aged management produce a forest with trees all about the same age (Castillon, 1996:190), whereas those used in uneven-aged management produce a forest consisting of different ages and sizes of trees (Castillon, 1996:192). The primary method of timber harvesting in Canada is clear-cutting (Potvin et al., 1999), with an annual average of 10,000 km^2 being harvested by this method (ACCP, 1992; qtd. in Potvin et al., 1999). Clear-cutting involves removing all trees from an expanse of land (Bolen and Robinson, 2003). This method often leads to complete habitat loss for some species, however it may make the habitat more attractive to other species that prefer open spaces and edge habitats (Bolen and Robinson, 2003:333).

In shelterwood cutting, 40-60% of the trees are removed, with the remaining trees removed only after the new trees have been established under them (Castillon, 1996:190; Bolen and Robinson, 2003:331). Less nutrients are removed with this method than with clear-cutting, and some habitat is retained for wildlife (Castillon, 1996:190).

Seed-tree cutting is similar to clear-cutting, except a few seed-bearing trees are retained to aid in regeneration of the new forest (Castillon, 1996:190; Bolen and Robinson, 2003:331); however it is postulated that this method is not always successful due to the seed trees ending up as windthrow (Castillon, 1996). In group selection, small groups of trees are cut, and in individual selection only individual trees are cut. Both of these types aid in forest regeneration through increased light penetration to the forest floor (Castillon, 1996:192).

These aforementioned partial cutting systems may be favored over clear-cutting when managing for some wildlife (e.g. small mammals), but since 85-90% of harvesting in Canada is clear-cutting (ACCP, 1992; qtd. in Potvin et al., 1999), the focus needs to be on sustainably managing for this silvicultural method. Different species are adapted better to different post-harvest habitats, and so depending on the management objectives, differing silvicultural treatments associated with clear-cutting are recommended. The following silvicultural methods and prescriptions are discussed as they pertain to, and are recommended for woodland caribou in the boreal forest.

Clear-cuts vary in size from relatively small to quite extensive. Size and placement of clear-cuts is very crucial when managing for woodland caribou ranges. Basically the goals are to 1) reduce the length of time a disturbance is in any one particular area (Hristienko, 1985; Anonymous, 2006; M. Manseau, pers. comm., 2006), 2) to ensure that the animals will be able to make use of the adjacent areas during harvesting (Cross and Smith, 1995), and 3) that they will be able to return to the area once harvesting is finished (M. Manseau, pers. comm., 2006). This can be accomplished by concentrating the disturbance temporally by minimizing multiple entries into an area through the harvesting of larger cut-blocks (Tolko Industries Ltd., 1999; M. Manseau, pers. comm., 2006). Larger cut-blocks also create less edge habitat than many small cut-blocks (Smith et al., 2000; Anonymous, 2006), which is important in terms of reducing favorable habitat for other ungulates, and subsequently wolves (Tolko Industries Ltd., 1999; Smith et al., 2000). Moreover, large cut-blocks more closely resemble natural disturbances like fire (Smith et al., 2000), and when the forest grows back it will be more suitable caribou habitat (Smith et al., 2000; Anonymous, 2006).

Some state that it is also important for these large cut-blocks to be localized spatially, instead of several smaller cut-blocks being spread out all over the landscape (Smith et al., 2000; Schaefer, 2006; M. Manseau, pers. comm., 2006). This may also require that the rotation age of forests be lengthened (Anonymous, 2006), possibly logging large blocks in 3 or 4 passes, with a rotation cycle of up to 100 years between each pass as recommended by Thomas and Armbruster (1996) for harvesting in woodland caribou range in Saskatchewan. Edmonds and Bloomfield (1984) also recommend in their timber harvest guidelines for Alberta, that a 3 pass system with cuts 50 years apart be used, so that 1/3 of the forest is at least 100 years old at any one time. This is important in terms of the remaining habitat being able to meet caribou need for forage, security cover, and also separate them from other ungulates (and thus wolves) which prefer young forests instead. Longer rotations between harvesting also allow cut-blocks to reach optimal conditions for caribou to use before being logged again. If left uncut, some forests will eventually become less suitable for caribou, at which point they may move to different portions of their range (Cumming and Beange, 1993). At this point it would be beneficial for harvesting to take place in order to rejuvenate the stagnant forest and encourage the re-establishment of lichens, and no caribou habitat will have been compromised prior to this. This is the value in harvesting over-mature forests, as opposed to mature or under-mature forests which are also most valuable (or will become valuable) to woodland caribou.

It is also recommended in the literature that harvesting should avoid presently defined core areas (e.g. rutting, calving, and wintering areas) (Edmonds and Bloomfield, 1984; Darby and Duquette, 1986; Cumming, 1992; Cumming and Beange, 1993) as well as travel corridors (Brown et al., 2000). Avoiding these areas will keep them suitable for woodland caribou (free of disturbance and no damage to lichen sources), and unsuitable for other ungulates and hence wolves (Cumming, 1992). The latter is important because woodland caribou are very vulnerable to predation at these times of aggregation, in particular during the rut (Cumming, 1992). More importantly, predator-free habitat must be available over winter and during calving, so that enough calves can be produced to balance out mortality (Cumming, 1992). If insufficient habitat is available for caribou to avoid predation during these critical times, this might compromise the future of the entire population (Cumming, 1992; Brown et al., 2000). It has also been recommended that harvest activities avoid important food sources such as lichen-rock ridges (Hristienko, 1985; Tolko Industries Ltd., 1999) or sandy areas where open pine stands develop (Thomas and Armbruster, 1996).

In addition to avoiding harvesting on important caribou use areas and travel corridors, it is suggested by some that these areas also be buffered (Hristienko, 1985; Cumming and Beange, 1993; Cross and Smith, 1995; Brown et al., 2000). These buffers must be mature upland habitat that can support terrestrial lichen as well as provide security cover for caribou (Cross and Smith, 1995). For example, Thomas and Armbruster (1996) recommends that buffers of at least 1-2 km be left around fens and stream channels that are known to be used by caribou, and that at least half of the forest in these buffers be older than 50 years. These recommendations help to reduce fragmentation of the remaining intact forest, in order to ensure animals can travel along undisturbed tracts of land between their important use areas (Tolko Industries Ltd., 1999).

Harvesting can technically occur year-round in most places, and the timing is crucial for woodland caribou. Obviously, avoiding harvesting during a time when the animals are expected to be in the area is recommended if possible. For example, Edmonds and Bloomfield (1984) recommend ceasing logging in calving and breeding areas during these seasons. Some recommend that logging should take place in summer (e.g. Edmonds and Bloomfield, 1984), however it is suggested that harvesting winter areas in summer may be too disturbing to the ground vegetation. So for example, Thomas and Armbruster (1996) recommend harvesting over compacted snow instead. In fact, Coxson and Marsh (2001) found that there was less damage to terrestrial lichen cover in stands harvested in winter. Hence in some cases it is recommended to avoid harvesting winter areas altogether (unless sufficient adjacent habitat is left in this wintering area as recommended by Edmonds and Bloomfield (1984)), and harvest on summer areas in winter instead (e.g. Tolko Industries Ltd., 1999).

There are also many ways of going about road-building in managed forests so as to lessen their impacts. To begin with, Metsaranta (2002) recommends that the number of roads be minimized, and Hristienko (1985) recommends being careful of road placement.

This is important in terms of avoiding the deleterious impacts that often accompany linear features. Others recommend the use of winter roads because the snow buffers damage to the ground, and their duration of use is also less (Anonymous, 2006). Using seasonal roads limits the amount of time that these roads serve as a conduit for predators and hunters into caribou areas (Brown et al., 2000). Since caribou tend to avoid linear features because of the increased predation, others suggest reducing or avoiding construction of roads in key sensitive areas such as travel corridors and high use areas (Brown et al., 2000; Kinley et al., 2003; Anonymous, 2006) or it could be detrimental to the population. Access management is also an important issue with logging roads. It is usually recommended that roads be de-activated once finished with them (Hristienko, 1985; Brown et al., 2000; D. Cross, pers. comm., 2006), or to have gates installed, in order to limit the amount of human or predator access via these roads (Hristienko, 1985; Brown et al., 2000; Terry et al., 2000; Metsaranta, 2002). As recommended by Racey et al. (1999), roads can be closed through "ditching, culvert removal or site preparation and regeneration".

Silvicultural prescriptions may involve whole-tree harvesting (WTH), which leaves no biomass behind, or stem-only harvesting (SOH) in which the tree trunks are removed, but the rest of the tree branches and leaves are left on-site as a nutrient source (Wei et al., 2000). Stem-only harvesting is a method which increases the amount of CWD and ground litter, which is reported to increase the productivity of a site (Tinker and Knight, 2000). Furthermore, there may be important sources of arboreal lichen left on-site after SOH, so some may recommend this method over WTH where this might be an important early winter forage source for some herds. For example, for caribou populations in high-snowpack ecosystems like the ones in the Selkirk Mountains of B.C., the arboreal lichens on windthrown trees is an important early winter food source (Rominger and Oldemeyer, 1989), so SOH slash may be as well. However, this method may create problems with respect to woodland caribou movements, as the amount of slash left over may make it harder to navigate over the landscape (Bolen and Robinson, 1999:332). The effects of this may be more pronounced depending on the amount of slash left behind. Furthermore, terrestrial lichen reserves may become unavailable under large amounts of slash. Thus SOH may not be recommended for those areas where terrestrial lichens are the main food source.

The treatments of the logged areas *post*-harvest will also have great impacts on terrestrial lichen supply, the resulting future forest, and the wildlife species attracted to the new habitat. Brown et al. (2000) and Metsaranta (2002) recommend that post-harvest treatments create forest succession patterns that do not favor moose or deer, but instead result in the rapid regeneration of high-quality caribou habitat (coniferous species such as jack pine or black and white spruce). As a species adapted to mature forest conditions, woodland caribou may prefer uneven-aged forests with great variation in canopy heights (Bolen and Robinson, 2003:331). Therefore, re-planting may be staggered in order to result in an uneven-aged forest. Before re-planting, machines may be used to bust up the forest floor (Ehnes and Sidders, 2001). This is a method known as scarification. Some authors suggest scarification is a method to expose fertile mineral soil and improve conditions of the seedbed (Prevost, 1997), although this method has also been reported to reduce available soil nutrients (Prevost, 1996; qtd. in Nguyen-Xuan et al., 2000), as well as damage remaining lichen mats. Prescribed burning is also used to improve forest regeneration and control competing species (Ehnes and Sidders, 2001) – the latter can also be achieved by herbicides. However, Hristienko (1985) recommends limiting the use of herbicides, as they may be toxic to lichens. Furthermore some recommend thinning the regenerating forest, which may increase the habitat value for caribou by opening the canopy and promoting lichen growth (Thomas and Armbruster, 1996; Wei et al., 2000), and reducing competition.

In order to reduce not only the impact of forestry activities, but the cumulative impacts of all industrial activity on caribou range, Smith (2004) recommends restricting both the oil and gas and the timber industry to the same area at the same time. Furthermore, he recommends that range-specific thresholds for amount of timber harvest, and number and location of roads, could be established as part of recovery plans. This would give managers an idea as to how much activity could occur before impacting the local woodland caribou population.

It is important to realize that recommendations should be tailored to the specific population of woodland caribou being managed for, as their habitat requirements may differ geographically, and over time. Furthermore, many of these silvicultural treatments have not been tested thoroughly and thus have uncertain impacts on woodland caribou and forestry, so caution must be taken when prescribing them (Racey et al., 1999). Moreover, the forest company will need to meet their timber needs, so in some situations and for economical reasons these recommendations may need to be adjusted.

2.5 Current Management Efforts

CPAWS and Sierra Club of Canada (2006) developed a comprehensive report on government action with respect to woodland caribou conservation in Canada's boreal forests. The report summarizes federal commitments, as well as the current state of government action across all provinces and territories which are home to woodland caribou. In the report, government efforts are summarized by province, with respect to four main areas: 1) protected areas, 2) land-use planning, 3) recovery planning, and 4) resource management policy. Regarding the first area, the report presents a table which shows what percentage of caribou range in each province that is currently in a protected area, and concluded that the current coverage is not sufficient to reverse the caribou's decline. Pertaining to land-use planning, the report states that current processes are inadequate to ensure caribou conservation because they do not include wildlife habitat as a primary objective, appropriate scales are not considered, and they do not consider cumulative effects of different resource activities.

With respect to recovery plans, the report indicates that Saskatchewan, Ontario and the Northwest Territories have not currently released them. Of the remaining provinces and territory that have released recovery plans, only Quebec and Yukon have outlined concrete mitigative strategies with respect to industrial activities such as logging. Furthermore, the report indicates various socio-economic considerations serve as barriers to recovery in each province/territory with recovery plans. It also demonstrates that none of these jurisdictions have explicitly identified critical habitat, nor do they have interim plans to protect habitat until critical habitat is identified. It did state however that

Newfoundland and Labrador's recovery team developed a functional definition for critical habitat, as did Quebec for the Gaspé population.

With respect to resource management policy, this report found that British Columbia, Alberta, Saskatchewan, Manitoba, Quebec and Yukon do not have any mandatory requirements to maintain large mature forests for woodland caribou. However, by 2008, in high caribou density regions of Quebec, special plans will have such requirements. Ontario's Caribou Guide has an objective to maintain large (>10,000 ha), mature, year-round conifer forests, and Newfoundland commits to retaining 15-20% of the forest as old-growth when calculating the wood supply. None of the provinces/territories have mandatory requirements for maintaining roadless areas, however Ontario's Caribou Guide recommends regional-level road-planning to avoid traditional winter habitat tracts and calving areas. Alberta has optional guidelines for road-planning, and for Yukon a forest harvesting best management practices contract is currently underway. Saskatchewan and Manitoba are the only provinces that require an access management plan and road closure program.

It is obvious from this comprehensive review that the ways in which the various provincial and territorial governments deal with caribou management varies considerably. Even though there currently is a lack of mandatory requirements for habitat protection and mitigative measures with respect to industrial activities, every province/territory with woodland caribou listed as threatened or endangered under SARA will eventually have to develop recovery strategies and identify critical habitat (CPAWS and Sierra Club of Canada, 2006). Of all provinces/territories, Ontario's "Forest Management Guidelines for the Conservation of Woodland Caribou: A Landscape Approach" (Racey et al., 1999) appears to be the best defined approach for minimizing the impacts of forest harvesting in caribou range. Accordingly, this plan is discussed in more detail below.

Ontario's "Forest Management Guidelines for the Conservation of Woodland Caribou: A Landscape Approach"

This plan was developed in order to guide resource planners and managers in conserving woodland caribou populations in northwestern Ontario (Racey et al., 1999). The guidelines evolved from existing caribou habitat management guidelines in Ontario, in addition to suggestions and recommendations from many sources, including special interest groups, and various public consultation and information sessions.

The plan outlines caribou biology, habitat and status, and the implications that forest management activities have on this species. It implies that resource managers should integrate this information with knowledge more specific to the caribou in their region, when following the regional, FMU, and stand level recommendations outlined in the plan. It is emphasized that any prescriptions developed as a result of these guidelines be tailored to the regional or local needs of caribou populations.

A valuable aspect of this plan is the direction for regional and sub-regional land-use planning which includes sections on what is required to support regional land-use planning, where to apply caribou habitat management, details on caribou habitat management as it pertains to winter, calving, snow-free season habitat, and long-term planning of primary access roads. More features of this plan are the appended sections on aspatial and spatial habitat supply analysis, with indications on what is required to do them, how to do them, and how to interpret the results. Also included are detailed instructions for using the guidelines and incorporating other guidelines such as the "Forest Management Guidelines for the Emulation of Fire Patterns".

The guidelines in this plan are broken down into three main levels of planning: regional and sub-regional, FMU, and stand level, with recommendations structured according to several spatial and temporal scales within these levels.

Regional Level Recommendations

These guidelines involve recommendations on 1) regional forest structure and composition, 2) protecting winter habitat, 3) protecting strategic calving areas, and 4) planning of primary access roads.

Forest Management Unit Level Recommendations

These recommendations are directed at specific FMUs, where broader landscape objectives have already been addressed at the regional level and in accordance with the "Forest Management Guidelines for the Emulation of Fire Patterns". They include recommendations for harvesting so as to conserve the value of: 1) calving habitat, 2) winter habitat, 3) snow-free season habitat, and 4) ensuring connectivity between these habitats.

Site-specific Recommendations

These recommendations involve three areas: 1) silvicultural objectives for regenerating and restoring the composition and structure of the pre-harvest forest, 2) mineral licks, and 3) road construction.

In sum, these forest management guidelines offer a wide-ranging set of recommendations for harvesting on woodland caribou range in Ontario, with directions on how to achieve the goals of each, so managers will be better equipped to assist with the conservation of this species.

2.6 Summary of Literature Review

Woodland caribou are adapted to living in mature forests, which supply them with lichens for food, and where they can exist at low densities separated from other ungulates and hence their primary predator, wolves. However, mature forests are also where forest companies often harvest vast amounts of timber. This creates conflict as the impacts of forest harvesting on woodland caribou are many, ranging from habitat loss and increased predation, to declines in populations. Since forestry will remain a major industry in Canada into the future, managing for logging in woodland caribou habitat must be adaptive. In order to be adaptive, this will require that the effects of recommended forest management prescriptions be monitored, and improvements/changes made as new information is discovered.

Current recommendations for harvesting in woodland caribou habitat cover all aspects of the process, from the initial road-building stage, up until the next planned harvest rotation. The ultimate goals of these prescriptions are 1) to ensure sufficient habitat remains on the disturbed landscape to meet the caribou's needs in terms of forage, cover, reproduction, and predator avoidance, 2) to ensure that sufficient habitat will be available in the future to meet these needs, 3) to minimize the mortality associated with such disturbances so that the future reproductive potential of a population is not compromised, and 4) to ensure that herds are not isolated from parts of their range and from other herds. Recommendations to meet these goals include: 1) larger cut-blocks concentrated in space and time, 2) increased harvest rotation lengths, 2) avoiding harvesting or building roads in key/sensitive areas like travel routes, rutting, calving, wintering or otherwise optimal habitats, 4) buffering these key areas, 5) harvesting during winter on summer ranges, 6) obliterating roads when finished harvesting or controlling access through gates or other means, and 7) promoting the quick regeneration of conifer forests to the structure and composition it was before harvesting.

Some governments and forest companies have begun to take steps to incorporate these recommendations into their caribou management plans. However, several provinces have not yet outlined concrete mitigative strategies with respect to harvesting on woodland caribou range, and where they do, these are often not mandatory. With respect to recovery plans for woodland caribou listed under SARA, every province will eventually have to develop these, which will be wrapped up under the National recovery strategy. Under SARA, any part of woodland caribou range which is identified as critical habitat, will be protected by law, so this will influence where and how forest harvest operations will be conducted.

In conclusion, it is important to note that management plans that work for one woodland caribou range, may not apply to other herds elsewhere. Although there are general recommendations for forest management on caribou range, it is recommended that managers take into account the local herd's requirements when developing specific forest management guidelines.

Plate 1. Woodland caribou crater revealing terrestrial lichen (used with written permission by Micheline Manseau, December, 2006)

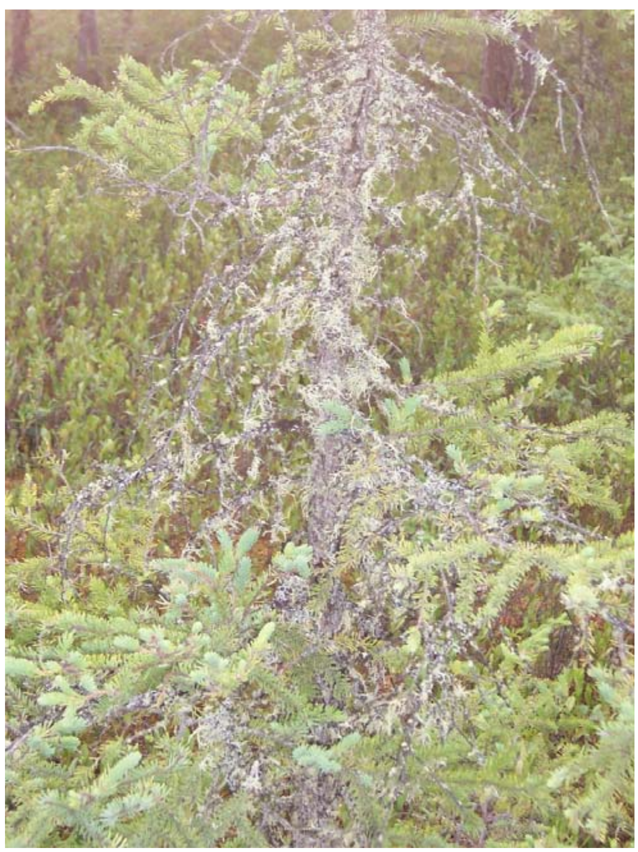


Plate 2. Arboreal lichen in study area

Plate 3. Reindeer lichens: *Cladina mitis, C. stellaris, C. rangiferina* found in study area

Plate 4. Measuring *Cladina spp*. with a 16-point plot frame


Plate 5. Logging trail in Naosap Operating Area


Plate 6. Logging trail with deciduous shrubs alongside

Plate 7. Researcher hiking over rocky terrain in study area

Plate 8. Irregular relief is typical of the boreal shield and study area

Plate 9. Retained trees fallen over

Plate 10. Young Sandhill Crane (*Grus canadensis*) posing in front of logging slash pile

Plate 11. Cut-block near Vamp Lake

Plate 12. Hydro transmission line traversing the study area

Plate 13. Regenerating coniferous forest

Plate 14. Regenerating forest with deciduous shrub competition

Plate 15. Woodland caribou in study area (used with written permission by Joel Kayer, November, 2006)

Chapter 3: Multi-scale Analysis of Habitat Selection by Woodland Caribou on Disturbed Landscapes in West-Central Manitoba

3.1 Introduction

3.1.1 Forest Management/Woodland Caribou Mitigation Plan

Of the 10 woodland caribou ranges that are identified by the province, several overlap with Tolko's Forest Management License (FML) area. The Kississing-Naosap range is one of three of these ranges which has been identified by Manitoba Conservation as being priority ranges for conservation, on the basis of potential future impacts on the caribou population due to industrial developments in the area (Tolko Industries Ltd., 1999; Manitoba Conservation, 2005). Past (1970's) and recent (1999-2006) forest operations in these operating areas prompted Tolko to develop a forest harvest plan which accommodates both the needs of the company and the requirements of the woodland caribou in this range. In 1999, Manitoba Conservation (Northwest Region) and Tolko Industries Ltd. cooperated together to produce the "Forest Management/Woodland Caribou Mitigation Plan" for the Naosap and Peterson Operating Areas within FMU 62 of the Highrock Forest Section.

This plan was the result of considerable discussions between the two organizations, supplemented with Tolko's forestry field data and existing information on known habitat requirements of woodland caribou (Tolko Industries Ltd., 1999). It is important to repeat that the existing information on the herd was limited – including mostly anecdotal information on the herd's habitat use and population demographics acquired through winter surveys and through observation by forestry field staff. In all aspects of the plan it is emphasized that any new information revealed from ground investigations, telemetry studies, or any other relevant caribou or forestry information will be fed back into the plan and modifications made accordingly (Tolko Industries Ltd., 1999).

Basically, the plan's objectives centered around promoting coniferous habitat regeneration suitable for woodland caribou and unsuitable for moose, and providing for ample undisturbed habitat adjacent to the harvest areas, and connected travel corridors throughout the harvest areas. Furthermore, special prescriptions were indicated for harvest activities in key areas like calving and wintering areas, as well as for protecting lichen reserves. These objectives can be viewed in detail in Appendix A of this document.

Other principal considerations when developing the plan included identifying summer caribou use areas to be harvested in winter, and delaying harvest of certain cut-blocks until further information on their importance to caribou was attained. The criteria for designating leave areas was based upon the unsuitability of certain blocks for harvest either permanently (for those areas within harvest blocks) or temporarily (with the potential for future harvesting). Efforts were made to include important caribou areas in these leave areas, but basically the leave patches include patches of sub-optimal timber or inoperable areas. Additionally, the linkages among these leave areas as well as between the leave areas and adjacent undisturbed habitat were also established based on their unsuitability for harvest at the current time. Proposals for access management in the area involve removal of an access bridge and continuation of gated road entrance after post-harvest renewal is complete. However, nothing is specified in the plan with respect to road obliteration post-harvest (D. Cross, pers. comm., 2006).

In this plan, Tolko has identified a gap in the knowledge of woodland caribou seasonal habitat selection in the Kississing-Naosap range (Tolko Industries Ltd., 1999). To reiterate, the purpose of this research is to assist in filling this gap, by determining the factors that influence seasonal distributions and movements in and around harvested landscapes as well as within the animals' home range. The resulting information will contribute to a more comprehensive understanding of habitat requirements and preferences, which will be used to improve upon the existing plan which was in place when the Naosap area was recently harvested, and assist in the development of future plans for the Peterson area pre-harvest. Harvesting has ceased in the Naosap area, and Tolko is now planning on harvesting significant amounts of timber from the Peterson area within the next 5 years (D. Cross, pers. comm., 2006). Information on the animal's requirements will assist in the delineation of leave areas, caribou travel corridors, and road placement in this area, as well as the development of post-harvest silvicultural prescriptions. Furthermore, this research will serve as a basis for monitoring the success of some mitigation measures already undertaken in the Naosap area, in particular those involving leave areas. For example, information gained on the animal's use patterns relative to existing leave areas will assist in the delineation of leave areas for the Peterson area with respect to composition, placement, and size of these areas. It will also assist in determining the size of future cut-blocks.

3.1.2 Habitat Selection

Resource selection is the process by which an animal chooses habitats and resources disproportionately to their availability (Manly et al., 1993), and may imply the fitness of a habitat and the quality and abundance of resources in those areas (Boyce and McDonald, 1999). Multi-scaled approaches are important because animals exhibit different selection patterns across different spatial scales (Rettie and Messier, 2000; Johnson et al., 2001). If only observed on one scale, actual resource selection patterns may be obscured (Schaefer and Messier, 1995; Johnson et al., 2000).

Johnson (1980) identifies a natural ordering of selection processes at different scales. He defines first-order selection as the selection of a species' geographical range. Second-order selection is the selection of home ranges of individuals or groups, within that geographical extent. Third-order selection is how those individuals or groups use the various habitat types within the home range. Finally, fourth-order selection is the actual acquisition of food items from feeding sites within the selected habitat types. This has important implications for assumptions on use-vs.-availability (habitat selection) studies because what is considered available will depend on which order of selection is being considered (Morris, 1987).

Furthermore, it is important that the scales chosen for analysis be specific to the species under question, because each species has different life-history traits and behavioral activities (Levin, 1992; Fuhlendorf et al., 2002), and each organism perceives its environment differently. In general, population limiting factors will drive selection at coarser scales, and will only influence selection at each finer scale until another factor becomes more important (Rettie and Messier, 2000). For example, predation is considered to be the proximate limiting factor for woodland caribou at coarser scales (Rettie and Messier, 2000). In other words, it may be wrong to assume that the animals have selected their feeding sites because of the food resources that are there, because they may in fact have chosen that site at a coarser scale to avoid predation. It is for these reasons that the findings must be interpreted carefully in analysing habitat selection.

It is also important for researchers to study the order of selection that is most important to the management objectives at hand. For example, where the goal is to determine the effects of industrial activity on an ungulate population in order to mitigate these impacts, selection would be studied at the extent of the disturbance, as opposed to the population's entire home range. Taking all of these factors into account, three scales of study were chosen for this research on the Kississing-Naosap range, reflecting the species' limiting factors as well as management objectives. The first is the home range scale, which is a scale similar to Johnson's (1980) category of third-order selection. By analysing habitat selection at this scale, we understand what habitats are most valuable to caribou within their home range. This information provides a baseline of knowledge of this herd's requirements, which is helpful when managing for disturbance on the landscape in terms of ensuring adequate habitat is available for the animals.

The second scale chosen for study – the harvest area scale – is not based on Johnson's ordering of selection, but rather was chosen based on the particular management objectives for this herd. Information on how the caribou distribute themselves within the Naosap Operating Area will give us an idea as to what extent the caribou corridors and leave areas are being used, as well as how the animals locate themselves in relation to cut-blocks and logging roads in the area. This information can be used to modify strategic level objectives in the mitigation plans for future harvesting, with respect to caribou corridor composition, size of leave areas, location of roads, and size of cut-blocks, etc.

The third scale chosen for study is the movement path scale within the harvest area. The information obtained at this level will give us an idea of what the animal is selecting in terms of forage, predator avoidance, navigability, and habitat at the finer scale. These are factors that cannot be understood from analysing remotely sensed data (such as telemetry data), and is also very important at a management scale, because it further defines habitat requirements of the animals in addition to landscape scale factors. For example, if caribou were found to avoid paths with rough topography, then management objectives could be refined to specify that leave areas must be of moderate-to-easy topography, in addition to being of a certain cover type. Moreover, if caribou avoid those areas with greater amounts of debris left behind after harvesting, harvest and post-harvest practices may need to be modified in order to reduce the amount of materials left that can create impediments to movement.

In addition to multi-scale analysis, patterns of habitat selection were also analysed temporally. The seasons chosen were the "snow-free" and "snow-covered" seasons, with the former defined as May 21 to September 21 and the latter defined as November 1 – March 31. It is important to look at seasonal habitat selection because different factors may influence the animals' habitat selection at different times of the year, or may be more or less determinant depending on the season.

In this study, resource selection functions (RSFs) (Boyce and McDonald, 1999) were used to model and predict woodland caribou habitat use at the home range, harvest area, and movement path scales during the snow-free and snow-covered seasons, and the statistical techniques used to estimate these RSFs is described further in section 3.3.

3.2 Study Area

3.2.1 Study Area

The Kississing-Naosap range is found within the boreal shield and boreal plains ecozones of west-central Manitoba, approximately 600 km to the northwest (54°40´N, 100°51´W) (O'Brien et al., 2006), and northeast of the towns of Flin Flon and The Pas (Figure 1 and 2). The typical boreal shield region is characterized by irregular relief and many bedrock outcrops (Metsaranta, 2002), while the boreal plains are comprised of "gently rolling hills interspersed with lakes, rivers and extensive peatlands" (O'Brien et al., 2006). The predominant tree species is black spruce (*Picea mariana*), which is often associated with jack pine (*Pinus banksiana*) in upland areas. Black spruce also grows on wetter lowlands, and is often associated with tamarack (*Larix laricina*) (Rowe, 1972; qtd. in Tolko Industries Ltd., 1999). Other tree species include white spruce (*Picea glauca*), trembling aspen (*Populus tremuloides*) and white birch (*Betula papyrifera*). Snow-free periods are mid-April to mid-November. Maximum snowfall occurs during January and February, reaching maximum mean depths of 40-45 cm (Metsaranta, 2002). Ungulate species include woodland caribou and moose. Because moose exist at expected densities in the study area (~0.15 km^{-2}) (Cross, 1991), it is probable that wolves are also at relatively low or expected densities. Other possible predators of woodland caribou residing in this area include black bears (*Ursus americanus*), cougars (*Felis concolor*), lynx (*Lynx lynx*), coyotes (*Canis latrans*) and wolverines (*Gulo gulo*).

Figure 1. Map of Manitoba showing highlighted study area (Base map taken from DMTI Spatial Inc.; Environmental Systems Research Institute Inc., 1999).

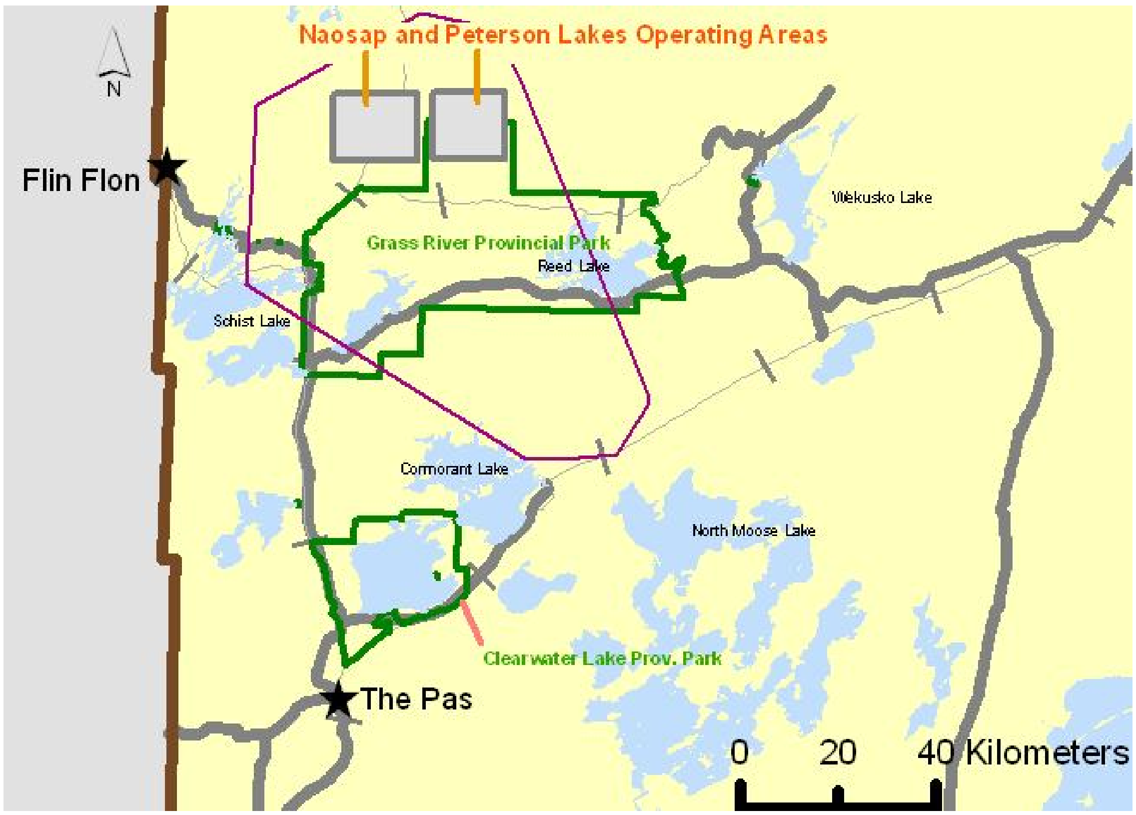


Figure 2. Finer scale map showing highlighted section from Figure 1. Shown are the Kississing-Naosap woodland caribou herd home range (purple polygon), Naosap-Peterson Lakes Operating Area, Provincial Parks, and main roads which traverse the study area (Base map taken from DMTI Spatial Inc.; Environmental Systems Research Institute Inc., 1999).

3.2.2 Human Activities

Traversing the study area is the Sherridon rail line, a hydro right-of-way, and Provincial Trunk Highway (PTH) #10, PTH #39, and the Sherridon road (Rebizant et al., 2000), in addition to several roads associated with logging activities. Fire suppression is currently practiced in this area, however the Webb Lake fire of 1989 burned a significant portion of the Kississing-Naosap caribou range (~125,000 ha) (Anonymous, 1996; qtd. in Metsaranta, 2002). This range also overlaps Tolko's Naosap and Peterson Operating Areas, which fall within Forest Management Unit (FMU) 62 in the Highrock Forest Section (Tolko Industries Ltd., 1999). Extensive timber harvesting has occurred in this FMU since the 1970's, with harvesting in the vicinity of Naosap Lake occurring primarily in the mid-1970's to mid-1980's, some in the 1990's (Tolko Industries Ltd., 1999), and from 1999-2006. Mining is also an important industry in the area (D. Cross, pers. comm., 2006). First Nations hunting also occurs in this area, as well as recreational activities such as ATVing, camping, fishing, and tourism within Grass River Provincial Park (D. Cross, pers. comm., 2006). Figure 2 shows the distribution of parks, main roads, railway, and recent logging on the Kississing-Naosap range.

3.2.3 Study Population

This research focused on a population of approximately 100-200 animals (Rebizant et al., 2000) living on the Kississing-Naosap range. It is uncertain as to whether this is an accurate population estimate, as there is limited census data, and there is great variation in what population data does exist. For example, Johnson (1993) estimated between 100-200 caribou in 1992, and Cross and Smith (1995) estimated 90-164 animals based on aerial surveys in the winters of 1993-94. In general however, this population is suspected to have remained stable over the last fifteen years (Metsaranta, 2002). Metsaranta (2002) stated that predation by wolves was the cause of most adult mortality. However hunting and vehicle collisions on PTH#39 also account for some mortality. One estimate suggests that 10-20 animals are harvested annually by First Nations (Rebizant et al., 2000). However, D. Cross (pers. comm., 2006) stated that only about 6 animals are reported, through word of mouth, to be harvested each year.

Metsaranta (2002) also concluded that the caribou on the Kississing-Naosap range had behavior and traits typical of other boreal populations of woodland caribou. For example, winter home ranges were larger than summer (856 km^2 and 162 km^2, respectively). Furthermore, movement rates for the Kississing-Naosap herd were calculated based on GPS telemetry data, and indicated the animals traveled an average of 169.02 m/h (C. Dyke, 2006, unpubl.), which is similar to other herds such as the Owl Lake herd in southeastern Manitoba (M. Manseau, pers. comm., 2006).

Winter distribution surveys (Cross and Smith, 1995) and VHF telemetry work (Metsaranta, 2002) concluded that caribou use a mosaic of habitat in this region. These included mature upland conifer forests, treed muskeg, and lakes, in both winter and summer. These habitat selection results are very limited, as they are based on observational data and VHF telemetry, and extremely small sample sizes. The 1989 Webb Lake burn within the east portion of Peterson Operating area is also avoided by the Kississing-Naosap caribou according to 1995-97 winter distribution surveys (Tolko Industries Ltd., 1999). This data is also limited, as it is based only on observations. This review on woodland caribou habitat selection, movements, and group size in the

Kississing-Naosap range demonstrates the lack of current good quality information for the herd in this area.

In summary, despite having a stable population in the short term, the Kississing-Naosap herd of woodland caribou are at risk due to a number of factors related to logging in this area. Work in the area suggests the area provides valuable summer and winter habitat to woodland caribou (Tolko Industries Ltd., 1999), however disturbances such as logging will create conditions where some habitat will be lost or fragmented. Furthermore, an increase in mortality may potentially occur due to the increased access of predators and hunters, which can be facilitated by logging or access roads (Edmonds and Bloomfield, 1984; James and Stuart-Smith, 2000). Tolko is aware of the value of this area to the woodland caribou, and the potential impacts their forest operations could have on them. As such, they have developed a forest harvest plan that seeks to mitigate these impacts (Tolko Industries Ltd., 1999), as discussed in a previous section.

3.3 Methods of Data Collection and Analysis

3.3.1 Introduction to Methods

Lotek GPS collars were deployed in January, 2002 on 11 animals, and were removed in 2005. Locations were recorded every 3 hours for a resulting 1782-6890 telemetry locations per animal, and a total dataset of 52,937 positions as of December 31, 2004.

As a precursor to resource selection analysis in which woodland caribou habitat selection is evaluated, the landscape must first be classified into discrete habitat categories. These categories may then be further analysed in order to describe the landscape on which the caribou live, and to facilitate resource selection analysis. Vegetation data was obtained from the Provincial Forest Resource Inventory (FRI). The vegetation data was then reclassified to more accurately represent the habitat types available to woodland caribou as opposed to simply catering to forestry requirements (L. Toretti, 2003, unpubl.). These types include: young coniferous, jack pine dominated, spruce/spruce dominated, treed muskeg, softwood/hardwood-mixedwood, muskeg and other wetlands, cultural, water and islands. Furthermore, data on forest fires in Manitoba from 1980-1997 was obtained from the Provincial fire inventory, and leave area and cut-block data for 1968-2004 was obtained from Tolko.

3.3.2 Modelling Approach

Resource selection functions (RSFs) represent the probability that each habitat feature will be selected by the animals if all habitat features are equally available to them (Manly et al., 1993). The set of random points represent those areas "available" to caribou, while actual caribou locations represent "used" areas. Numerous statistical techniques are available for estimating RSFs (Manly et al., 2002). At the movement path scale, I used paired logistic regression to determine the effects that the sampled variables have on woodland caribou habitat selection. Logistic regression is required because of the binary nature of the response variable (presence/absence) (Quinn and Keough, 2002), and paired logistic regression is an alternative approach to traditional use-vs.-availability analyses. It is based on sampling random locations paired with each animal location (Compton et al., 2002). This is the chosen analysis because it more closely represents the choices that animals are actually making along a movement path, as the animal and random points are measured at the same time, under the same conditions, as opposed to comparing use with availability at inappropriate spatial and temporal scales (Compton et al., 2002). This is important, because it is unrealistic to assume that all habitat everywhere in the home range is equally available, when it is the movement path we are looking at. Generalized estimating equations (GEEs) were used for the harvest area and home range scales to accommodate correlated telemetry data (SAS Institute Inc., 2005). Proc Phreg and Proc GENMODE in SAS 9.1® statistical software (SAS Institute Inc., 2003) and the associated QIC macro (N. Koper and M. Manseau, pers. comm., 2006) was utilized for these analyses (more details on the analysis will be presented in section 3.3.4).

3.3.3 Data Sources and Variables

The following data sources were used to meet the objectives:

1. *Habitat composition.* The re-classified Provincial FRI GIS layer was converted from raster to ascii format and then imported into FRAGSTATS® statistical software (McGarigal and Marks, 1995) where class metrics were analysed, and results used to describe the landscape composition for the home range and harvest areas. Class metrics used to describe habitat composition included total area and percent of landscape occupied by indicated habitat type, as well as number and mean area of patches of indicated habitat type on landscape.
2. *Home range scale – snow-free and snow-covered seasons.* To determine distances of caribou to various cover and disturbance types, the nearest-feature script in Arcview 3.2 GIS® and Mapping Software (Environmental Systems Research

Institute, Inc. (ESRI), 1999) was used. This calculates the distance of the nearest indicated cover/disturbance type (based on the provincial FRI layer, and cut-block, fire, and linear feature layers) to each telemetry point. To determine what habitat type caribou select, habitat variables were obtained by calculating the proportion of each cover/disturbance type within a 100-m buffer around each telemetry point. These made up the set of independent variables, and were calculated for the full set of GPS telemetry points divided by season (Figures 3 and 4). Random points were derived using the random-point generator in Arcview 3.2, and were limited to those areas within the 100% MCP herd range of study animals. Total number of telemetry points used in the analysis was 18,917 and 21,257 respectively for the snow-free and snow-covered seasons. See Table 1 for list of independent variables sampled for this scale. Because telemetry points were collected since 2002, some may appear on the recent habitat map as falling on a cut-block, when in fact the animal may have been in that location *before* it was harvested. To account for this potential source of error, the habitat map was split into three years, with each of the three maps containing only cut-blocks prior to and including that year. Telemetry points occurring only *after* each year of harvest were used for that layer in the analysis.

3. *Harvest area scale – snow-free and snow-covered seasons.* Distance-based and habitat variables (Table 1) were obtained using the method used for the home range scale. The harvest area was delineated using Arcview 3.2 clip function, and was based on the extent of the Naosap Operating Area (Figures 5 and 6). Only those telemetry points falling within the extent of this clipped area were used for

the analysis, and the random points were generated based on this extent as well. Variables for this scale were obtained for 3371 and 2640 telemetry points respectively for the snow-free and snow-covered seasons.

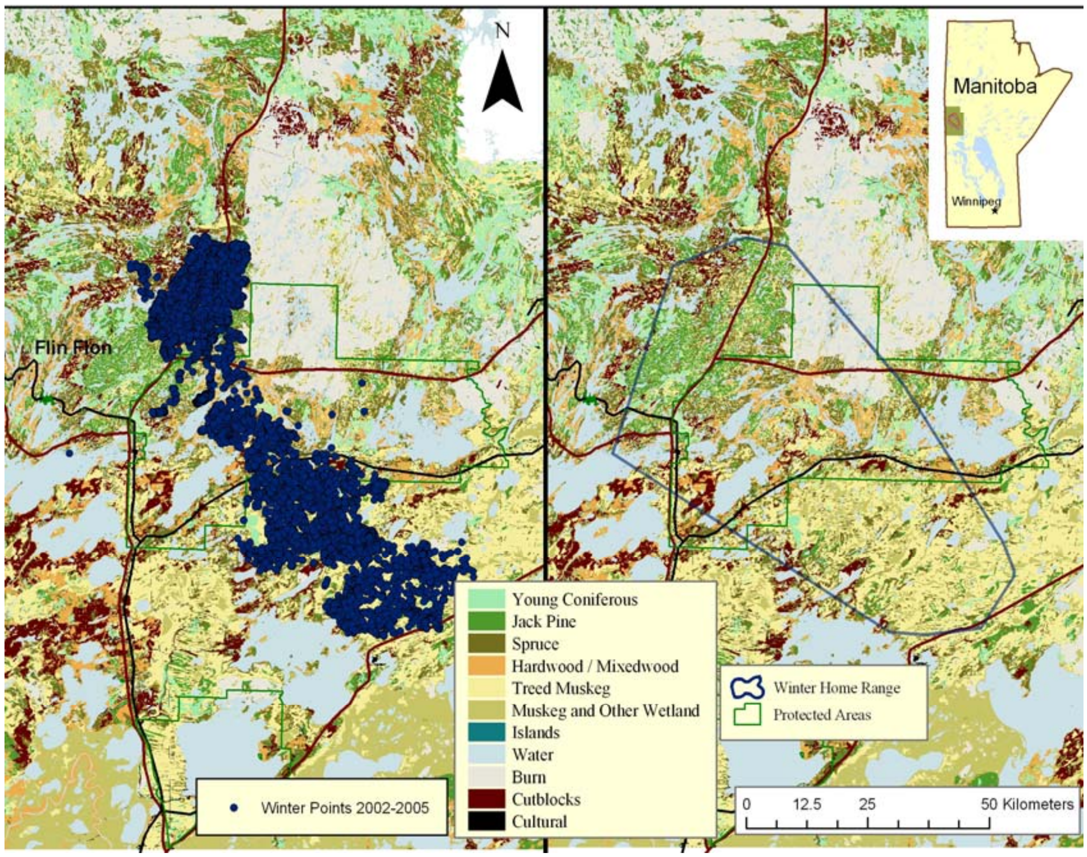


Figure 3. Reclassified Provincial FRI map showing Kississing-Naosap woodland caribou snow-covered season home range (right side) and GPS telemetry locations (left side, blue points).

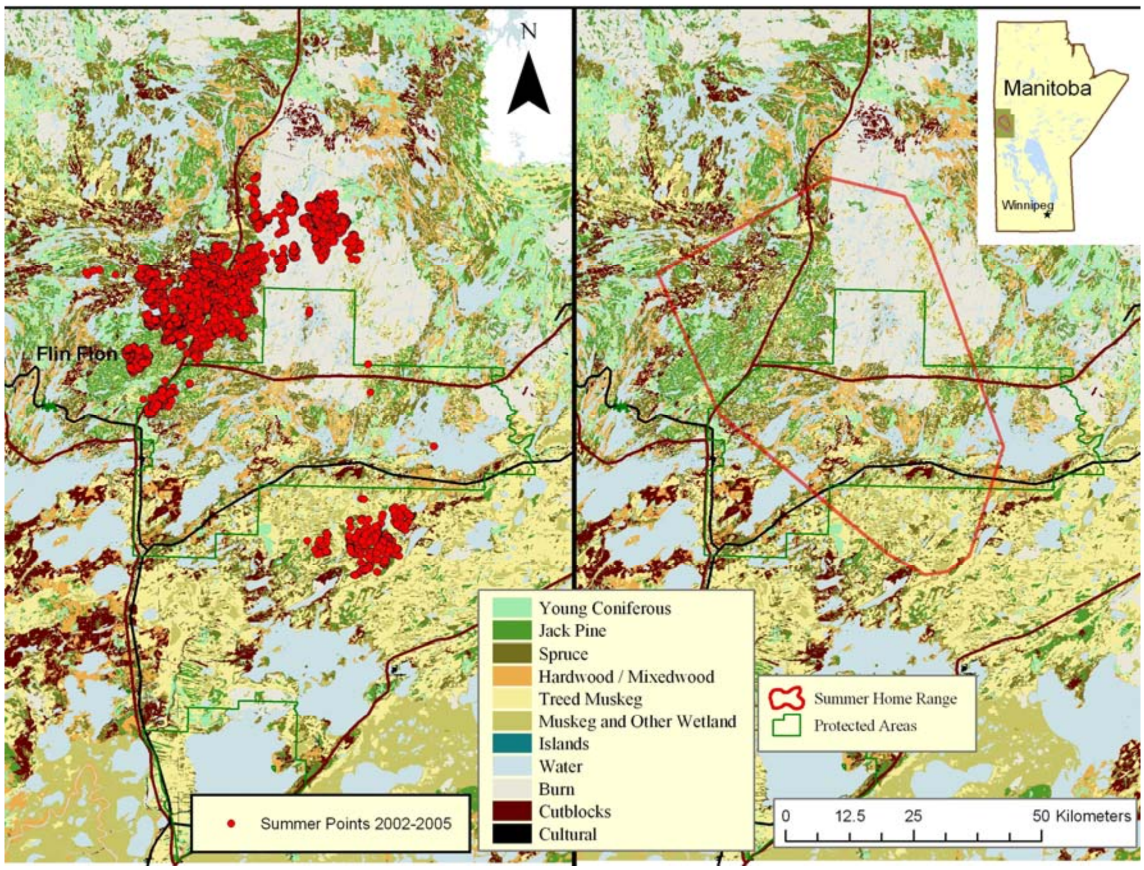


Figure 4. Reclassified Provincial FRI map showing Kississing-Naosap woodland caribou snow-free season home range (right side) and GPS telemetry locations (left side, red points).

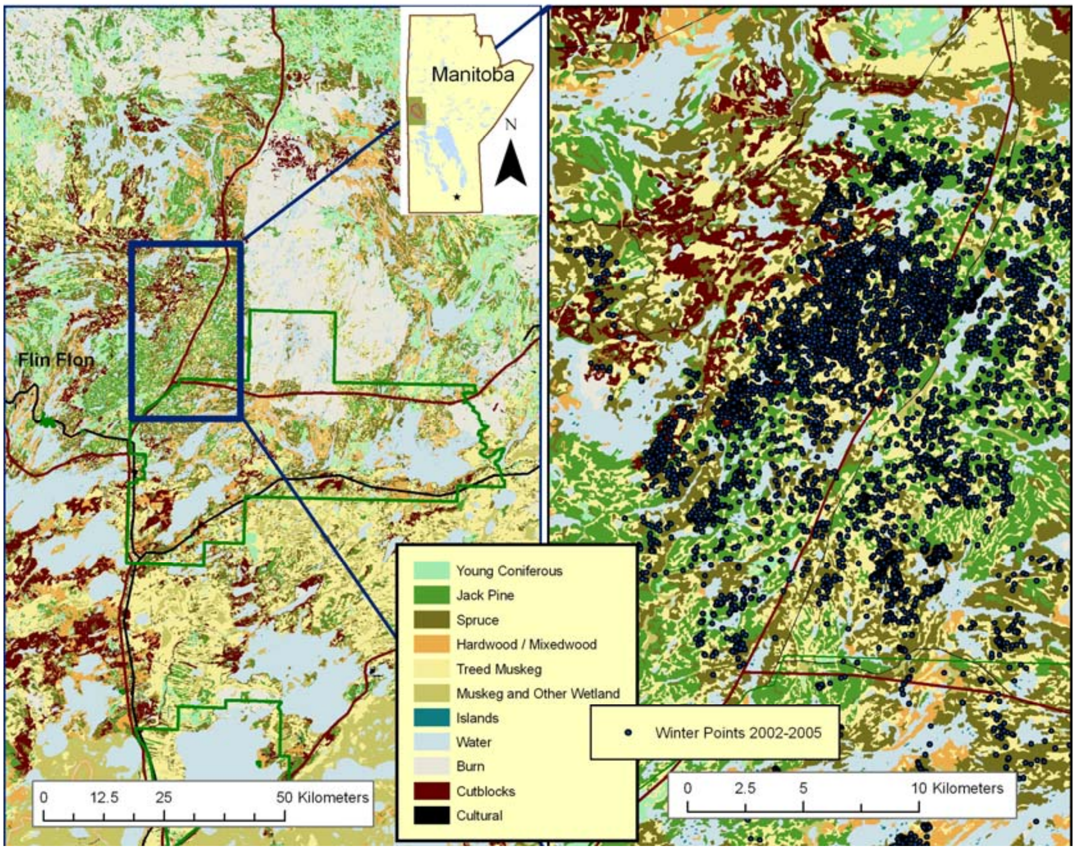


Figure 5. Harvest area scale map showing snow-covered season GPS telemetry points (right), and Reclassified Provincial FRI map showing the location of harvest area within the study area (left, blue box).

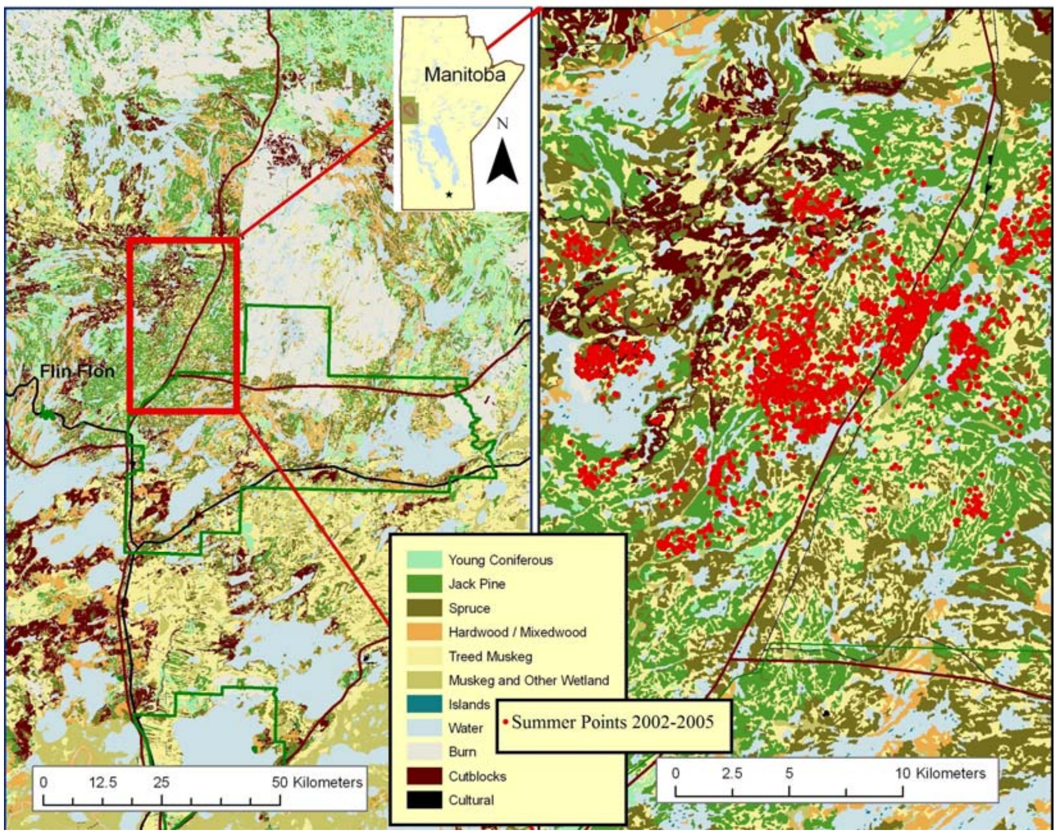


Figure 6. Harvest area scale map showing snow-free season GPS telemetry points (right), and Reclassified Provincial FRI map showing the location of harvest area within the study area (left, red box).

4. *Caribou locations in cut-blocks and cover – snow-free and snow-covered seasons.* To determine woodland caribou distribution in harvested areas, with respect to distances to forest cover and openings, average "distances to forest edge" of treed habitats and cut-blocks were calculated for both the home range and harvest area scales, in both seasons. The resulting information was expected to give us an idea as to whether the animals use or remain close to leave areas as outlined in the mitigation plan, and also to give us an idea of preferred leave area widths. Distance-to-forest-edge variables were obtained using the cut-block layer and cover layer derived from the Provincial FRI data. Data for these variables were derived by first converting the polygon layers to line layers using the polygon-to-line script in Arcview 3.2, and then using the "nearest-feature" script to calculate distance of each point to each edge. Distance to edge of cover is the distance of caribou locations within treed habitat to non-treed disturbed habitat, and distance to edge of cut-block is the distance of caribou locations within cut-blocks to treed habitat. Variables for caribou use were based on the GPS telemetry points that fell either within cut-blocks or within cover, by season, while random points were derived using the random-point generator in Arcview 3.2, and were limited to the extent of these areas. At the harvest area scale, the resulting data for telemetry points falling in cut-blocks was derived from 88 and 74 points respectively for the snow-free and snow-covered seasons. For telemetry points falling in cover, 1110 (snow-free) and 1217 (snow-covered) points were used. At the home range scale, for points falling in cover, 4802 (snow-free) points and 5399 (snow-covered)

points were used. Mean used and random distances were compared using two-tailed T-tests in S-Plus 6.2® statistical software (Insightful, 2003).

5. *Movement path scale – snow-covered season*. Tracking was conducted during the winters of 2003-2004 and 2004-2005 (See Appendix B for winter data collection sheet). Several variables related to cover, ease of movement, and forage availability and accessibility were measured (Table 2). Researchers recorded these variables at points along actual woodland caribou trails in the Naosap Operating Area, every 100 m and for approximately 2 km for each trail. Random trails were sampled the same way, with the same starting point as the actual trails and then random angles chosen from the distribution of movement angles derived from GPS telemetry data (3 hour time lag). 84 trails were sampled (Figure 7). Tracks were located via aerial surveys, as well as through reported sightings by local foresters and residents in the area.

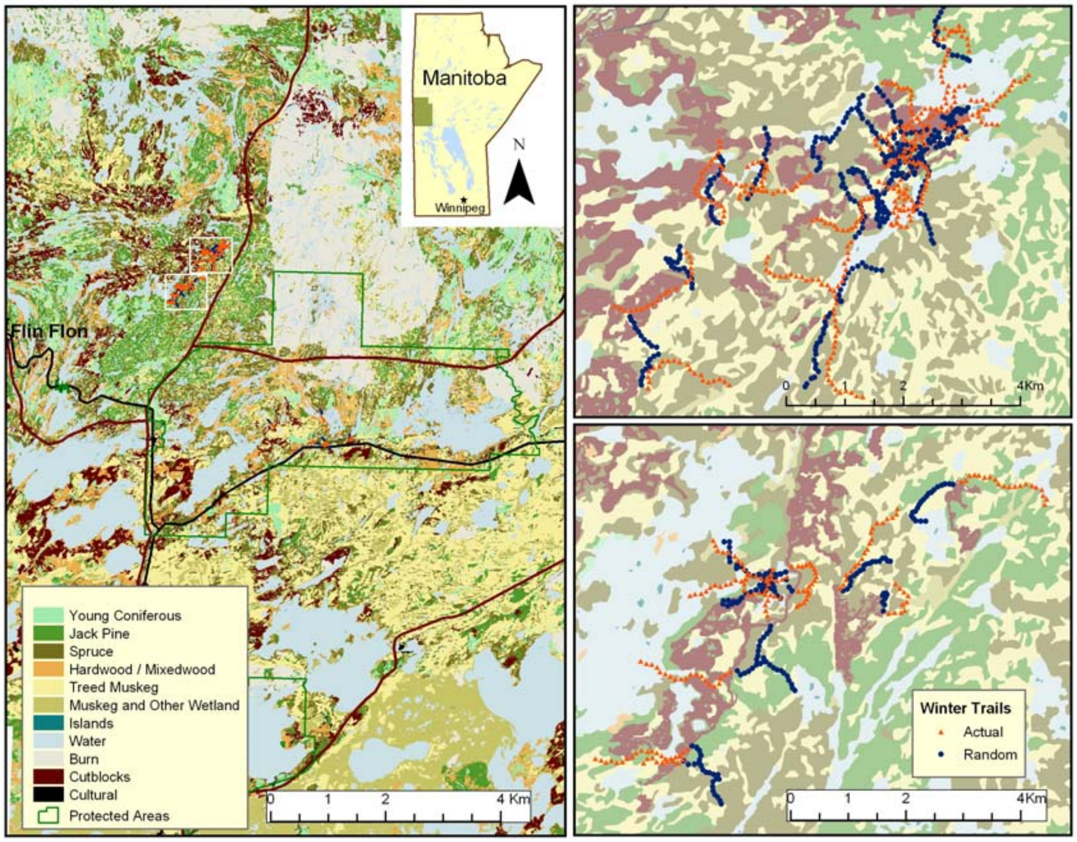


Figure 7. Location of winter tracking field work in relation to study area (left side, white boxes) and finer scale of winter tracking (right side).

6. *Site scale – snow-free season.* Snow-free season site data (similar variables as snow-covered season) (Table 3) was collected in 2005 at 205 sampling sites in the Naosap Operating Area (See Appendix C for summer data collection sheet). Sites were chosen randomly from a set of GPS telemetry locations of woodland caribou in the logged regions. Paired random points were chosen based on a list of random angles (0-360º) and random distances from the actual animal location. The random distances were generated based on actual distances between consecutive telemetry locations (3 hour time lag).

Table 1. Independent variables used to derive RSF models for woodland caribou found across the study area during both seasons at the **home range** and **harvest area** scales.

Variable	Code Name	Description
Distance to roads (km)	dist_road	Refers to the distance of each point to the closest linear feature.
Distance to habitats (km)	dist_jp, etc.	Measured for 5 habitat types: jack pine dominated coniferous (jp), black spruce (bs), treed muskeg (tm.), burn, cut-blocks (cut).
Habitat type (%)	hab_jp, etc.	Measured for 7 habitat types: jack pine dominated coniferous (jp), black spruce (bs), treed muskeg (tm.), hardwood-mixedwood (hm), water, burn, cut-blocks (cut).

Table 2. Independent variables used to derive RSF models for woodland caribou found across the study area during the **snow-covered season** at the **movement path** scale.

Variable	CodeName	Description
Field Data		
Topography (cat.)	topo	2 classes: A) easy, B) rough
Terrestrial Lichen (%)	terrlichen	Presence/Absence of *Cladina* Species
Shrub Cover (%)	shrub	2 classes: A) 0 -25%, B) 25-100%
Canopy Cover (%)	canopy	3 classes: A) under 25%, B) 25-49%; C) 50-100%
Lateral Visibility (%)	visibility	Obstruction at 360º; 3 classes: A) under 25%, B) 25-49%, C) 50-100%
Obstructions (%)	obstruction	Yes/No to indicate presence or absence of obstructions on the path
Habitat Type (%)	hab_up, etc.	4 categories: upland, treed muskeg, ice, cut
Snow Depth (cm)	snowd	Measured in centimeters, continuous scale
Arboreal Lichen (%)	arblichen	3 classes: A) under 25%, B) 25-49%, C) 50-100%
GIS-derived data		
Distance to roads (m)	dist_road	Refers to the distance of each point to the closest linear feature

Table 3. Independent variables used to derive RSF models for woodland caribou found across the study area during the **snow-free season** at the **movement path** scale.

Variable	CodeName	Description
Field Data		
Arboreal Lichen (%)	arblichen	3 classes: A) under 25%, B) 25-49, C) 50-100%
Lateral Visibility (%)	visibility	Obstruction at 360º; 3 classes : A) under 25%, B) 25-49%, C) 50-100%
Terrestrial Lichen (%)	terrlichen	% Cover of *Cladina* species
Deadfall (count)	deadfall	Tally number and size of felled trees (size classes 1-3)
Habitat Type	habitat	4 categories: A) upland, B) cut, C) treed muskeg, D) water
GIS-derived data		
Distance to roads (m)	dist_road	Refers to the distance of each point to the closest linear feature

3.3.4 Model Construction and Selection

Before models were constructed, the variables were explored to assess collinearity, and to see if they met the assumptions of the analysis (linearity of the logit). Correlated variables were removed from further analysis, and those with a non-linear logit were log-transformed to linearize the relationship between two variables (Quinn and

Keough, 2002:65). Frequency tables for the categorical variables, and logit graphs for the continous variables, were examined for trends, and those which did not show distributions in the data were considered for removal from the candidate models. Candidate models were developed based on a grouping of independent variables related to resources deemed biologically important to woodland caribou, in terms of food acquisition, navigability, predator avoidance and habitat. Tables 4, 5, and 6 present the various models employed in the analysis of woodland caribou resource selection at the home range, harvest area, and path scales, respectively.

From this set of candidate models I selected the model(s) which best explained woodland caribou selection of *movement paths* by evaluating the Akaike's information criterion for small sample sizes (AIC_c). Burnham and Anderson (2002:66) recommend using AIC_c instead of the conventional AIC, when the sample size is small with respect to the number of parameters (ratio of $n/K<40$). AIC_c is computed as: $AIC_c = AIC + 2K(K-1)/n-K-1$) (Burnham and Anderson, 2002:66). The model with the smallest AIC_c value is considered to be the model that best fits the data – in this case the selection of movement paths by woodland caribou. To see how the other candidate models rank in comparison to this one, the "AIC differences" were calculated ($\Delta i = AIC_i - AIC_{min}$) (Burnham and Anderson, 2002:71). Models with $\Delta i \leq 2$ have considerable support and may explain some substantial explainable variation in the data. Models with Δi between 4-7 have considerably less support, and finally those with $\Delta i > 10$ have essentially no support (Burnham and Anderson, 2002:70).

Table 4. Logistic regression models used to analyse habitat use by woodland caribou at the **home range** scale.

Season	Model Name	Variables*
Snow-covered		
	1) Distance-to-Disturbance	dist_road + dist_burn + dist_cut
	2) Distance-to-Selected-Habitat	dist_jp + dist_bs + dist_tm
	3) Distance-to-All	dist_road + dist_burn + dist_cut + dist_jp + dist_bs + dist_tm
	4) All Habitat	hab_jp + hab_tm + hab_hm + hab_bs + hab cut + hab_burn + hab_wat
	5) Selected Habitat	hab_jp + hab_bs +hab_tm
	6) Disturbed Habitat	hab_cut + hab_burn
Snow-free		
	1) Distance-to-Disturbance	dist_road + dist_burn + dist_cut
	2) Distance-to-Selected-Habitat	dist_jp + dist_bs
	3) Distance-to-All	dist_road + dist_burn + dist_cut + dist_jp + dist_bs
	4) All Habitat	hab_jp + hab_tm + hab_hm + hab_bs + hab cut + hab_burn + hab_wat
	5) Selected Habitat	hab_jp + hab_bs + hab_tm
	6) Disturbed Habitat	hab_cut + hab_burn

*See Table 1 for further description of variables.

Table 5. Logistic regression models used to analyse habitat use by woodland caribou at the **harvest area** scale.

Season	Model Name	Variables*
Snow-covered		
	1) Distance-to-Disturbance	dist_road + dist_cut
	2) Distance-to-Selected-Habitat	dist_jp + dist_bs + dist_tm
	3) Distance-to-All	dist_road + dist_cut + dist_jp + dist_bs + dist_tm
	4) All Habitat	hab_jp + hab_tm + hab_hm + hab_bs + hab cut + hab_wat
	5) Selected Habitat	hab_jp + hab_bs + hab_tm
Snow-free		
	1) Distance-to-Disturbance	dist_road + dist_cut
	2) Distance-to-Selected-Habitat	dist_jp + dist_bs + dist_tm
	3) Distance-to-All	dist_road + dist_cut + dist_jp + dist_bs + dist_tm
	4) All Habitat	hab_jp + hab_tm + hab_hm + hab_bs + hab cut + hab_wat
	5) Selected Habitat	hab_jp + hab_bs + hab_tm

*See Table 1 for further description of variables.

Table 6. Logistic regression models used to analyse habitat use by woodland caribou at the **movement path** scale.

Season	Model Name	Variables*
Snow-covered		
	1) Food	snowd + arblichen + canopy + terrlichen
	2) Obstruction	visibility + topo + obstruction + dist_road
	3) Habitat	hab_up + hab_tm + hab_cut + hab_ice
Snow-free		
	1) Food	terrlichen + arblichen
	2) Obstruction	visibility + deadfall + dist_road
	3) Habitat	hab_up + hab_cut + hab_tm + hab_water

*See Tables 2 + 3 for further description of variables.

For model selection at the *harvest area* and *home range* scales, an alternative approach is used. To model resource selection based on telemetry data, generalized linear models with generalized estimating equations (GEEs) are used instead of conventional regression models. This is because telemetry data is correlated due to the repeated sampling of individual animals (M. Manseau, pers. comm., 2006), and this violates the assumption of independence of observations, necessary when using conventional models (Quinn and Keough, 2002:93). To select the most parsimonious model from the subset of candidate models, QIC_us (quasi-likelihood under the independence model information criterion) are used instead of AICs (Pan, 2001). Like with AICs, the model with the smallest QIC_u value is considered to be the one that best fits the data. The equation for QIC_u is: $QIC_u = -2Q(g^{-1}(x\beta_R))+2p$ (Hardin and Hilbe, 2003:142). AIC cannot be used in this case because estimation of GEEs is based on the quasi-likelihood rather than the maximum likelihood (Pan, 2001). Therefore, QIC is used because it is the quasi-likelihood equivalent to AIC (Pan, 2001:140).

3.4 Results

3.4.1 Landscape Composition Analysis

The Kississing-Naosap annual range is composed of approximately 27% treed muskeg, 13% black spruce, 7% jack pine dominated coniferous, 6% hardwood-mixedwood, 5% young coniferous, 5% logged, and 9% burns (Table 7 and Figures 3, 4). The Naosap Operating Area is composed of similar stand types (Table 7 and Figures 5, 6), with a slightly higher percentage of cut-blocks (8%). From these figures it might appear that the overall disturbance in the home range, and even in the harvest regions, is presently relatively low. However, upon closer analysis, we see that a large amount (25%) of total available jack pine dominated coniferous stands are within the harvest areas, but <3% is actually protected in leave areas. Furthermore, after harvesting in the Peterson Operating area takes place, the amount of jack pine in the harvested areas will decline, thus potentially creating a significant reduction of high-quality habitat in the range.

In addition to lacking high-quality habitat such as jack pine stands, the composition of the leave areas is of interest because about 18% is composed of cut-blocks (Table 7 and Figures 8, 9). However it is important to note that these cut-blocks are quite old and may be considered young forests. Nevertheless, this is important because young forests are avoided by caribou, thus reducing their value as leave areas. In fact Figures 8 and 9 show how the animals are avoiding a major portion of the leave area, potentially because the area is composed of old cut-blocks.

Table 7. Landscape metrics describing the Kississing-Naosap caribou range, the Naosap harvest area and the leave areas.

Scale	Habitat Type	Total Area (ha)	% Land	# Patches	Mean Area Patch (ha)	Std. dev.
Home Range						
	Treed Muskeg	241528.00	26.71	5240	46.09	1171.64
	Black Spruce	120762.25	13.36	7818	15.45	61.66
	Jack Pine Dominated	63567.50	7.03	2766	22.98	189.40
	Hardwood-Mixedwood	60117.75	6.65	4668	12.88	68.17
	Young Coniferous	46690.00	5.16	3440	13.57	85.06
	Burns	81380.25	9.00	542	150.15	2730.80
	Cut-blocks	46889.75	5.19	872	53.77	250.96
	Water	196120.25	21.69	2476	79.21	821.25
Harvest Area						
	Treed Muskeg	15142.00	20.77	972	15.58	84.40
	Black Spruce	14197.25	19.47	974	14.58	58.37
	Jack Pine Dominated	15141.50	20.77	472	32.08	181.75
	Hardwood -Mixedwood	2599.25	3.56	211	12.32	45.51
	Young Coniferous	3388.50	4.65	274	12.37	45.65
	Burns	921.75	1.26	39	23.63	79.11
	Cut-blocks	6072.75	8.33	172	35.51	102.48
	Water	13692.50	18.78	338	40.51	182.02
Leave Areas						
	Treed Muskeg	1609.89	40.65	98	16.43	33.51
	Black Spruce	1066.28	26.92	124	8.60	21.55
	Jack Pine Dominated	405.89	10.25	67	6.06	13.88
	Hardwood -Mixedwood	6.42	0.16	3	2.14	0.60
	Young Coniferous	32.93	0.83	27	1.22	1.64
	Burns	0.43	0.01	1	0.43	0.00
	Cut-blocks	722.40	18.24	73	9.90	37.73

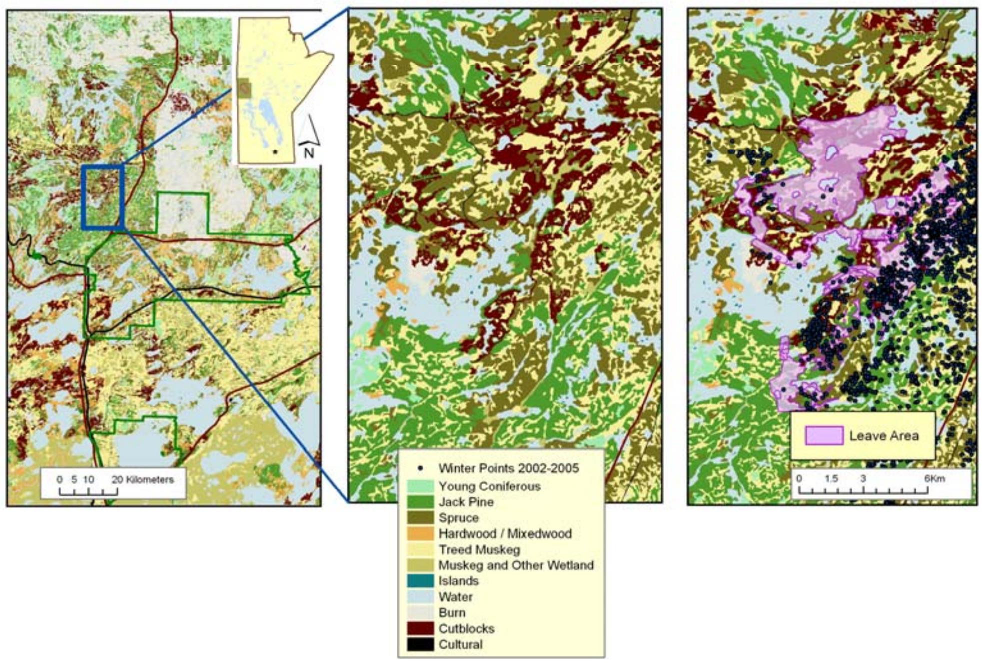


Figure 8. Reclassified provincial FRI (far left) showing location of harvest area within the study area (blue box), harvest area zoomed in (middle map) and snow-covered season GPS telemetry points in relation to leave areas (far right).

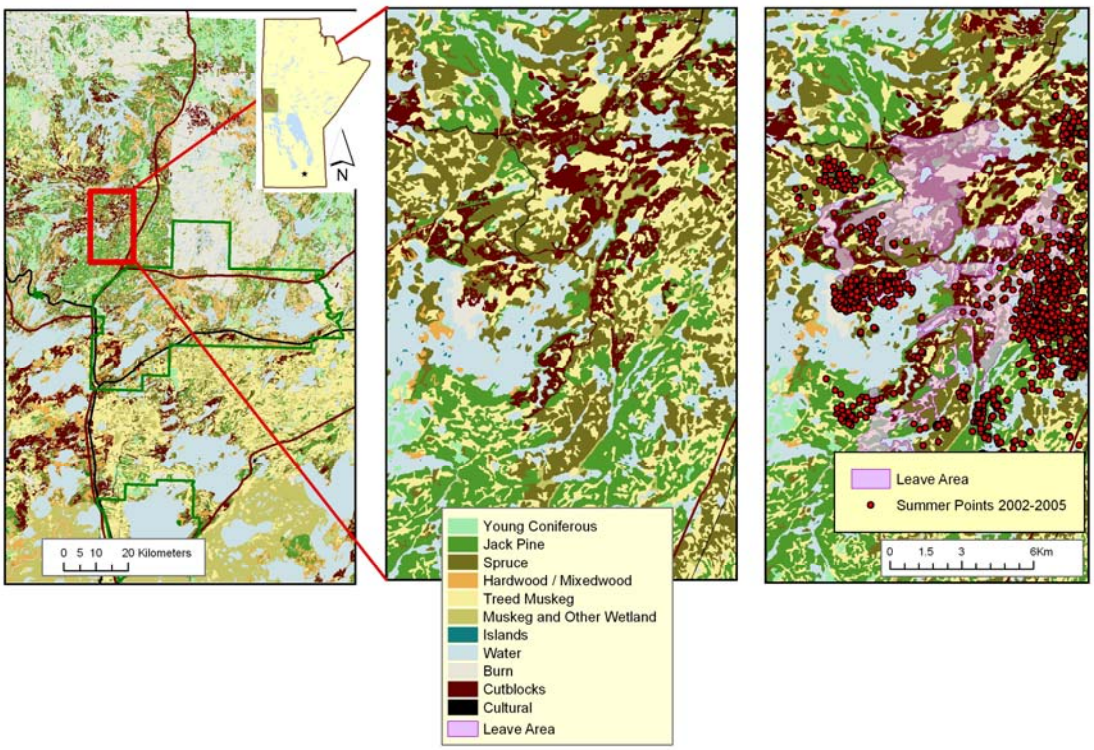


Figure 9. Reclassified provincial FRI (far left) showing location of harvest area within the study area (red box), harvest area zoomed in (middle map) and snow-free season GPS telemetry points in relation to leave areas (far right).

3.4.2 Home Range Scale

Snow-covered Season

The best model for predicting woodland caribou habitat selection at the home range scale in the snow-covered season is the "all habitat" model, as indicated by the lowest QIC_u value (Table 8). The model reveals that the animals strongly selected jack pine dominated coniferous and black spruce stands, and avoided burns, cut-blocks, and water (Figure 10). The second best model is the "distance-to-all" model (Δi=154.51) (Table 8), which suggests that the animals selected areas in proximity to treed muskeg (random locations: $\bar{x}$ =255.75, *sd*=432.81; actual locations: $\bar{x}$ =77.29, *sd*=98.82) and jack pine dominated coniferous stands (random locations: $\bar{x}$ =1179.61, *sd*=1198.17; actual locations: $\bar{x}$ =695.50, *sd*=953.47).

Snow-free Season

The model with the lowest QIC_u, which best explains woodland caribou selection at the home range scale in the snow-free season, is also the "all habitat" model (Table 8). The results of this model show that woodland caribou strongly selected jack pine dominated coniferous and treed muskeg stands and avoided water (Figure 11). Like the snow-covered season, the second best model in the snow-free season is the "distance-to-all" model (Δi=285.16) (Table 8). It indicates that the animals selected areas closer to jack pine dominated coniferous stands (random locations: $\bar{x}$ =1205.42, *sd*=1231.90; actual locations: $\bar{x}$ =475.27, *sd*=613.96).

Table 8. Logistic regression models for evaluating **home range** selection by woodland caribou in both seasons. Values that indicate substantial support for models are in bold under "Variable estimates" column. The ß coefficients indicate the direction and extent of habitat selection (positive values for selection, negative values for avoidance). Models that best explained caribou selection are indicated in bold.

Season	Models	QIC_u	Δi	Variable estimates (ß)
Snow-covered				
	Distance-to-Disturbance	57050.29	4415.49	**dist_burn 0.27** dist_cut 0.11 dist_road -0.09
	Distance-to-Selected-Habitat	53327.70	692.90	**dist_tm -2.90** **dist_jp -0.36** dist_bs -0.29
	Distance-to-All	52789.31	154.51	**dist_tm -2.60** **dist_jp -0.35** dist_bs -0.41 dist_burn 0.13 dist_cut 0.10
	All Habitat	52634.80	Min.	**hab_burn -1.35** **hab_cut -0.96** hab_tm 0.21 **hab_jp 1.11** **hab_bs 0.75** **hab_wat -0.89** hab_mix -0.30
	Selected Habitat	54378.47	1743.67	**hab_tm 0.58** **hab_jp 1.28** **hab_bs 0.92**
	Disturbed Habitat	57363.45	4728.65	**hab_burn -1.81** **hab_cut -0.88**
Snow-free				
	Distance-to-Disturbance	51797.98	3944.99	dist_burn 0.05 dist_cut 0.06 dist_road -0.15
	Distance-to-Selected-Habitat	48397.31	544.32	**dist_jp -0.27** dist_bs -0.10
	Distance-to-All	48138.15	285.16	dist_burn -0.06 dist_cb 0.05 dist_road -0.02 **dist_jp -0.29** dist_bs -0.13
	All Habitat	47852.99	Min.	hab_burn 0.28 hab_cut -0.53 **hab_tm 0.62** **hab_jp 1.17** hab_bs 0.38 **hab_wat -0.55** hab_mix -0.30
	Selected Habitat	48562.41	709.42	**hab_tm 0.72** **hab_jp 1.11** **hab_bs 0.72**
	Disturbed Habitat	51958.88	4105.89	hab_burn -0.48 hab_cut -0.69

Figure 10. Histogram showing frequencies of random and actual GPS telemetry points across the various habitat types at the home range scale in the snow-covered season.

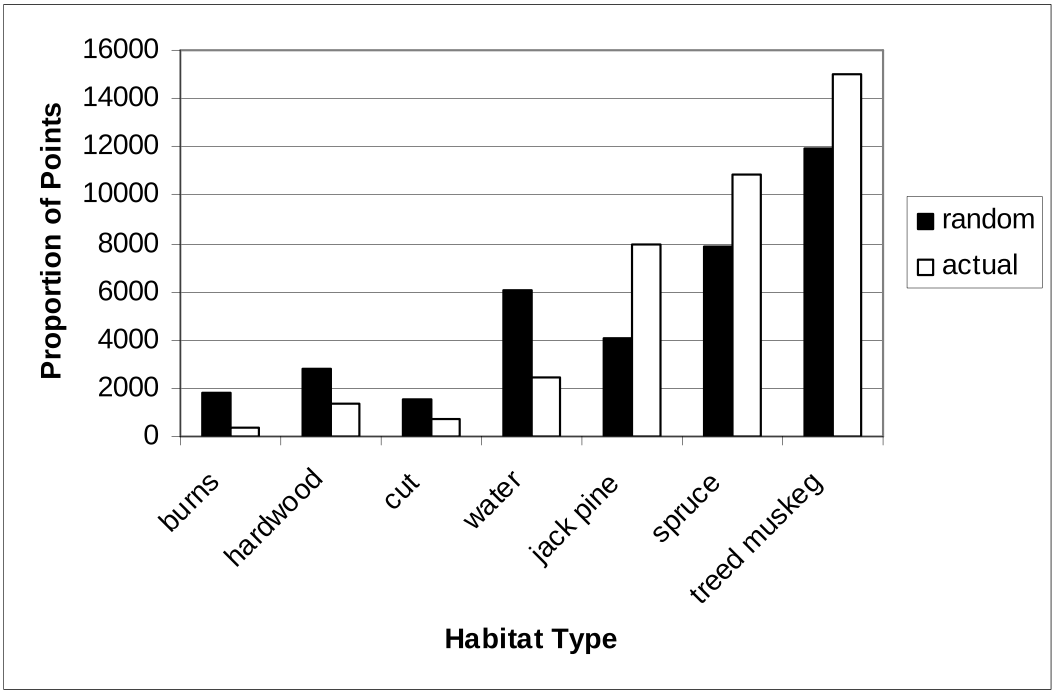
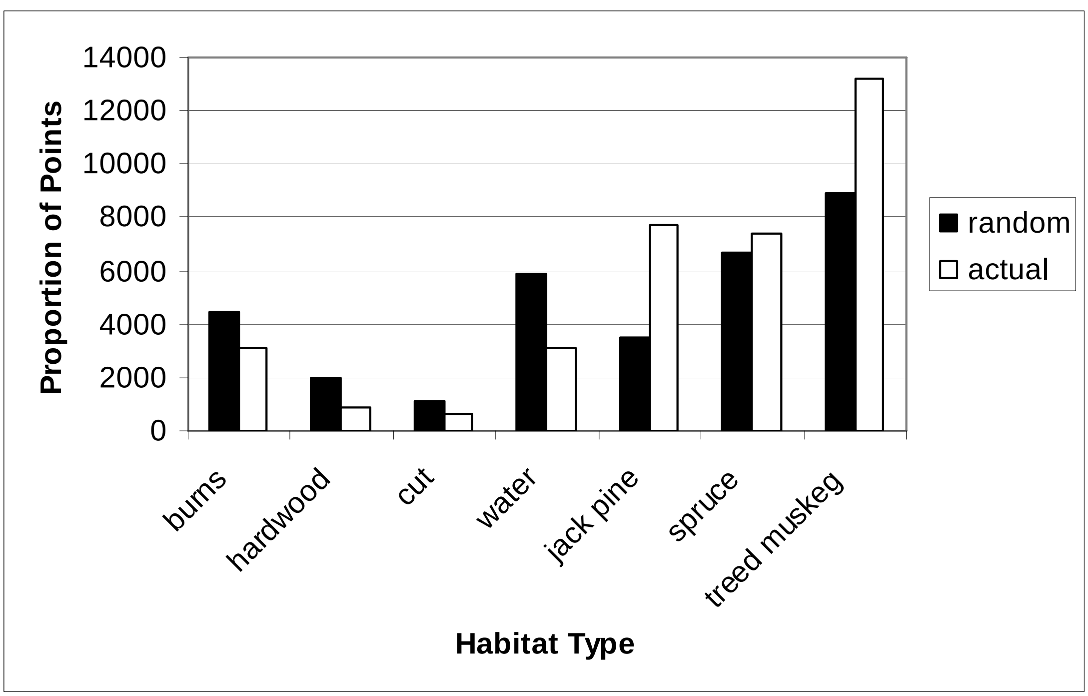


Figure 11. Histogram showing frequencies of random and actual GPS telemetry points across the various habitat types at the home range scale in the snow-free season.



3.4.3 Harvest Area Scale

Snow-covered Season

The best model for predicting woodland caribou habitat selection at the harvest area scale in the snow-covered season, is the "all habitat" model (Table 9). This model suggests the animals avoided cut-blocks and water (Figure 12). The second best model is the "distance-to-all" model (Δi=372.59) (Table 9), which indicates the animals selected areas in proximity to treed muskeg (random locations: $\bar{x}$=123.03, *sd*=172.91; actual locations: $\bar{x}$=80.63, *sd*=85.15) in the harvest area.

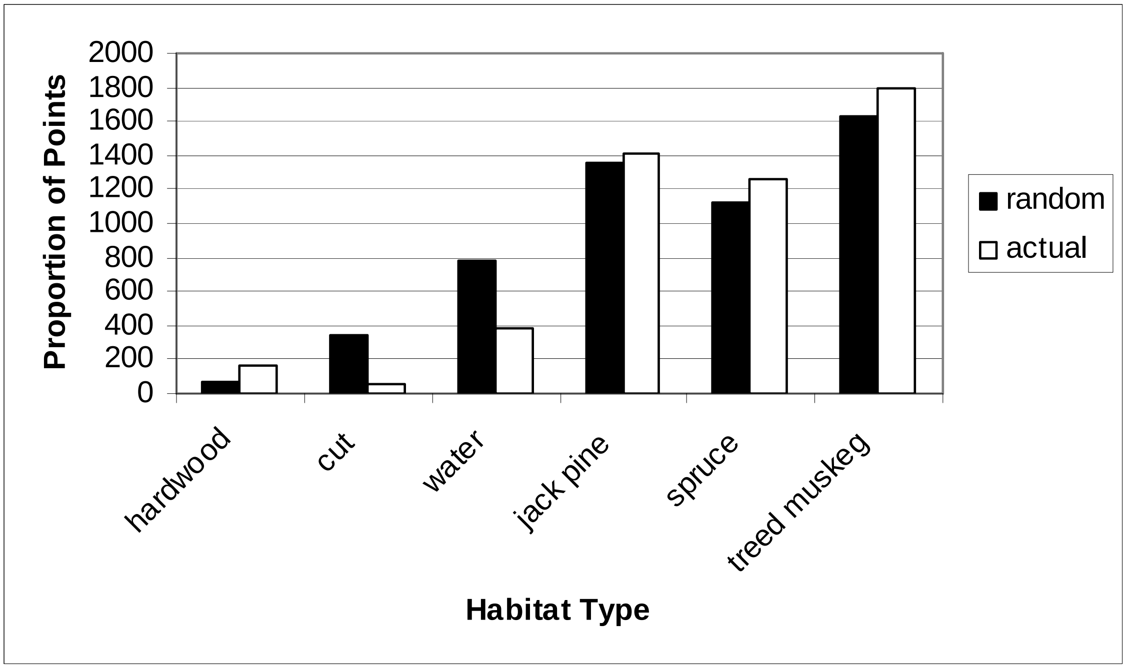
Snow-free Season

The model which best explains woodland caribou selection at the harvest area scale in the snow-free season, is the "distance-to-all" model (Table 9). The results of this model indicate that the animals strongly selected areas closer to treed muskeg (random locations: $\bar{x}$=144.40, *sd*=196.57; actual locations: $\bar{x}$=65.45, *sd*=96.08) and further from cut-blocks (random locations: $\bar{x}$=3453.37, *sd*=3975.51; actual locations: $\bar{x}$=4046.22, *sd*=2388.19). The second best model is the "distance-to-disturbance" model (Δi=332.37) (Table 9), which also suggests the animals selected areas farther from cut-blocks.

Table 9. Logistic regression models for evaluating **harvest area** scale selection by woodland caribou in both seasons. Values that indicate substantial support for models are in bold under "Variable estimates" column. The ß coefficients indicate the direction and extent of habitat selection (positive values for selection, negative values for avoidance). Models that best explained caribou selection are indicated in bold.

Season	Models	QIC_u	Δi	Variable estimates (ß)
Snow-covered				
	Distance-to-Disturbance	7283.48	549.28	dist_cut 0.01 dist_road -0.17
	Distance-to-Selected-Habitat	7154.13	419.93	**dist_tm -2.38** dist_jp -0.43 dist_bs 0.19
	Distance-to-All	7106.79	372.59	dist_cut -0.01 dist_road -0.13 **dist_tm -2.12** dist_jp -0.55 dist_bs 0.22 dist_mix 0.08
	All Habitat	6734.20	Min.	**hab_cut -2.19** hab_tm -0.11 hab_jp 0.32 hab_bs 0.48 hab_mix 1.62 **hab_wat -1.14**
	Selected Habitat	7275.13	540.93	hab_tm 0.22 hab_jp 0.31 hab_bs 0.39
Snow-free				
	Distance-to-Disturbance	8535.44	332.37	**dist_cut 0.38** dist_road -0.38
	Distance-to-Selected-Habitat	8837.82	634.75	**dist_tm -3.79** dist_jp -0.46 dist_bs -0.09
	Distance-to-All	8203.07	Min.	**dist_cut 0.39** dist_road -0.36 **dist_tm -3.24** dist_jp 0.19 dist_bs -0.41
	All Habitat	8630.23	427.16	**hab_cut -1.57 hab_tm 0.61** hab_jp 0.15 hab_bs 0.22 hab_mix 1.03 **hab_wat -0.76**
	Selected Habitat	9083.17	880.10	**hab_tm 0 .81** hab_jp 0.25 hab_bs 0.12

Figure 12. Histogram showing the frequencies of random and actual GPS telemetry points across the various habitat types at the harvest area scale in the snow-covered season.



3.4.4 Caribou Locations Within Cut-blocks and Cover

At the harvest area scale, results indicate that in both the snow-free and snow-covered seasons, woodland caribou selected locations further into cover when in cover, as compared to random (Table 10). In both seasons, they also selected locations closer to the edge of cut-blocks, or closer to cover. A similar comparison was made, to see how animals are distributed with respect to forest edges in treed areas across the entire home range (as opposed to just in the Naosap Operating Area). At the home range scale, results indicate that in both seasons, they were located further into cover, when in cover (Table 10, Figures 13 and 14). Caribou were found further from forest edge in the snow-covered season as compared to the snow-free season at both scales. This again emphasizes that the animals may be more impacted by disturbance in the snow-covered rather than the snow-free seasons.

Table 10. Average "distances to forest edge" for woodland caribou GPS telemetry points found across the study area during both seasons at the harvest area and home range scales.

Scale	Distances to edge (m)	Actual $\bar{x}$ (*sd*)	Random $\bar{x}$ (*sd*)	*n*	t-test
Harvest Area					
	Snow-covered Season				
	Distance to edge of cover	430.40 (241.17)	237.99 (221.97)	172	$P<0.001$
	Distance to edge of cut-block	26 (23)	153 (258)	74	$P<0.001$
	Snow-free Season				
	Distance to edge of cover	362.32 (289.28)	240.26 (230.04)	283	$P<0.001$
	Distance to edge of cut-block	28 (24)	74 (115)	88	$P<0.001$
Home Range					
	Snow-covered Season				
	Distance to edge of cover	411.21 (282.52)	297.26 (272.65)	905	$P<0.001$
	Snow-free Season				
	Distance to edge of cover	309.12 (268.90)	234.42 (219.59)	1246	$P=0.001$

Figure 13. Home range scale "distance to forest edge" frequencies for random and actual GPS telemetry points in the snow-covered season. Distance categories are in meters.

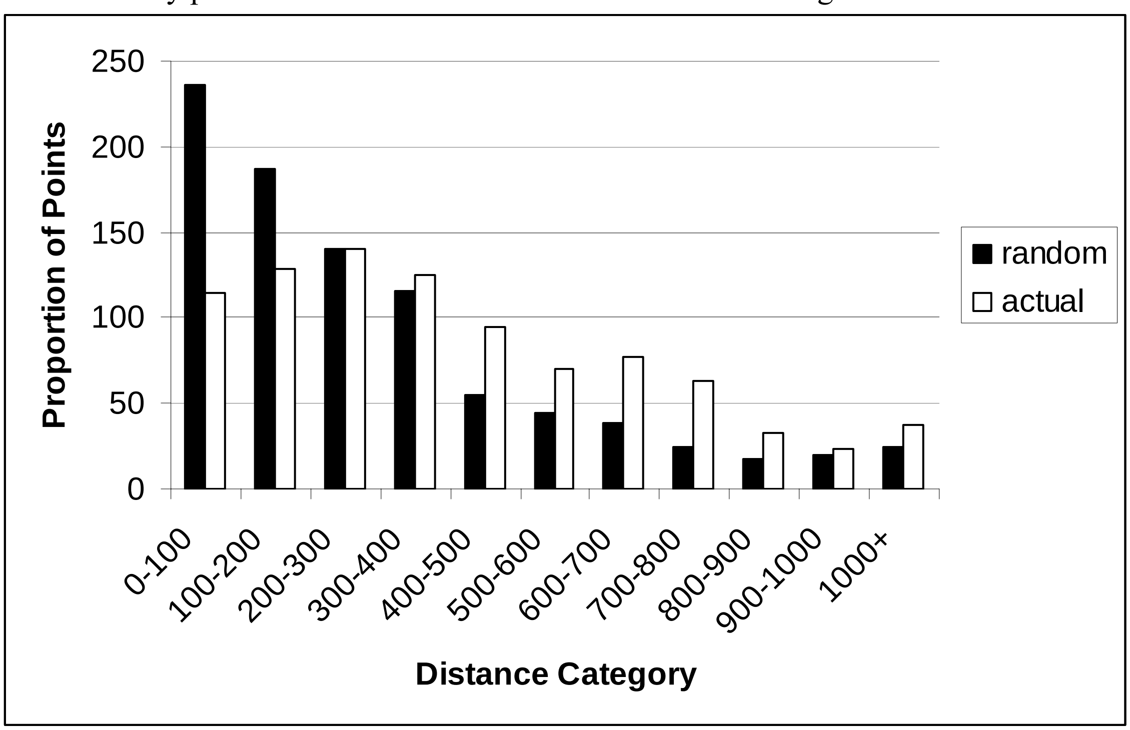
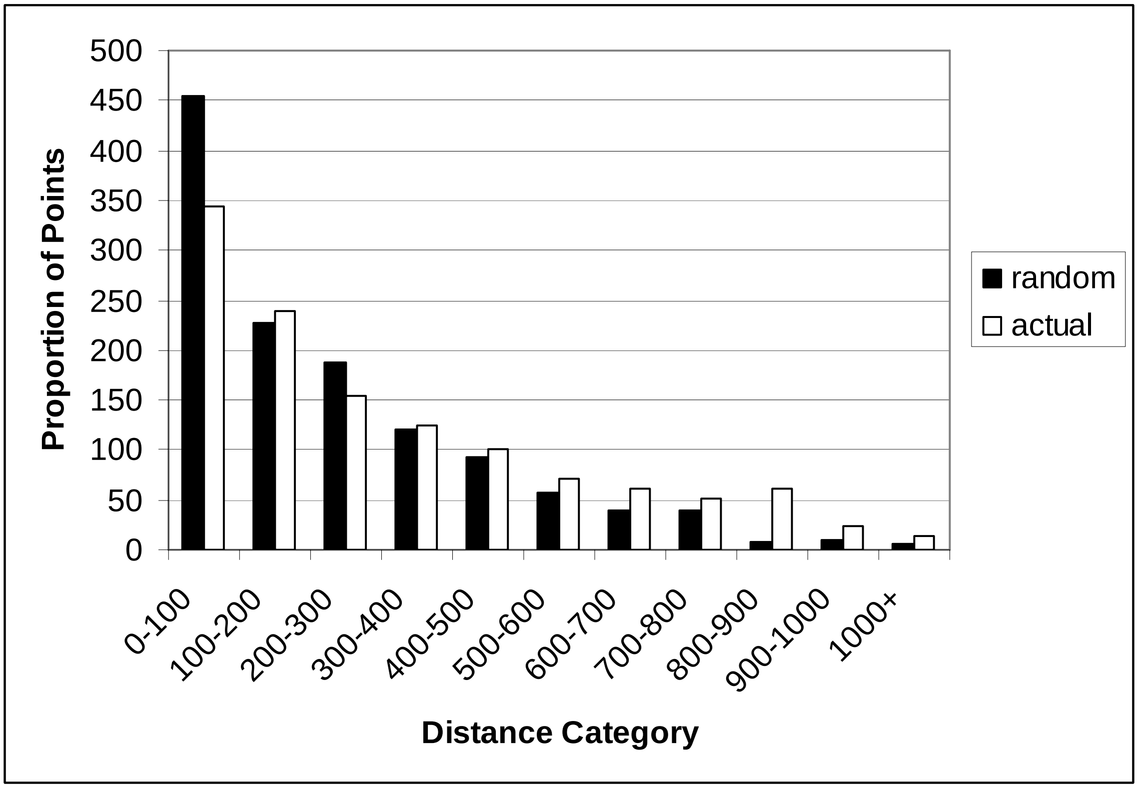


Figure 14. Home range scale "distance to forest edge" frequencies for random and actual GPS telemetry points in the snow-free season. Distance categories are in meters.



3.4.5 Movement Path Scale

Snow-covered Season Selection

The best model for predicting woodland caribou movement path selection through disturbed areas in the snow-covered season is the "obstruction" model, as indicated by this model having the lowest AIC_c score (Table 11). The model indicates animals strongly selected paths with greater visibility. The other models all have considerably less support, with a $\Delta AIC_c > 7$.

Snow-free Season Selection

In the snow-free season, the best model for predicting woodland caribou movement path selection through disturbed areas is the "food" model (Table 11). The results demonstrate that the animals strongly selected paths with greater arboreal lichen cover compared to random. The "obstruction" model also has substantial support, with a $\Delta AIC_c<2$. The results indicate a selection of paths further from roads (random locations: $\bar{x}$ =1061.01, *sd*=527.09; actual locations: $\bar{x}$ =1347.19, *sd*=475.71). The "habitat" model has essentially no support, with a $\Delta AIC_c>10$.

Table 11. Logistic regression models for evaluating **path** selection by woodland caribou in both seasons. Values that indicate substantial support for models are in bold under "Variable estimates" column. The ß coefficients indicate the direction and extent of habitat selection (positive values for selection, negative values for avoidance). Models that best explain caribou selection are indicated in bold.

Season	Models	-2LL	AIC	AIC_c	Δi	Variable estimates ß
Snow-covered						
	Without covariates		58.22			
	Food	44.03	56.03	56.05	9.25	snowd -2.77 arblichen2 1.14 arblichen3 1.02 canopy2 1.27 canopy3 1.02 terrlichen 0.28
	Obstruction	36.29	46.29	46.79	Min.	**visibility3 2.83 visibility2 1.20** obstruction -0.54 dist_road 0.0003
	Habitat	47.18	55.18	55.56	8.76	**hab_up 1.69** hab_cut -0.08 hab_ice 0.04 hab_tm 0.20
Snow-free						
	Without covariates		76.25			
	Food	57.85	63.85	63.96	Min.	**arblichen2 1.38 arblichen3 3.21** terrlichen -0.01 shrub2 -0.01 shrub3 -0.74
	Obstruction	57.57	65.57	65.80	1.84	**dist_road 0.0026** visibility2 0.12 visibility3 -0.14 deadfall -0.03
	Habitat	71.84	77.84	77.88	13.92	hab_cut -0.77 hab_tm 0.04 hab_wat -1.08

3.5 Discussion

At the home range scale, caribou in the Kississing-Naosap range showed habitat selection patterns typical of woodland caribou found elsewhere in the boreal forest (Darby and Pruitt, 1984; Chubbs et al., 1993; O'Brien et al., 2006). They avoided young or deciduous forests and selected mature upland habitat types such as black spruce in the snow-covered season, and jack pine dominated stands in both seasons. In the snow-free season they also selected treed muskeg habitat. They also selected locations closer to these habitat types, when not in them. Woodland caribou in this study are probably selecting mature coniferous forests to separate themselves from moose (and higher predator populations associated with moose) (Rettie and Messier, 2000), because moose tend to prefer early seral stage forests (Bolen and Robinson, 2003). Their selection of treed muskeg in the snow-free season may also be to reduce predation, but they may not select for treed muskeg in winter because snow is deeper in these areas (Darby and Pruitt, 1984).

Similar to caribou populations elsewhere, the caribou in this study also avoided disturbed areas and selected areas further from them than random (Chubbs et al., 1993; Smith et al., 2000; Schaefer, 2006). In west-central Alberta, caribou locations were 1.2 km farther from newly harvested cut-blocks than were random locations, and only 0.6 % of caribou radio-locations were found in clear-cuts in the final stages of logging (Smith et al., 2000). Female caribou in Newfoundland stayed an average of 9.2 km away from active cut-overs, with displacement occurring even pre-harvest (Schaefer, 2006). Moreover, half of the female caribou studied by Chubbs et al. (1993) in east-central Newfoundland were farther away from those areas that had been clear-cut, than they were prior to logging. In this same study, the animals also used burns and hardwoods disproportionately less during cutting than they did prior to the disturbance.

O’Brien et al. (2006) documented that the Owl Lake and Kississing woodland caribou herds were both associated with larger areas of high-quality habitat (upland forest stands). A similar conclusion can be interpreted from the results of the present study, in which caribou were found at further distances into treed habitat at both the home range and harvest area scales.

The value of conducting a multi-scale analysis is that relationships between caribou locations and available habitat may differ across various scales, due to differing selection pressures. In general, selection at coarser scales is influenced by factors more important to fitness (such as predation), and persists over finer scales if these limiting factors are not overcome at the coarser scale (Rettie and Messier, 2000). In this study, it was important to not only examine the selection patterns at the home range scale with the use of GIS, but to examine patterns at the finer scale, using field-based methods. This decreased the chances that important habitat selection patterns would be overlooked. Rettie and Messier (2000) also implemented a multi-scaled approach, and their data supported this hierarchy of habitat selection by woodland caribou. Woodland caribou habitat selection in southern British Columbia also differed across spatial scales (Kinley et al., 2003). For example, at the foraging-path scale, Kinley et al. (2003) found a preference by woodland caribou for paths with Engelmann Spruce (*Pinus engelmannii*) and Subalpine Fir (*Abies lasiocarpa*), but they note that other authors found no such selection of these types at a coarser scale of analysis in the same study area.

In the present study, finer scale selection such as that observed at the movement path scale would not have been observed with only the use of a GIS database and subsequent analysis of coarser scale patterns. For example, the best model at the movement path scale during the snow-free season showed that the presence of arboreal lichen influenced woodland caribou selection most. Woodland caribou in southern British

Columbia also foraged on trees with greater lichen abundance along movement paths (Kinley et al., 2003) as did those of the Gaspé herd in Quebec (Mosnier et al., 2003) and a population in northern British Columbia (Johnson et al., 2000). However, because arboreal lichen is not as important a food source as terrestrial lichen for the boreal ecotype of woodland caribou, it may be that the animals are selecting the habitat type associated with greater arboreal lichen cover (mature upland habitat), as opposed to selecting for the lichen itself (M. Manseau, pers. comm., 2006). However, boreal woodland caribou have been documented to feed on arboreal lichen, such as the Aikens Lake herd did during summer (Darby and Pruitt, 1984), and arboreal lichen was also found to be an important predictor of habitat suitability on the Kississing-Naosap range in a study by Metsaranta (2002). In either case, it will be important to preserve habitats associated with greater arboreal lichen cover when planning for leave areas in harvested regions.

Another important selection variable that may have been overlooked by only analysing selection at the larger scales, was distance of the animal's locations relative to roads. Although not a significant finding at the home range or harvest area scales, caribou were shown to select locations further from roads at the snow-free season site scale, and this has implications for road management as will be discussed later. This may also reflect different selection pressures at different scales. For example, at the home range scale the selection of mature upland cover types and avoidance of large-scale disturbances such as cut-blocks and burns may be more important than avoiding roads. At finer scales (such as the movement path scale) selection may be influenced more by roads because the animals are in an area of more concentrated disturbance, therefore they are responding more strongly to disturbances such as roads.

The use of a multi-scaled approach also allowed us to observe important selection patterns that persisted across scales. For example, this study showed that caribou avoided disturbance across all three scales of analysis. This is an important finding because it offers support for the existing mitigation practices on the Kississing-Naosap range with respect to leave areas and road obliteration. For those animals that use disturbed areas, adjacent undisturbed high-quality habitat must be available, because even at this scale animals are avoiding disturbance. Further supporting this notion, is the fact that at the movement path scale the animals are selecting parameters associated with mature upland stands (i.e. paths with greater arboreal lichen cover).

It is also important to analyse habitat selection in more than one season, because different environmental pressures may influence animals at different times of the year. This results in different seasonal selection patterns, and the results may have implications for management. For example, food availability and accessibility changes with seasons, and lack of food, predation or disturbance may be more or less critical depending on the time of year. Avoiding disturbance and predation, and finding food may be energetically costly, especially in cold winter months. In this study, disturbance influenced caribou distribution more during the snow-covered season at the home range scale. This is probably because there is less available forage in cut-blocks (and burns) during winter, coupled with greater snow depths, which makes it harder for animals to move. Furthermore, they would be more visible to predators in open habitats like cut-blocks and burns (Chubbs et al., 1993), so to decrease the chances of detection they may avoid these areas during this critical season. It is important to note that in this study, at the home range scale there are many older cut-blocks, and these young forests may not have effects as pronounced as more recent logging disturbance. Therefore the animals may not show as much displacement from logging at this scale, and this is reflected in the results. More importantly, in the Naosap Operating Area, caribou avoided disturbance in both the snow-covered and snow-free seasons. This further supports the need for the retention of quality habitat within the harvested areas throughout both summer and winter parts of the animal's range.

Furthermore, treed muskeg was selected for during the snow-free season at the home range scale, but not in the snow-covered season – suggesting that treed muskeg is better summer habitat. In contrast, black spruce may be more important during winter. It is also interesting that water is avoided in the snow-covered but not the snow-free season, at the harvest area scale. This could be simply a reflection of the fact that islands and shorelines are used in early summer for calving, but are not needed during winter for this purpose.

Furthermore, seasonal differences were observed in movement path selection. Food availability was more influential in the snow-free season than in the snow-covered season, where the obstruction model was more important. Selection of paths with greater visibility in winter may be a strategy to reduce the risk of a predator surprising or catching them (Johnson et al., 2001).

In addition to giving support to the existing mitigation measures such as leave area designation, the results from this study can be used to improve upon these and other mitigation measures. For example, the information on habitat selection fills a major gap in the current mitigation plan with respect to understanding the herd's habitat requirements. The results can be used to assist with planning of future leave areas, with respect to composition and extent of habitat types appropriate for caribou protection. Furthermore, the information gained with respect to distance of caribou locations within and with respect to cover, will help us improve the value of the leave areas and the configuration of the cut-blocks themselves. Because caribou were found further into forest cover, larger leave areas are preferable. It is important to note that in addition to size and type of habitat, the spatial location and shape of leave patches are also important factors to consider when planning for caribou habitat. For example, depending on the type of adjacent habitat, caribou may be less inclined to use certain leave patches. This would result in some functional habitat loss.

My results also support a lower density of roads in the Peterson Operating Area, and the placement of roads away from key sensitive areas/leave areas. An increased risk of predation has been found to be associated with use of roads, as found in a study by James and Stuart-Smith (2000), and the caribou in this study may be responding to that increased risk. As well, these results support post-harvest obliteration of the existing roads in the Naosap Operating Area.

Lastly, the results for this study show some support for post-harvest treatments which may reduce shrub competition in the regenerating forest. In this study caribou selected winter paths with greater visibility in the harvested areas. As shrub cover increases, visibility may be reduced. Energy expenditure may also increase with denser shrub cover, and so animals may choose paths which are easier to move through. Although they studied topography and not shrub density, Johnson et al. (2002) found that woodland caribou in northern British Columbia moved across terrain that is less energetically costly.

Chapter 4: Conclusions and Recommendations

This chapter involves three sections. The first section summarizes the results of this study with respect to the objectives set out in the beginning of the research. The second section outlines the management implications resulting from each of these results, and in the third section recommendations for future research are outlined.

4.1 Summary of Results

4.1.1 Landscape Composition Analysis

Disturbance is currently relatively low in both the Kississing-Naosap home range and the Naosap Operating Area, but has the potential to become high with further logging activities. Only 7% of the total available habitat in the Kississing-Naosap home range is composed of high quality habitat (jack pine dominated coniferous stands). In the Naosap Operating Area this habitat type accounts for about 20% of the total available habitat, however less than 3% of it is actually set aside for caribou habitat protection in leave areas. Moreover, one-fifth of the habitat set aside for caribou leave areas is actually old cut-blocks, and subsequently the animals are avoiding using a significant portion of the leave areas that are composed of this lower quality habitat.

4.1.2 Home Range Scale

In both seasons at the home range scale, caribou selected jack pine dominated stands and areas in proximity to these stands, as well as avoided water. In both seasons they also selected other preferred cover types: black spruce and proximity to treed muskeg in the snow-covered season, and treed muskeg in the snow-free season. Caribou avoided burns and cut-blocks in the snow-covered but not the snow-free season, suggesting that disturbance (i.e. logging and burns) may not influence caribou distribution as much during the snow-free season at this scale.

4.1.3 Harvest Area Scale

In both seasons, disturbance influenced caribou locations within the harvest area. They selected areas further from cut-blocks in the snow-free season and avoided cut-blocks in the snow-covered season. They also selected areas in proximity to treed muskeg at this scale. Water was avoided during the snow-covered season only.

4.1.4 Caribou Locations Within Cut-blocks and Cover

Over their entire annual range, caribou selected locations further into forest cover during both seasons. At the harvest area scale, caribou selected locations further into forest cover during both seasons, suggesting that larger leave patches are required in these disturbed areas. This also implies that parts of leave areas are being utilized in both seasons. When in cut-blocks, caribou selected locations closer to treed habitats in both seasons, also suggesting that the leave areas are of value on these disturbed landscapes.

4.1.5 Movement Path Scale

In the snow-covered season, caribou selected paths with greater visibility when moving through the harvested areas. In the snow-free season, caribou selected locations within the harvested area that had greater arboreal lichen cover, suggesting that stands associated with more arboreal lichen cover (such as mature upland habitats) were being selected. In the snow-free season caribou also selected locations farther from roads. These results imply that although the animals are responding to visibility/ease of movement parameters, they may also be avoiding disturbed parts of the landscape by choosing locations within cover at this finer scale.

4.2 Management Implications

The results of this study, and the recommendations found in the current supporting literature, have the following implications for woodland caribou and forestry management on the Kississing-Naosap range:

1) Caribou habitat use patterns were selective at all scales and across all seasons, therefore the results should be used to support decisions related to leave area delineation. By preserving habitats known to be selected by caribou, this will increase the likelihood that the leave areas will continue to meet the needs of this herd. It is recommended that leave areas be composed of a mosaic of mature jack pine, treed muskeg and spruce cover types, to ensure continued use in all seasons. Furthermore, the landscape connectivity analysis done by O'Brien et al. (2006) should be used to identify core activity areas and when delineating leave areas. Mitigation plans should be modified to specify the long-term protection of these important caribou areas.
2) Since caribou were located further into forest cover, away from logging, it is recommended that the leave area patches be at least 1 kilometer in width. This recommendation is based on habitat selection pattern, and the average and median distances of caribou into cover, calculated for their home range. Continued

monitoring is necessary to further develop this recommendation. Furthermore, if key sensitive areas such as calving, rutting, wintering, or travel corridors are delineated, this width should increase.

3) The post-harvest treatment of logging roads is an area where the management plan is lacking important mitigation objectives. Roads may increase the mortality and disturbance of caribou on this range through increased access of hunters, predators, and alternate prey, and the avoidance of roads at the fine scale by this herd may be a response to this. Therefore it is recommended that steps be taken to make in-block logging roads inaccessible post-harvest. This may be accomplished through re-planting over the road as soon as harvesting is completed (D. Cross, pers. comm., 2006). For larger roads, it is recommended that gates be used to control access, such as the case with Naosap Road (where it is recommended that gate control continue). Where there are problems with humans still accessing gated roads, an option could be to strategically place ditches across them, to prevent vehicle access. Furthermore, it is recommended that the total density of roads and trails in the operating areas be kept to a minimum, and that they avoid key sensitive areas. To ensure continued use of leave areas by caribou, it is also recommended that road-building be avoided near these areas.

4) As expected, deciduous forest cover types were avoided by the animals on this range. This type of habitat is preferred by other ungulate species like moose, so where the goal is to provide for current and future caribou habitat, it is recommended that post-harvest silviculture treatments ensure the regeneration of coniferous stands. This will ensure that moose densities will not increase in the

regenerating forest, therefore minimizing the risk of increased predation associated with increased alternate prey densities.

5) It is recommended that the objectives in the mitigation plan be followed through with, with respect to harvesting larger cut-blocks and/or minimizing multiple entries into the harvest areas if larger cut-blocks are not feasible. This will reduce the amount of time the caribou are exposed to disturbance, as well as facilitate the re-growth of forests more suited to woodland caribou.
6) It is recommended that the distribution of caribou throughout their home range and in the harvest areas be used to assist with further decision-making, with respect to future forest operations and other human developments on this range. This information will assist in filling a gap with respect to caribou distribution as outlined in the mitigation plan.

4.3 Future Research

Future research in a few main areas is needed on the Kississing-Naosap range:

1) Monitoring of the effectiveness of leave areas should continue, to ensure that these areas continue to be used by the caribou in this range, or to find out what might be preventing continued use of these areas.
2) Monitoring of roads should continue, to ensure they are being returned to a natural state.
3) As there is only limited data on calving, rutting, and key wintering areas, research on this is essential. The resulting data from a study which delineates these key

caribou habitats will greatly improve the effectiveness of the mitigation plan with respect to leave area placement and road construction.

4) It is recommended that a current population estimate be obtained for this range, as there are inconsistencies between the various current estimates. This will serve as baseline knowledge for monitoring the effects of disturbance on the Kississing-Naosap caribou range with respect to population stability or declines.
5) It is recommended that the causes of caribou mortality on this range be investigated, with particular attention to harvest estimates. The current predicted number of caribou killed by First Nations annually in this area ranges from 6-20, so this number needs to be more closely estimated. Information on annual mortality rates caused by predation, coupled with an accurate estimate of harvested caribou, will give us an idea as to the stability of the current population, and may guide future management efforts with respect to forest harvest operations on this range.

The main purpose of this research was to gain a better understanding of woodland caribou habitat use on the Kississing-Naosap range, in order to monitor the effectiveness and assist with the improvement of Tolko Industries Ltd.'s Forest Management/Woodland Caribou Mitigation Plan. This study met the objectives by quantifying the composition of the landscape in the study area, assessing use patterns of leave areas, and describing habitat use patterns across three scales and two seasons. The knowledge gained from this research can be used to improve areas of the mitigation plan that are not currently effective or are lacking, and contribute to the development of future mitigation plans for this range pre-harvest. Ultimately, the goal is to ensure the persistence of this herd into the future.

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Appendix A – Objectives from Tolko's Forest Management/Woodland Caribou Mitigation Plan.

Strategic Level Objectives

- *Harvest larger cut-blocks to provide future contiguous habitat for caribou. Larger cut-blocks will minimize multiple entries into a specific area and reduce favorable habitat conditions for moose (which may lead to increased predation on caribou).*
- *Alternatively, when conditions do not allow for large cut-blocks, the harvest strategy should minimize multiple entries into an operating area.*
- *Maintain contiguous blocks of undisturbed habitat separate from disturbed habitat to facilitate continued use by woodland caribou. Undisturbed habitat should be represented as a mosaic of habitats known to be occupied by caribou.*
- *Maintain undisturbed "corridors" of habitat which link recognized important habitats (e.g. summer and winter ranges).*
- *Development of special management prescriptions in known traditional calving and wintering areas. This may include modifications to road locations, additional buffering of these areas and restricted activity during certain seasons (e.g. harvest the timber in a summer area during the winter).*

Operational Objectives

- *Within cut-blocks maintain fringes of treed habitat adjacent to open and poorly stocked treed muskegs to facilitate movement and provide cover.*

- *Where rocky terrain is present, restrict equipment from harvesting timber on the exposed rocky areas. These are poorly stocked sites with a high lichen component which are difficult to renew.*

Where possible, and where the stand type is appropriate, emphasize natural regeneration with minimal ground disturbance to minimize the suckering of hardwoods and promote conifer and lichen regeneration.

Appendix B – Sample Field Data Collection Sheet for Winter Tracking Work

2006 Woodland Caribou Winter Movement Trail Monitoring

-Plot # ________. Date:________.

-Start Point/Plot Point (GPS Coordinates) ____________________.

-Comment on weather/cloud cover, general visibility, days since last snow, type of site, etc.____ .

-Caribou Trail followed forward or back tracked.

-Topography (flat, undulating, rough, very rough).

-Facility of Movement (easy, moderate, difficult) comments ____________________.

-Habitat Type (JP, Spruce dominated, TM, muskeg/other wetlands, mixedwood-hardwood, young coniferous, cut blocks, linear features, ice, other.

-For cut blocks/young stands, indicate the following:

-approximate age of cut.

-presence of re-growth, and

-whether re-growth appears to be plantation or natural.

-When in open habitat (cut blocks, ice, open wetlands, roads, etc.), record the approximate distance to edge of cover (3 classes: 1)on edge: 2)<25m from edge: 3)> 25m from edge.

Plot

-evidence/signs of human activity: (yes/no, if yes detailed comments).

-evidence/signs of caribou activity: (yes/no, if yes detailed comments).

-evidence/signs of predator activity: (yes/no, if yes detailed comments).

-snow depth(cm)_____,and density(cm)___________.Skagland.

-remove snow from ground, and record presence/absence of terrestrial lichen.

-canopy cover at center of quadrat (4 classes:<25%, 25-50%, 50-75%, 75-100%).

-Visually record the percent shrub cover in the plot (4 classes: <25%, 25-50%, 50-75%, 75-100%).

-Lateral visibility (4 classes:<25%, 25-50%, 50-75%, 75-100%).

Along Pathway between points, record:

-the number of other paths (merging or intersecting) encountered between plots____ .

-the number of deadfall or other obstruction encountered between plots (anything that inhibits easy movement along path is recorded as an obstruction) ________________ .

-Number of Beds _________ .

-Number of Craters_________.

COMMENTS:

Appendix C – Sample Field Data Collection Sheet for Summer Field Work

1. Date: ____________________
2. Location Code: __________________
3. Caribou path: Actual or Random
4. Random Angle ________ Random Distance __________
5. GPS Coordinates: ____

From within 2-meter diameter circular plot, determine habitat:

6. Topography: easy/moderate/rough/very rough
7. Stand Origin: Fire/Logged/Unknown
8. Habitat Type: upland, treed muskeg, muskeg/other wetlands, shrub, cut
9. Edge/other habitat types visible? Yes/No, If yes, class: 1) on edge, 2) <10 m from edge, 3) 10-50 m from edge, 4) >50 m
10. Neighboring cover type(s) (only if within 25m) _____________________
11. Lakes/Rivers Visible? Yes/No, If yes, class: 1) on water, 2) <10 m from water, 3) 10-50 m from water, 4) >50 m
12. Linear features visible? Yes/No, If yes, class: 1) on linear feature, 2) <10 m from linear, 3) 10-50 m from linear, 4) >50 m
13. Dominant tree species (visually assessed): WS-BS-TA-BA-WB-TL-JP and height________
14. Secondary tree species (visually assessed): WS-BS-TA-BA-WB-TL-JP and height ________
15. Arboreal lichen scale, 3 classes: 1) <25% 2) 25-50% 3) >50%
16. Percent canopy cover immediately overhead from plot center (visually assessed): 1) <25%, 2) 25-50%, 3) >50%
17. Lateral visibility (visually assessed at 360degrees), 3 classes: 1) <25%, 2) 25-50%, 3) >50%
18. Evidence of caribou? Yes/No Comment _______________________________
19. Evidence of other ungulates? Yes/No Comment _________________________
20. Evidence of predators? Yes/No Comment _______________________________
21. Evidence of humans? Yes/No Comment ________________________________

10-m N-S Transect through middle of plot

23. # Deadfalls tallied in each of 3 length classes: 1) < 0.5m ______________,
    2) 0.5-1.0 m ______________, 3) > 1.0 m ________________
24. Lateral Visibility at 1 m eye level, 4 classes: <25%, 25-50%, 50-75%, >75%
    Lateral Visibility at 1.5 m eye level, 4 classes: <25%, 25-50%, 50-75%, >75%

1x1- meter plot

25. % Total Shrub, 4 classes: 1) <25 %, 2) 25-505%, 3) 50-75%, 4)>75%
    Shrub Species 1: _________________%, Shrub Species 2: ___________________%,
    Shrub Species 3: _________________% (To add up to % Total)
26. % Total Herbs, 4 classes: 1) <25%, 2) 25-50%, 3) 50-75%, 4) >75%
    Herb Species 1: _________________%, Herb Species 2: __________________%
    Herb Species 3: _________________%
27. % Total Grass, 4 classes :1) <25%, 2) 25-50%, 3) 50-75%, 4) >75%
    Grass Species 1: _________________%, Grass Species 2: __________________%
    Grass Species 3: _________________%

28. % Total Moss, 4 classes :1) <25%, 2) 25-50%, 3) 50-75%, 4) >75%
    Moss Species 1: ________________%, Moss Species 2: _________________%
    Moss Species 3: ________________%

0.5x0.5-m Lichen Plot

29. Cladina Height (cm) Pin 1___Pin 2___Pin3___Pin4___Pin5___Pin6___Pin7___
    Pin 8___Pin 9___Pin10___Pin11___Pin12___Pin13___Pin14___Pin15___Pin16__
30. Cladina Percent Cover (based on how many pins fall on lichen) _____________%

The End