EFFECTS OF ROADS AND LOG HAULING ON WOODLAND CARIBOU USE OF A TRADITIONAL WINTERING AREA NEAR ARMSTRONG, ONTARIO

by

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ABSTRACT

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Key Words: disturbance, grey wolf, habitat partitioning, log hauling, moose, noise, predation, woodland caribou.

Increasing concern for the viability of forest-dwelling woodland caribou (*Rangifer tarandus caribou*) in Ontario has resulted in recommendations for more restrictive timber harvesting practices. Caribou populations have steadily retreated northward except for small remnant populations. While there is much agreement that the fundamental cause of the decline is timber management, there is much less agreement on the proximate causes. Debate has focussed upon three causal hypotheses: 1) habitat degradation or change; 2) predation; and 3) displacement or stress by human activities in critical habitats such as wintering or calving areas.

A three-year field experiment (fall 1990-spring 1993) tested the third hypothesis and showed that woodland caribou significantly altered their winter dispersion when log trucks drove through their traditional wintering area. All radio-collared caribou that occupied the experimental area moved 8-60 km after log hauling began. Track counts indicated that most caribou moved 3-60 km away from the road after it was plowed and hauling commenced, often into range that had fewer lichens and more predators than winter refugia. In a nearby undisturbed control area, no such movements occurred.

The Wabinosh Road prime study area bisects a traditional wintering area of open-stocked mature jack pine (*Pinus banksiana* Lamb.) and black spruce (*Picea mariana* (Mill.) B.S.P.) with lichen (*Cladina spp.*) ground cover. Caribou presence and movements were monitored by fixed-wing aircraft using both high-level telemetry and low-level transects recording tracks.

Pronounced habitat partitioning between moose (*Alces alces*) and caribou excluded moose from the caribou wintering area. Grey wolf (*Canis lupus*) tracks were frequently associated with the moose tracks, but rarely near caribou tracks. No wolf predation on caribou was observed within the winter refugia; three kills were found outside them. Wolf predation was almost exclusively upon moose, frequently utilizing roads and human trails to access them.

Due to the possibility of displacing caribou from winter refugia to places with higher predation risk, winter log hauling through caribou winter habitat should be avoided wherever possible.

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I) INTRODUCTION

During the last century there has been a huge, albeit unintentional, experiment conducted in northwestern Ontario northward from Lake Superior to the present northern limits of roads and timber harvesting. That experiment, had anyone chosen to think of it as such around the turn of the century, might have been described this way: "What will be the effect upon woodland caribou populations in northwestern Ontario if we start near Lake Superior and gradually harvest trees further and further north? We will build roads, convert many conifer stands to hardwood and mixedwood stands, increase fire frequency in some areas, decrease fire frequency in others. We will begin with horse logging and winter roads, change in the 1950's to skidders and all-season roads, convert further to larger harvesting machines and even higher grade roads in the 1970's, 1980's and 1990's, and all through the century increase the size of the clearcuts. Every twenty years we will try to double the rate of harvest until the end of the century, when we will be approaching the limits of sustained harvest yields."

The results of that unstated experiment upon caribou seem to be clear to the majority of scientists and natural resource managers who have pondered it. There has been little refutation of (and a growing consensus on) the belief that forest harvesting practices, their associated activities, and their effects upon forest composition have had a deleterious effect upon woodland caribou. That there is virtually total inverse correlation between forest management activities and caribou does not seem to be contentious. What is roundly and hotly debated is what mechanism or mechanisms are responsible for these profound adverse effects. Further, if we can identify them and agree upon such causes, can we devise ways to change them or compensate for them in some way such that timber management and caribou can be compatible? Some researchers believe that timber management can be modified in order to become compatible with woodland caribou; others believe that caribou will survive only in the absence of roads and harvesting. Many researchers, managers, and the concerned public are undecided. Before prescriptions for change (or remediation or even restoration) can be applied, we must be reasonably certain about both the fundamental and proximate causes of woodland caribou decline in Ontario and beyond.

There seem to be a few main hypotheses about why timber management activities have caused a decline. Three of the most frequently espoused categories of hypotheses include:

1) **direct habitat effects** (e.g. loss of mature and overmature conifers and associated lichens), causing the caribou to emigrate or die, due to nutritional factors (Cumming and Beange 1987, Cumming 1992);

2) indirect habitat effects (decreases in stand ages and increases in hardwoods), resulting in increases in moose biomass, further resulting in **increases in wolf densities** leading to unsustainable predation upon caribou (Bergerud 1974); and

3) **direct disturbance effects** by timber management or other human activities, causing caribou to emigrate, perhaps into adjacent areas with poorer food supplies, or increased risk of predation, or both.

In 1990, Buchanan Forest Products Ltd. (BFPL) made a request to plow the Wabinosh Road southeast of Armstrong, Ontario; its wish was to haul wood during the winter of 1990-1991. The request was at first denied, as the road bisects an area of important traditional winter habitat for woodland caribou in the region. The request was eventually granted, but tied to a condition set by the Ontario Ministry of Natural Resources (OMNR). OMNR required that an intensive experiment be conducted to determine what effects upon the caribou would result from plowing and log hauling on the Wabinosh Road. Such a study would add significantly to current limited knowledge of the effects of direct mechanical disturbance upon woodland caribou. A research partnership was formed in the fall of 1990 between Lakehead University (Dr. H. Cumming, Professor of Forestry), OMNR (M. Millar, Acting Regional Director, North Central Region), and BFPL (G. Swant, Chief Forester). A steering committee and academic advisory committee were set up, and I was asked to execute the project.

The major goal of the three-year partnership, as suggested by the partners, was to try to answer the following primary question:

What is the direct and immediate effect of road plowing, truck traffic, and log hauling on use by caribou of their traditional wintering area located to the east of Armstrong, south of the Pikitigushi Road and the airport, and adjacent (east and west) to the Wabinosh Road?

II) THE PROBLEM: THE CONTEXT FOR THE ARMSTRONG SITUATION

There is increasing concern for the viability of remnant woodland caribou (*Rangifer tarandus caribou* Gmelin) along the southern limit of their current distribution in the boreal forest. Literature cited here describes research which may have implications for the Armstrong situation, where the increase and encroachment of human activities and the attendant management actions may affect the viability or behaviour of woodland caribou.

The northward progression of the southern limit of continuous caribou distribution over the last century suggests that some human activities (e.g. building railroads, changes in fire frequency and distribution, land clearing for settlement, building towns, cities, and roads, timber harvesting) might be affecting caribou adversely.

Cumming and Beange (1993) showed that caribou cease using cut areas for many years, and that in five documented cases the common factor in disappearance of local caribou bands was timber harvesting. Although their results do not constitute proof, they suggest timber harvesting as the most likely cause of caribou decline. Specific mechanisms of decline remain contentious. Recently, bold proposals and draft policies have been proposed (and even begun to be implemented) in northwestern Ontario regarding cutting patterns and practices, in the hope that the decline of caribou can be halted or slowed (OMNR 1991, 1994). Draft Caribou Guidelines (OMNR 1994) have been contentious, with some detractors finding the proposals simplistic and highly experimental (e.g. Geraldton LCC 1995, Cumming 1996). Nonetheless, some wildlife managers feel it to be imperative that a policy be implemented even if imperfect and without certainty of success, given that the previous lack of a caribou management plan has constituted a far larger experiment, albeit unintentional. Furthermore, in many areas of northwestern Ontario, timber harvesting is proceeding in occupied caribou range in the absence of a policy (Armstrong pers. comm. 1995).

Over the past hundred years, the distributions of northwestern Ontario caribou populations have shifted dramatically, and their populations have declined northwards (Fig. 1). Concern for this reduced range has been expressed (DeVos and Peterson 1951, Cringan 1957, Darby *et al.* 1989, Racey *et al.* 1992, Cumming and Beange 1993). Some small remnant populations persist, mainly along the north shore of Lake Superior (Godwin 1990). Several key factors have been cited by Godwin to have resulted in population declines in the boreal forests north of Lake Superior. Since Cringan's (1957) paper, timber harvesting has been suspected as a likely cause, but evidence was lacking. Increasingly, recommendations have been made for restrictions on timber harvesting practices, as logging activities penetrate caribou range (Freddy 1979, Bloomfield 1980, Ritcey 1988). Loss of mature forest habitat, increased hunting and human disturbance, and increased predation related to

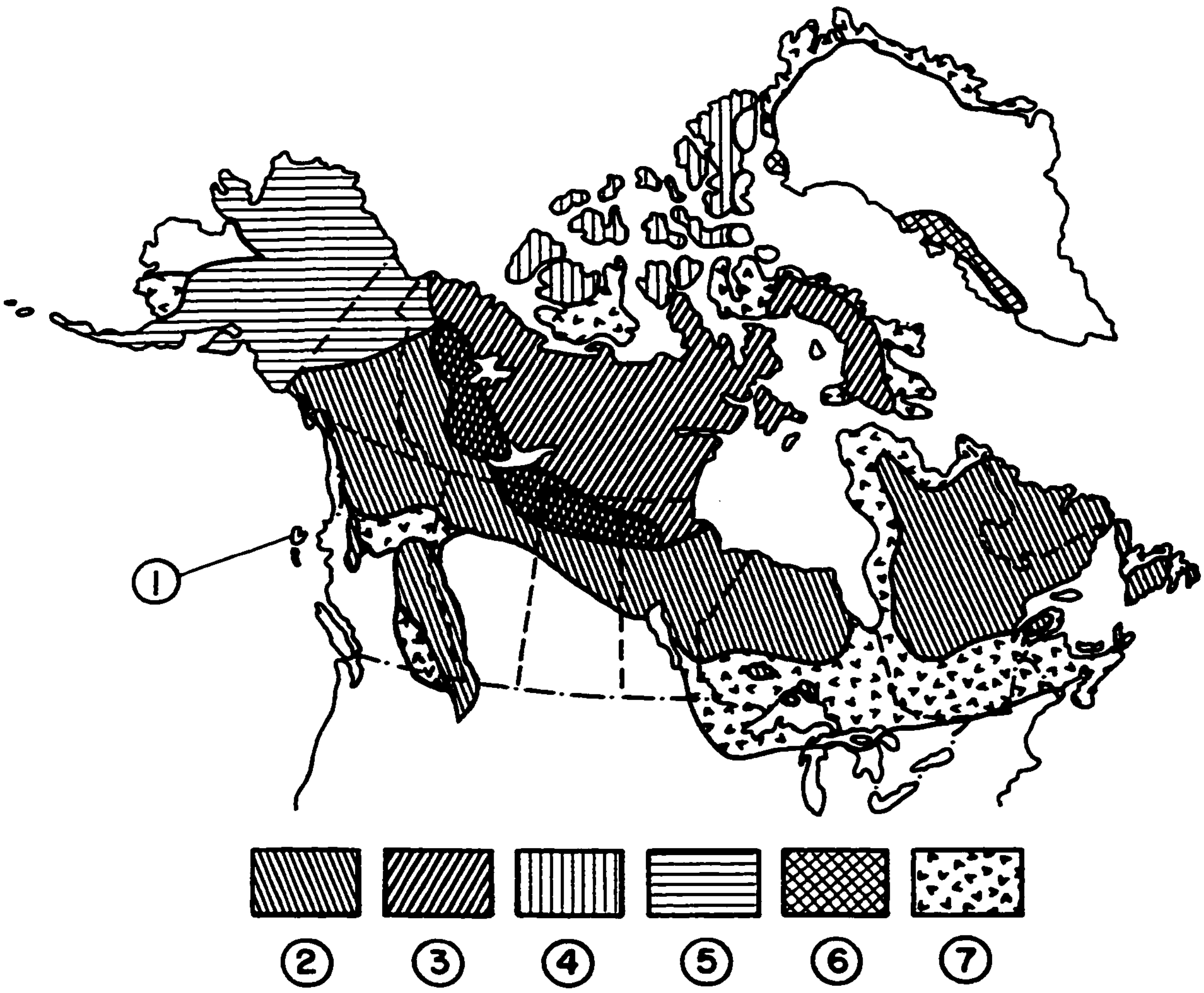


Fig. 1. Past and present distribution of caribou in North America: 1. *Rangifer tarandus dawsoni* (extinct); 2. *R. t. Caribou;* 3. *R. t. Greonlandicus;* 4. *R. t. Pearyi;* 5. *R. t. Granti;* 6. *R. t. Eogreonlandicus;* and 7. Former range. (*In:* Bergerud 1978).

habitat changes have been suggested as possible causes (Darby *et al.* 1989). All of these factors may be created or increased by logging activity. My interviews and discussions with many caribou scientists and wildlife managers suggest that a consensus is emerging that the fundamental cause of woodland caribou decline in Ontario is associated with timber harvesting and/or road access. There is less agreement, and far more debate, as to what the intermediate and proximate causes may be.

Leopold (1933) described two kinds of factors that could affect wildlife populations: welfare factors and mortality factors. The former are habitat attributes that provide opportunities for the animals to exploit (e.g. food, cover); the latter are factors such as predation, disease and emigration. The total of the mortality factors must be kept below the reproductive rate for the population to sustain itself. This balance is particularly critical for caribou, that have a low reproductive rate, usually do not twin, and whose cows do not conceive until 2.5 or 3.5 years of age (Bergerud 1978). Reasons for widespread caribou declines have traditionally been assigned to one or more of these welfare or mortality factors.

One view has been that the main factors involve habitat degradation or change (e.g. Edwards 1954, Scotter 1972, Klein 1982, Van Ballenberghe 1985). Another is that predation is the main factor (e.g. Ahti and Hepburn 1967, Bergerud 1974, Gauthier and Theberge 1986, Edmonds 1988, Elliot 1989, Hayes *et al.* 1989, Seip 1990).

Cumming (1992) suggested that both factors might be important, with one or the other coming into prominence under certain circumstances, or at a given time. Predation may be involved in many instances, but it may be paramount only in a proximate sense. Human disturbances, or habitat changes caused by fire or timber harvesting, may force caribou into habitats or situations where predation is increased. Also, roads associated with logging are thought to increase poaching access and facilitate access by wolves (Bergerud *et al.* 1984, Darby and Duquette 1986).

According to Cumming (1992), caribou and their habitat should be managed so as to maintain winter ranges with abundant lichen supplies, preserve calving refuges and travel corridors, reduce predation within winter and summer calving areas, and minimize or eliminate human disturbance wherever possible. Key mortality factors, in increasing order of significance, have been suggested to include parasites and diseases, accidents, hunting, and predation (Bergerud and Elliot 1986, Darby *et al.* 1989, Cumming pers. comm. 1990). Brousseau (1978) suggested that logging disturbance in the Cliff Lake area of northwestern Ontario (near Dryden) caused caribou to abandon their range, even when the majority of it remained uncut.

III) THE ARMSTRONG EXPERIMENT

Without disputing the validity of either or both of the "habitat change" or "predation" theories in certain situations, I author sought to explore further Brousseau's contention: that severe or chronic disturbance (by sounds, sights, or scents of human or mechanized activities) to woodland caribou, an animal that depends heavily on predator avoidance, can cause range reduction or population decline. Could it be that when caribou occupy traditional winter habitats, they are highly sensitive to predation, or the perceived risk of predation? Could they be sensitive to sounds that are unfamiliar, or that might mask the sounds of predators? Might they abandon, temporarily or permanently, otherwise suitable habitat if stressed acutely or chronically by noise or other stimuli (e.g. sight, smell) that may put them on "predator alert"? Might they be forced into inferior habitats with increased metabolic demand, decreased quality or quantity of food, or increased susceptibility to predation?

I attempted to answer these questions by testing the following hypotheses on the population of woodland caribou that have traditionally utilized the specific winter habitat south of the Armstrong airport.

HYPOTHESES:

Research Hypothesis: Truck traffic involved in transporting wood through a traditional woodland caribou wintering area will cause caribou to shift, or otherwise to modify their winter movements or activities in a measurable way.

Null Hypothesis #1: Woodland caribou will continue to use a traditional wintering area during the months of January to March despite log hauling and associated human activities. Their movements and activities will not change measurably.

Null Hypothesis #2: Caribou may move coincident with hauling activities, but those movements are due to other identifiable factors not directly associated with the timber hauling.

Primary Research Objective: Determine the effects of timber hauling, and associated human activities, on caribou use of traditional wintering areas south and east of the Armstrong airport.

IV) HISTORY OF CARIBOU IN THE LAKE NIPIGON-ARMSTRONG AREA

RETREAT OF CARIBOU NORTHWARD TO THE ARMSTRONG-LAKE NIPIGON AREA

In the early and mid-1800's, woodland caribou resided in Maine, northern Vermont, New Hampshire, the Great Lake States north of 45-46 degree N latitude, and throughout Atlantic Canada (Seton 1909, Banfield 1961) (Fig. 1). Herds disappeared from Vermont during 1830-1839, Wisconsin 1840-1849, New Hampshire 1860-1869, Maine 1906-1914, mainland Michigan 1900-1910, Nova Scotia 1905-1912, New Brunswick 1927, and Isle Royale, Michigan 1920-1930 (Bergerud and Mercer 1989). Woodland caribou range once extended well into Minnesota (Darby and Duquette 1986), and the last large numbers of them there were reported in the northeast in the 1890's (Heinselman 1996). After 1850, moose and later white-tailed deer (*Odocoileus virginianus*) expanded their range northward and caribou populations declined. One factor associated with the decline was an increase in the biomass of the prey populations which allowed the wolf population to expand (Simkin 1965, Bergerud 1974, Darby *et al.* 1989).

The northern advance of white-tailed deer was especially serious because not only do deer live at higher densities than moose and caribou, which greatly augments wolf numbers, but they also transmit a fatal disease caused by *Paralaphestrongylus tenuis* (Anderson 1972) to caribou. In North America, there are no reported examples of caribou coexisting with a high density of eastern white-tailed deer. Nor have any caribou reintroductions succeeded where deer are present (Bergerud *et al.* 1984).

Caribou were observed by fur traders from Old Fort William. For example, Hind (1857) recorded "cariboos" among animals found along the banks of the Kaministiquia River. A Fort William Report (1824) stated that both moose and caribou were declining locally from hunting pressure, along with a similar decline in caribou numbers on Isle Royale. Earlier reports (Dobbs 1744) reported "elk" (caribou?) and "wild asses" (moose?) along the river.

Caribou were found in Thunder Bay environs until the turn of the century. A particularly large bull was reported in the Port Arthur "Sentinel" in March of 1886 (Ekholm 1972). J. Cross reported an estimated 500 caribou inhabiting the Sibley Peninsula in the 1920's, with a single herd of 59 observed on Pickerel Lake in what is now Sleeping Giant Provincial Park. He reported that they routinely crossed to the Black Bay Peninsula and Isle Royale (Ekholm 1972). Caribou hunting was outlawed in the all of Ontario in 1929, yet despite this hunting ban, caribou continued to dwindle rapidly. Caribou sightings were made close to Thunder Bay, including at the Black Bay Peninsula and the Dog Lake area north of the city, until the early 1950's (Fig. 2). Cumming and Beange (1993) stated that caribou were observed in Sibley Park (now Sleeping Giant Provincial Park) until 1970.

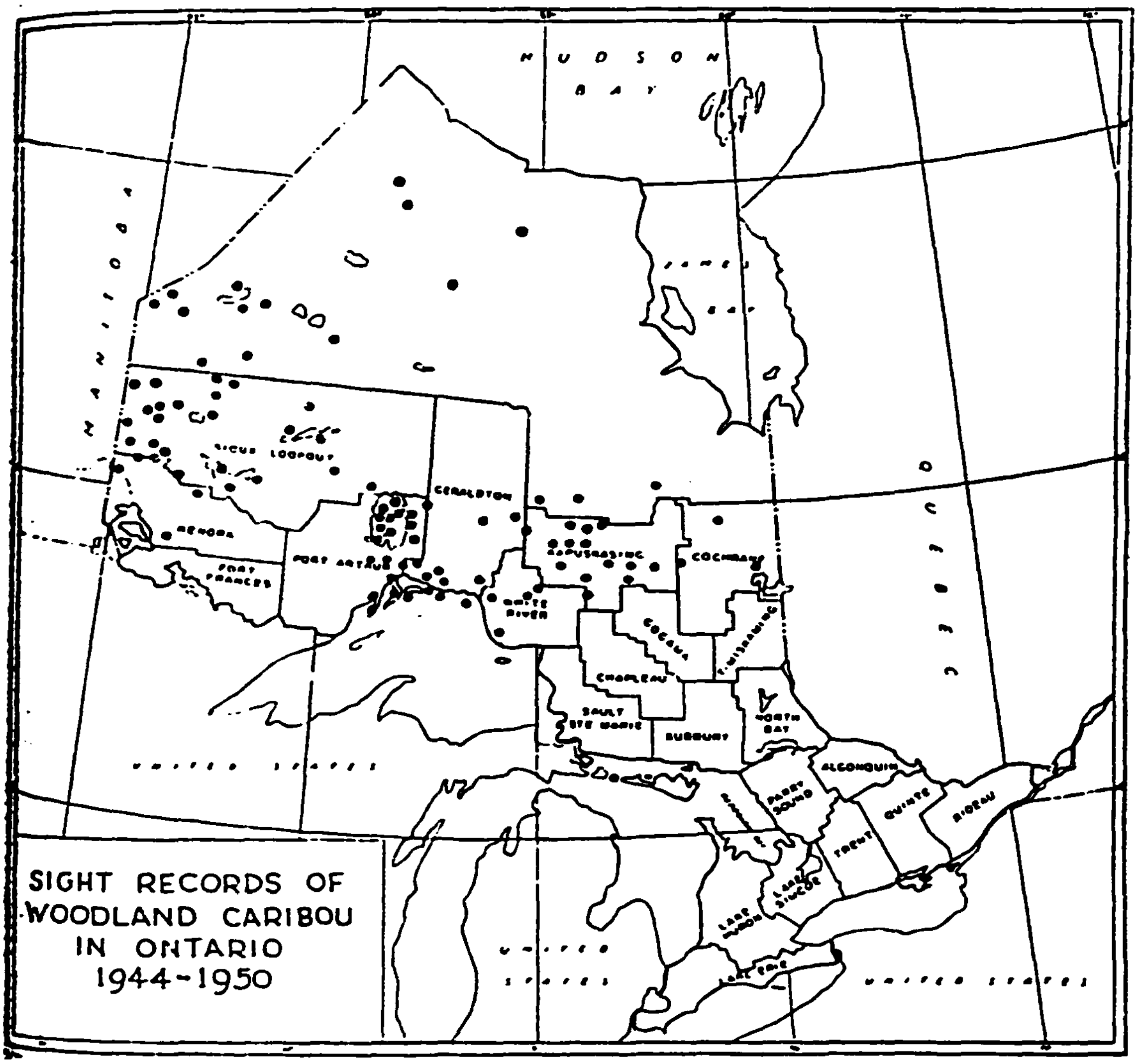


Fig. 2. Sight records of woodland caribou in Ontario, 1944-1950 (*In* DeVos and Peterson 1951).

THE ARMSTRONG AIRPORT SITUATION

For many decades (at least since the mid-1940's when the airfield was built as an emergency landing location for aircraft flying across Canada), Armstrong residents and OMNR personnel have been aware of the winter presence of woodland caribou in the jack pine sand flats south of the Armstrong airport, a few kilometres east of town (Bergerud and Butler 1975, Cumming and Beange 1987, Beange and Timmermann, pers. comm. 1990). Timmermann (1967) reported and mapped a group of 23 animals in March 1967 in a stand of jack pine (90% Pj 40-50', 10% Bw, with lichen understory) on sand flats south of the Armstrong airport. Monk (1967) reported the poaching of a caribou in the same year, southeast of the Armstrong airport. The airport was improved by the U.S. military in the 1950's as a part of the 'Pinetree Line'. Since the military base was closed in the early 1970's there has been no regular air service. Current airport use is minimal in any season, particularly in the winter months (usually less than one flight per week) although the east-west runway is plowed by the Ministry of Transportation of Ontario (Nicholl pers. comm. 1991).

In 1972, an OMNR Sensitive Areas Report identified the habitat south of the airport as important winter habitat, and urged that it "be protected from...recreational use, resource production, and transportation and communications alignments..." (OMNR Nipigon District 1972). Contrary to that recommendation, and over the objections of the regional biologist, a 100' right of way was cut 10 miles southward from the airport along the present Wabinosh Road alignment in 1975. The Nipigon District Forester assured the biologists that "logging would take place at least 5 miles south of the airport". An accompanying map identified the habitat as extending westward to Randolph Lake, north to the airport, 0.5 km east of the Wabinosh Road, and southward from the airport (Elsey, 1975).

In June 1975, the District Manager of OMNR approved timber harvesting in the southern half of the valley sand flats thought to be utilized by caribou in winter. Conditions placed upon the timber company included harvesting in summer and rendering secondary and tertiary roads impassable to prevent free access to the cut areas. Moreover, it was stipulated that "strips or patches will be left standing, basically for site protection, but they may also prove beneficial to the caribou." A low-quality timber access road called the Wabinosh Road had been previously constructed by Hammermill Timber in the late 1940's or early 1950's, running south from the airport toward Wabinosh Lake (Timmermann pers. comm. 1990, quoting Hagan pers. comm. ca. 1970). In 1975, the road was significantly upgraded, through the wintering habitat (Elsey 1975), and approximately half (the southern half) of the winter caribou range was cut. In response to the biologists' concerns that road construction or other sources of disturbance might have caused the caribou to leave the area, the District Manager stated that "if the caribou do not return, Domtar would be permitted to cut the rest of the area" (Koistinen 1975). The stands in question were still standing in 1990, many of which constitute a key portion of this study area. Also in 1975, Bergerud and Butler (1975) investigated and documented caribou winter use near the airport, as well as travel corridors to and from Lake Nipigon.

In the period 1976-1981, Cumming and Beange (1987) used a variety of methods, including "driving" islands, tagging captures, radio telemetry, lichen browse surveys, pellet counts and aerial track surveys, to study the dispersion and movements of caribou in the Armstrong - Lake Nipigon area. They documented that at least some animals of the wintering Armstrong herd utilize islands on Lake Nipigon for calving, and that this wintering range was the most consistent of all used by the Nipigon Islands caribou. In a similar way, animals that summered on Lake Nipigon wintered near Humboldt Bay, northeast of Lake Nipigon. Cumming and Beange (1987) showed that nearly 100 of more than 200 estimated woodland caribou in the 32,000 km^2 study area lived from April to December on islands in Lake Nipigon. During autumn, caribou moved from summer locations, but remained on islands until after ice formation. In spring, they returned to the islands before ice breakup. Migration routes averaged 46 km, but the exact travel corridors were indistinct at that time. All caribou aggregated in large, traditional wintering areas or small, temporary ones similar to the "yards" of white-tailed deer.

Bergerud *et al.* (1990) reported that each spring from 1975 to 1985, caribou migrated in April to the islands in Lake Nipigon where they remained for the summer. Bergerud *et al.* (1990) tested three hypotheses for this migration: 1) to reduce insect harassment, 2) to seek more abundant or nutritious forage, or 3) to reduce predation risk. They found that the food and insect relief hypotheses were neither necessary nor sufficient explanations for these migrations. Caribou used the shoreline of the islands even in the absence of insects. There was less green forage on the islands than on the winter range and the smaller islands were very overgrazed. Bergerud *et al.* (1990) found that the dispersed nature of the population, the use of shorelines suitable for escape, and the avoidance of islands travelled by wolves suggest that the migration of this herd was a spacing tactic used to reduce predation risk during calving.

In 1979, another potential conflict arose with a proposed Indian Reserve in the Wagaming station area, just east of the airport. The Parks Branch of OMNR, quoting Bergerud's (1975) study, identified the proposed reserve area as "a location for winter feeding, and also as a travel corridor between the Armstrong area and Lake Nipigon" (Fawcett, 1979). Also in 1979, Great West Timber applied to harvest timber in the Whitesand River area, southeast of the airport. The Nipigon District Wildlife Management Officer refused to approve this request, citing reasons that included 1975 and 1976 documentations of wintering use and migrations to and from summer range on Lake Nipigon (Beange 1979). Bergerud and Butler (1975) counted up to 47 caribou using the habitat in winter within 2 km of the (unplowed) Wabinosh Road.

Schraeder (1982) completed a literature review for the OMNR Nipigon District on the effects of logging on woodland caribou. The review was done from the perspective of possible factors relevant to the Armstrong situation. Schraeder's report included the following conclusions and observations:

- Local population declines have usually been attributed to disturbance of climax forests by logging and fire and subsequent increases in predation and disease.
- Habitat manipulations which favour moose and deer are detrimental to caribou.
- Woodland caribou winter ranges may be determined by the extent of terrestrial lichens.
- Disturbances on winter ranges will cause the animals to vacate.
- Commercial timber extraction does not permit lichen regeneration.
- Caribou should not be confined to relatively small tracts of isolated habitat. The protection of the lichen stands determining the Armstrong range and the travel corridors to Lake Nipigon is tantamount to preserving the caribou herd.
- The access afforded by haul roads will lead to an increase in harassment and poaching of caribou.
- Recent destruction of caribou range in the Dryden District was attributed to logging. The 40-60 animals which traditionally utilized the Cliff Lake area there have disappeared.

In 1989, caribou winter habitat in the airport area was reviewed (Timmermann 1989) and a map developed that identified "Core Area: Prime Winter Woodland Caribou Habitat, Armstrong Airport", extending several kilometres either side of the Wabinosh Road, and south of the CNR mainline. The Armstrong winter range (180 km^2) was estimated to be comprised of 35% mature and overmature conifer (> 80 years), 26% conifer (mainly immature jack pine 40-79 years), 11% deciduous forest, 17% mixed forest, 7% muskeg and open land, and 4% water (Darby *et al.*, 1989). From 1974 to 1985, the several contiguous clearcuts that occurred in mature and overmature conifers in the winter range totalled ca 1,140 ha. Caribou have not been known to use those areas since cutting, but have continued to use adjacent uncut winter range (Cumming and Beange 1993). The winter core habitat all lies within an area classified as lacustrine sands with associated sand dunes (Zoltai 1965).

In the fall of 1989, the OMNR received a request from BFPL to haul timber that had been cut at the southern terminus of the Wabinosh Road through caribou winter habitat south of the airport. After an initial position that such hauling would not be allowed in the winter, OMNR modified that position after the company pointed out that there was insufficient evidence to support the OMNR contention that disturbance in the form of plowing and log hauling would cause significant adverse effects on the caribou. The company stated that "we see a need to collect practical data and information on the impact of consumptive uses in the caribou winter range" (Swant 1989). After considerable debate, OMNR decided to allow hauling in December and February, subject to specific conditions. The company also retained a contract biologist to conduct some monitoring of effects upon the caribou in the area (Jackson 1990). According to his report, it appeared that the caribou "began moving out of the area in mid-December while the road was being used by logging trucks". Jackson's 15-day survey (February 13-27, 1990) involved three days of aerial reconnaissance, along with ground track surveys by truck along the Wabinosh and Pikitigushi roads. Among the findings in Jackson's (1990) survey were:

- "it appeared during the aerial surveys that the local moose population has increased...particularly in the logged areas west and south" of the caribou winter range., but that "areas of moose activity and caribou showed little overlap"....,
- the few caribou remaining in the area crossed the roads (Wabinosh and Pikitigushi) at right angles, and did not linger or feed near the roads,
- "moving (by caribou to new wintering areas) could mean increases in mortality over past years"...., and
- "it is obvious that the management of the Armstrong herd must occur over a larger area" than just the Wabinosh Road environs.

Jackson's maps of the aerial surveys showed use by caribou of several square kilometres of previously undocumented winter habitat between Jojo Lake and Whitesand Lake.

In the winter of 1989-90, OMNR staff observed "many more caribou among the islands than usual" (i.e. they returned early that year). Some caribou kills by wolves were noted by OMNR staff that winter on the ice of Lake Nipigon, among the islands used as summer calving habitat (Beange pers. comm. 1990).

When the company reapplied to continue hauling in the following year, the decision was made to allow winter hauling through the caribou winter range, but only if a more rigorous experiment was designed and executed (i.e. this study).

V) WOODLAND CARIBOU IN ONTARIO AND BEYOND

Woodland caribou is the only ungulate species in Ontario adapted to an open taiga or tundra biome, a habitat that represents more than 30% of Ontario's 1.1 million km^2. Settlement and development caused a general northerly recession of caribou range, except for a few isolated and dispersed remnant populations (Simkin 1965). At one time, the extinction of the species in Ontario was feared (Peterson 1956), but with improved and more extensive inventories, population estimates have increased from 3,000 in the late 1940's (DeVos and Peterson 1951), to 7,200 in 1954 (Cringan 1957), to an estimated 13,000 (Simkin 1965), and to the current provincial estimate of 15,000 (Darby *et al.* 1989). Cumming (1996) reported that most of these "woodland" genotypes are found north of the commercial forests, with many spending much of their year on the Hudson Bay lowlands. However, only an estimated 1800 caribou in Ontario living within the commercially licensed forest areas. With their adaptation to the boreal forest that evolved after the last glacial period, caribou were apparently the dominant cervid in northern Ontario until human activities caused moose and deer to be favoured (DeVos and Peterson 1951, McNicol and Timmermann 1981). Unfortunately, as we try to unravel the mysteries of their decline, woodland caribou remain a contentious enigma, in part because "little behavioural information is available on closed habitat or boreal forest forms, partially due to the difficulty of direct observation" (Shoesmith and Storey 1977).

ASSOCIATED FACTORS

Forest access roads

Construction and use of forest access roads through caribou winter range may displace populations directly or indirectly (e.g. through human presence or activities), into less preferred habitat. In addition to noise and traffic, roads lead to increases in hunting (Stevenson and Hatler 1985). Bergerud *et al.* (1984) studied the demography, movement, and behaviour patterns of several caribou populations (Kaminuriak, Nelchina, Central Arctic, Forty Porcupine, British Columbia, Newfoundland, and Snohetta) exposed to industrial activities or transportation corridors. They stated that:

> there is evidence that disturbance activities or habitat alteration have affected productivity... transportation corridors have adversely affected caribou numbers by facilitating access by hunters. Caribou must not be prevented from crossing transportation corridors by the construction of physical barriers, by firing lines created by hunting activity along a corridor, or by intense harassment - a loss in usable space ultimately resulting in reduced abundance.

Darby and Duquette (1986) felt that expansion of logging and roads in Ontario's boreal forest will require mitigation of effects on woodland caribou. They reviewed initial results from three examples of caribou-forestry interaction. In two studies, caribou were apparently displaced from portions of their winter range by logging. In a third, caribou disappeared when exposed to logging in a portion (approximately the central third) of their winter range, along with increased deer density and a probable increase in predation. They suggested that:

> in all cases there is no evidence of human harvest. The literature plus experience in Ontario suggest the following mitigative techniques: (1) protection of winter concentration areas, significant calving areas and traditional migration routes from logging; (2) directing timber harvest to forest stands of least value to caribou; (3) restricting disturbance to one large clearcut in a peripheral portion of range rather than dispersing disturbance over a large portion using several small clearcuts; (4) modified site preparation and regeneration, and; (5) restricted road access.

Darby and Duquette (1986) also stated that "research is required on the effect of forestry on caribou with and without mitigation, and on causes for effects observed".

Several other actual or potential confounding factors might explain caribou movements near the Wabinosh Road. These factors include the following:

Caribou vs. Moose

Moose are thought to be incompatible with caribou because increased moose densities may lead to increased population densities of wolves, which may in turn prey on caribou at increased rates (Bergerud 1983, 1984, 1986, 1987, 1988, 1989, 1990; Seip 1989, 1990, 1992). Recently, the OMNR built upon Bergerud's theories in formulating draft caribou management guidelines. Through a mosaic of large even-aged harvest areas, it is hoped that two main goals may be furthered: 1) to create or recreate suitable future caribou range containing all elements of caribou habitat including terrestrial lichens; and 2) by minimizing edge, to prevent increases in moose and wolf densities that have previously followed timber harvesting (Racey *et al.*

1990, OMNR 1994).

Forest Fires and Timber Harvest

Mature and overmature conifer stands which have extensive lichen understories formed over time under partially open canopies provide critical areas of winter habitat (Godwin 1990). If those stands are set back by fire or harvesting, they are lost to caribou for use as important winter habitat for many decades (Ahti and Hepburn 1967). Also, timber harvest often leads to the proliferation of woody browse, resulting in increases in moose populations. Increased wolf populations follow increased moose populations, which may then increase predatory pressures on caribou. Caribou have low reproductive rates, so the population may not be able to withstand such increased predation (Darby and Duquette 1986). A good deal of timber harvest has occurred over the last several decades in the study area, but some mature and overmature conifer/lichen stands remain (Timmermann 1990, Antoniak 1993).

Hunting

Hunting by Aboriginal people is not regulated presently, and may exceed the reproductive rate of some caribou herds (Simkin 1965, Hamilton 1978, Timmermann pers. comm. 1990). Some native communities prefer to eat moose, but in other communities, caribou are preferred. Consequently, some caribou harvests can be quite high, particularly for communities in the Hudson Bay lowlands. Modern use of snowmobiles and high-powered rifles and telescopic sights has produced higher hunting success rates, particularly against a species which herds and sometimes collects or travels in open areas, such as frozen lakes and streams. For example, in December of 1996, approximately 500 caribou were taken by the community of Peawanuck (formerly Winisk), apparently exceeding the ability of the residents to consume them. A First Nation leader was quoted as saying that while the elders are embarrassed by the incident, that it is not the first time that it has happened. In the spring of many years, uneaten caribou carcasses have been found in the local dump, due to excessive harvests by younger hunters in the community (Chronicle-Journal 1996, CBQ Radio 1996). To keep this in perspective, these animals are in an area (Hudson Bay lowlands) where caribou densities are considerably higher than at the southern edge of caribou range. Further, while these animals are of a woodland caribou genotype, they are not a "forest-dwelling ecotype" as described by Mallory (pers. comm. 1997).

Predators

Several Ontario researchers have noted that woodland caribou populations and range have continued to decline, despite the closure of legal hunting by non-natives in 1929 (Devos and Peterson 1951, Cringan 1957). Simkin (1965) felt that there was an immigration or increase in moose about 1900, resulting in an increase in ungulate biomass, and a subsequent increase in predator densities.

There is a significant schism in the scientific community concerning the role of predators in controlling or suppressing ungulate populations. Bergerud (1974, 1985) and others have put forth compelling arguments for the role of wolves (and also bears (*Ursus americanus)* and lynx (*Lynx rufus*) not only as proximate controlling factors, but also as fundamental controlling factors. Bergerud (1974, 1980) suggested that predation can maintain caribou densities at levels of 0.4-0.8/km^2, which is sometimes well below the theoretical stocking levels based upon food availability. Bergerud (1992) later reduced the woodland caribou density figure downward to 0.04/km^2 (1992), because he felt that below this level woodland caribou are too rare (resulting in high searching times for predators) or too low in biomass to support a predator population, unless the predators are supported primarily by another major food source.

Mech (1970) offered a related concept in predator/prey ratios, theorizing that when ungulate biomass is under 11,000 kg/wolf, predation is the major factor in determining populations. However, above that ratio, wolf predation can not keep up with reproduction. Messier (1988, 1995) felt that the population cycles of caribou living on barren grounds are due to inadequate predation of a species whose numbers in certain situations can increase faster than their lichen forage base. Predator/prey ratios can and do change over time: on Isle Royale; Peterson (1978) found that the ratio of wolves:moose increased from 1:80 in 1969 to 1:20 in 1976, with moose numbers decreasing as wolves increased. However, Peterson warned readers about assumptions regarding cause and effect, as he believed that predators benefit from a declining moose herd with aging and unhealthy moose, caused by an overbrowsed or otherwise declining forage base.

A number of other studies have supported the contention that predation can play an important role in suppressing caribou populations (e.g. Edmonds 1988; Elliot 1989; Gauthier and Theberge 1986; Hayes *et al.* 1989; Seip 1989, 1992). Seip (1992) found that mountain-dwelling woodland caribou that separated themselves from wolves by migrating to high mountain pastures had low calf mortality and thus had calf recruitment adequate to maintain populations or to y increase populations slowly. In contrast, caribou that did not spatially separate themselves from moose and wolves had low recruitment. Throughout the year, wolves and moose used similar areas and habitats, and moose were the primary prey of wolves. In winter most caribou used high-elevation habitats and were spatially separated from wolves and moose living in valley bottoms. In summer, caribou, wolves, and moose at Quesnel Lake, B.C. used similar areas and habitats, whereas in Wells Gray Park most caribou migrated to rugged, mountainous areas, which kept them spatially separated from wolves and moose. The Quesnel Lake caribou population had a high adult mortality rate (29%/year), wolf predation being the major cause according to Seip (1990). Calf survival to October was low (2.5/100 adult females) when wolves were present and uncontrolled in the area, but was significantly greater (30/100 adult females) when wolves were reduced or absent. The Quesnel Lake caribou population was found to be declining by about 25%/ year, and wolf predation appeared to be the major limiting factor. However, caribou in Wells Gray Park had a low adult mortality rate (8%/year) and comparatively high calf survival to October (37/100 adult females). Therefore, the Wells Gray caribou population was found to be slowly increasing, apparently because its migratory behaviour kept it separated from wolves and moose throughout the year, resulting in low wolf predation on the caribou (Seip 1990).

Bergerud *et al.* (1984b) found similar anti-predator strategies by caribou in Spatsizi Provincial Park, northern British Columbia, where they sought high south slopes in mountains for calving locations as an apparent antipredator tactic. By dispersing in heterogeneous and rugged mountains and away from moose, they forced wolves and grizzly bears (*Ursus arctos*) to search large areas, reducing their capture success. There were tradeoffs, however. By remaining at high elevations for 2-3 weeks in June, females with calves had to forego foraging in plant associations with high phytomass and nutrient concentrations. The antipredator tactic of dispersion in mountains was only moderately successful in 1976 and 1977; 90% of the calves died prior to 6 months of age, largely from predation. The relatively recent increase of moose in northern British Columbia in the early 1900's has resulted in more wolves per unit area, and has somewhat reduced the utility of leaving valley bottoms and being dispersed in mountains as a tactic for caribou to increase the searching effort of predators. Segregating geographic features like mountains, islands, or bogs are good mechanisms for creating refugia. However, such options are not readily available, another way caribou can reduce predation (especially during calving) is by achieving "rareness" through dispersal (Bergerud 1992), assuming that the area for such dispersion is available.

Bergerud and Butler (1975) completed a one-week study in the Armstrong-Nipigon region, investigating the range condition, status and distribution of caribou. The purpose of this investigation was to test the hypothesis of Bergerud (1974):

> that the decline of caribou in North America and their regulation of numbers was and is strongly influenced by predation. A disproof of this hypothesis is to find a stable or increasing population living year-round in an area of high moose-wolf numbers. The disproof requires that such a population does not have an escape advantage relative to wolves at calving time (does not calve on islands). ... It was suggested that the Armstrong herd might be such a herd - possibly living year-round in the vicinity of Armstrong. The Armstrong herd could escape this disproof if they calve on the Islands in Lake Nipigon, or Caribou Lake, or elsewhere on some islands. Thus, our first approach was to visit Armstrong in the post calving period in June to see if the animals were present (a disproof). When we could not find the animals at Armstrong we went to Lake Nipigon to see if they were there... it had been reported that there was only 3-5 caribou resident on the Nipigon islands in the winter (an aerial survey of Murchison & Jackfish-Murray in April 1975 showed only 2 animals).

It is interesting to note that Bergerud considered it a disproof if calving on islands or points provided a successful anti-predator strategy; would it be considered a disproof if winter habitat partitioning also prevented predation? At what point do the exceptions overrule the theory?

Bergerud (1971) studied the population dynamics of Newfoundland caribou to try to ascertain what determines the rate of increase of woodland caribou there, seeking to find whether density-dependent competition intensifies, reduces, and finally halts continued growth, or rather that adjustments occur within populations to limit numbers. He reported on the factors that limited the rate of increase of caribou in Newfoundland from 1900 to 1967. Caribou were abundant in Newfoundland in the early 1900's (Millais 1907, Dugmore 1913). Then, from 1915 to 1930 the herds rapidly declined and nearly became extinct (Dugmore 1930). Since 1930 there has been a small increase in numbers; however, the population has never approached its former abundance even though the natural predator of caribou, the Newfoundland wolf, *Canis lupus beothecus*, became extinct in 1911. Legal hunting was prohibited from 1924 to 1934 and only a small kill was permitted from 1935 to 1965. Also, there has been a general decline in the illegal harvest of caribou since moose became common about 1945. Still the numbers of caribou, inexplicably, remained low (Bergerud 1971). Some might attribute significant continued predation to lynx or black bears still existing on the island.

Based upon this high level of concern about the need to reduce predation wherever possible to maintain caribou numbers, Racey *et al.* (1992) proposed forest management guidelines that would, hopefully, reduce the suitability of cutovers for moose, and thereby prevent increases in moose numbers in caribou range.

Others (e.g. Mech 1966, Peterson 1978) have argued that wolves are sometimes proximate controlling factors, but that the fundamental control of ungulate numbers is through environmental factors like food, cover, habitat type and productivity. According to Peterson (1978), "there appears to be no adequately documented cases of wolf predation imposing a long-term limit on ungulate populations independent of environmental influences." Peterson (1978) felt that a far greater effect of wolves and other large carnivores is to maintain the genetic and physical health of the ungulate, and the health and productivity of the habitat, through selective pressures against older, unhealthy adults. However, predation against calves can, in addition to the beneficial selective pressures noted by Peterson for moose, reduce or eliminate recruitment in the case of caribou when and if anti-predator strategies are unsuccessful (Seip 1990, 1992). Another researcher de-emphasizing predation as a fundamental cause of caribou decline was Van Ballenberghe (1985), who studied the Nelchina barren-ground caribou herd of south-central Alaska which erupted, crashed, and increased again during the period 1950-81:

> Annual survival of calves, an important determinant of population trends, was high during periods of population increase, but survival was low when the herd peaked and during some years of the decline. Poor survival of calves and adults (the former related to winter severity, the latter due to hunting mortality), contributed importantly to the decline. It is unlikely that gray wolf control triggered the eruption, nor did wolf predation significantly reduce calf survival at the herd's peak. Predation did not prevent caribou from increasing after the crash; despite a peak in wolf numbers and a threefold decline in prey biomass ungulate, wolf ratios were still too high for predation to have much impact.

Two options for limiting predation by wolves are direct predator control, and indirect limitations by managing habitats to reduce suitability for wolves. Bergerud and Page (1987) stated that "viable caribou populations cannot survive on ranges frequented by high numbers of wolves (maintained mainly by moose prey) unless there are special habitat features providing escape for cows with young calves." Cumming offered a third option: that of maintaining the "virtual refuges" (Cumming *et al.* 1994) formed when moose and caribou partition habitats (Cumming 1975, 1996), even when their ranges were adjacent or interspersed with the wolves appearing to remain with moose, those moose having more biomass and generally being more accessible. Cumming (1996) warned, however, that roads can functionally eliminate virtual refuges by facilitating easier predator access, just as Banfield (1974) reported the ambushing of caribou via seismic corridors.

Godwin (1990) summarized that " the challenge for retaining woodland caribou in northwestern Ontario's boreal forests will be to: 1) prevent caribou from being driven out of the few remaining refuges; and 2) prevent areas supporting caribou from being changed into places that favour moose and, consequently, wolves."

Annual Movements ("Migrations")

In exploiting favourable habitats, caribou usually occupy a much larger year-round range than moose. Major movements occur to and from spring/summer calving grounds, fall rutting areas, and winter habitats, and can reach up to 80 km (Bergerud 1974, Freddy 1979, Cumming and Beange 1987, Edmonds 1988). However, some woodland caribou move very short distances, remaining in the general area year-round (Darby and Pruitt 1984, Cumming and Beange 1987), presumably when their total year-round habitat needs are met in a smaller area.

Sometimes travel corridors are quite distinct and narrow. In some flat terrain, caribou may travel through broad bands of forest with indefinite boundaries (Brown *et al.* 1986, Cumming and Beange 1987). Travel corridors are believed to act as important linkages that facilitate movement between key seasonal habitats.

Flight behaviour

The escape reaction of barren-ground caribou in flat terrain is to flee toward open habitat (such as lake ice during winter). Factors that can elicit a flight response include scent of a threatening species, even in the absence of sight (Kelsall 1968). Bergerud (1974) observed that woodland caribou in Quebec, Labrador, Newfoundland, and Ontario move to open habitats after being disturbed. He felt that such a behaviour is an adaptive response to wolf predation.

Caribou winter habitat in forested areas of NWO

The winter habitat of woodland caribou in northwestern Ontario consists of open jack pine and black spruce forest with lichen ground cover (Ahti and Hepburn 1967, Bergerud 1989). Much of this habitat is described as Northwestern Ontario Forest Ecosystem Classification (NWOFEC) type V30 (jack pine-black spruce/blueberry/lichen) (Sims *et al.* 1989). Terrestrial lichens, especially reindeer lichens (*Cladina* spp.)

constitute most of the woodland caribou winter diet, although arboreal lichens, sedges, and some evergreen shrubs are sometimes eaten (Bergerud 1971, Schaeffer and Pruitt 1991). Although reindeer lichens prefer cool, sunny, moist environments, they can also tolerate severely dry conditions. Being slow-growing and poor competitors, they are easily displaced by mosses or most vascular plants, and therefore are rarely found on rich, moist sites (Ahti and Hepburn 1967). In northwestern Ontario forests, lichens normally flourish only on sites that are nutrient poor or very dry, or both. Such sites include: coarse to fine sands (NWOFEC soil types S1 and S2); shallow soils with exposed bedrock (NWOFEC types SS1); discontinuous organic mats on bedrock (SS1); extremely shallow soil on bedrock (SS2); very shallow soil on bedrock (SS3); and shallow-moderately deep/sandy soils (SS5) (Sims *et al.* 1989, Baldwin *et al.* 1990, Racey *et al. 1996*). Such lichen-rich stands may be interspersed with lichen-poor stands (Harris 1991, 1996).

Stardom (1977) stated that the three major woodland caribou habitats in Manitoba are open larch (*Larix laricina)* or black spruce bogs (the major source of arboreal lichens, e.g. *Usnea* spp.), intermediate-age to mature jack pine stands on rock ridges or sand plains (the major source of ground lichens), and rock-ridge-shored lakes (major travel, resting and feeding areas at the beginning of the spring thaw). During early winter, the caribou feed intensively on arboreal lichens in open bogs under windless, thin-snow cover conditions but, if the reverse conditions exist, intensive feeding shifts to ground lichens found in open forests. During the remainder of the snow period, major feeding occurs in intermediate to mature jack pine stands where the snow cover is softer due to the lack of wind crusts and thinner due to *qali* (fluffy snow adhering to conifer branches) formation. Stardom (1977) reported that major utilization of lakes occurs during periods of thick snow cover when the nival conditions on lakes are more conducive to resting and travel than adjacent forest types.

Prior studies on disturbance of woodland caribou

The effects upon woodland caribou of disturbance from sounds, sights and scents of human activities have been less thoroughly examined than some of the other suspected causes like range degradation or increased predation. Several studies examined effects of human disturbance on barren-ground caribou (e.g. Klein 1979, Curatolo and Murphy 1986) but relatively few studied woodland caribou. Results have been somewhat contradictory. Most have concerned caribou in Newfoundland. Bergerud (1974, 1984) maintained that caribou have little aversion to human developments, roads, or railroads, but Northcott (1985) reported that caribou avoided development areas in Newfoundland, and their movements were disrupted by vehicular traffic during construction periods; caribou returned to pre-construction locations after the development was completed. Hill (1985) found caribou in Newfoundland more alert and less inclined to feed while construction of a hydroelectric development was in progress, though they eventually became habituated to the construction.

Mercer *et al.* (1985) concluded that the distribution of caribou on the Avalon Peninsula, Fogo Island, and Random Island, relative to the road networks, implied avoidance of these structures. He pointed out that despite large numbers of caribou, only one has ever been recorded killed by vehicles on Newfoundland highways. This compared with 200-300 moose killed annually (Peterson 1955), suggesting that caribou avoid the roads. Peterson also drew attention to the fact that centres of the year-round ranges of all caribou herds, and especially calving grounds, are at maximum distances from roads and population centres, and that distributions of several herds have changed when high-use roads and railways were placed within their ranges. Bergerud (1974) suggested that a road could be a barrier if vehicular activity was perceived continuously; perhaps developments and road traffic have increased in Newfoundland since Bergerud (1974) made his observations. Benson (pers. comm. 1997) reported that in Hinton, Alberta, caribou have often been hit by vehicles.

Mercer *et al.* (1985) reported that both flushing and flight distances were reduced on the Avalon Peninsula since the 1960's. In British Columbia, Johnson *et al.* (1977) reported that mountain caribou near Kootenay Pass became habituated to the presence of highway traffic and continued to use traditional routes. However, Simpson (1985) stated that mountain caribou in southern British Columbia avoided single snowmobile trails and left areas where recreational snowmobiling was extensive, probably due to the presence of human scent and movements by large groups of people.

Movements, sex and age structure, and habitat selection of adult woodland caribou were examined in relation to clearcutting on summer range in east-central Newfoundland during 1987-1990 (Chubbs *et al.* 1993). Females displaced by clearcutting avoided open burns and hardwood stands and selected mature black spruce forest, whereas prior to cutting cows used habitats in proportion to their availability, without apparent selection bias. Sex and age ratios indicated that significantly fewer females and calves were present near clearcuts than elsewhere in the study area. Results demonstrated that clearcutting mature forests on summer range affected the movements and distribution of woodland caribou in Newfoundland.

Edmonds and Bloomfield (1984) expressed concern for woodland caribou in west central Alberta, in their studies from 1979 to 1983. This caribou population had been in decline for some two to three decades and the authors felt that, while predation had been an important factor in those declines, that continued long-term loss of traditional wintering areas through logging would further jeopardize their survival.

Brousseau (OMNR 1978) studied caribou decline in the Cliff Lake area of the Dryden District. He contended that the remaining caribou in the District had been maintaining numbers of at least 40 animals in an area that had been previously unaccessed, "highly inaccessible", and “rarely disturbed by human interference”. A six-year study concluded that at least a 75% reduction in numbers over an 11-year period was due to an expansion of access and harvesting into the area, resulting in "a strong inverse correlation between logging and caribou numbers." A total elimination of a herd in the Front Lake area might have been due, according to Brousseau (1978), to disturbance: “cutting operations approximately 2-3 km to the west of the area may have disturbed the caribou and caused them to move” out of the area, perhaps north or west “into the Kenora and Red Lake Districts where suitable, undisturbed habitat still exists” (Brousseau 1978).

VI) STUDY AREA

Several related study areas were surveyed at varying intensities. In decreasing order of intensity or frequency of survey were a Prime Study Area (PSA), an Extended Prime Study Area (EPSA), and a High Level Telemetry Area (HLTA); combined, they constituted the Overall Armstrong Study Area (Figure 4).

OVERALL ARMSTRONG STUDY AREA

The Overall Armstrong Study Area was defined as any area with present or historic caribou use within a radius of 32 km of the Armstrong airport, plus any islands used as spring/summer habitat in the northern half of Lake Nipigon (north of 50 degrees latitude), lying 20-70 km eastward (Fig. 3). In this area, lacustrine and glaciofluvial sands and gravels and glacial till thinly cover the Archean granitic uplands, typical of the heavily glaciated Precambrian Shield. While the surficial geology map shows a high percentage of the Armstrong area in general classified as bedrock, the PSA is all classified as lacustrine sands, with (old) dunefields in the area south of the airport, east and west of the Wabinosh Road (Zoltai 1965). Summer temperatures are cool (mean daily temperature 16°C) and winters are cold (-20°C mean daily January temperature). Total precipitation (750 mm/year) and snow depths are moderate (160-280 cm of average snowfall, with average maximum snow depths of 160 cm; 76 cm highest weekly average depth during the study). Snow cover lasts 160-200 days (RCNE 1985).

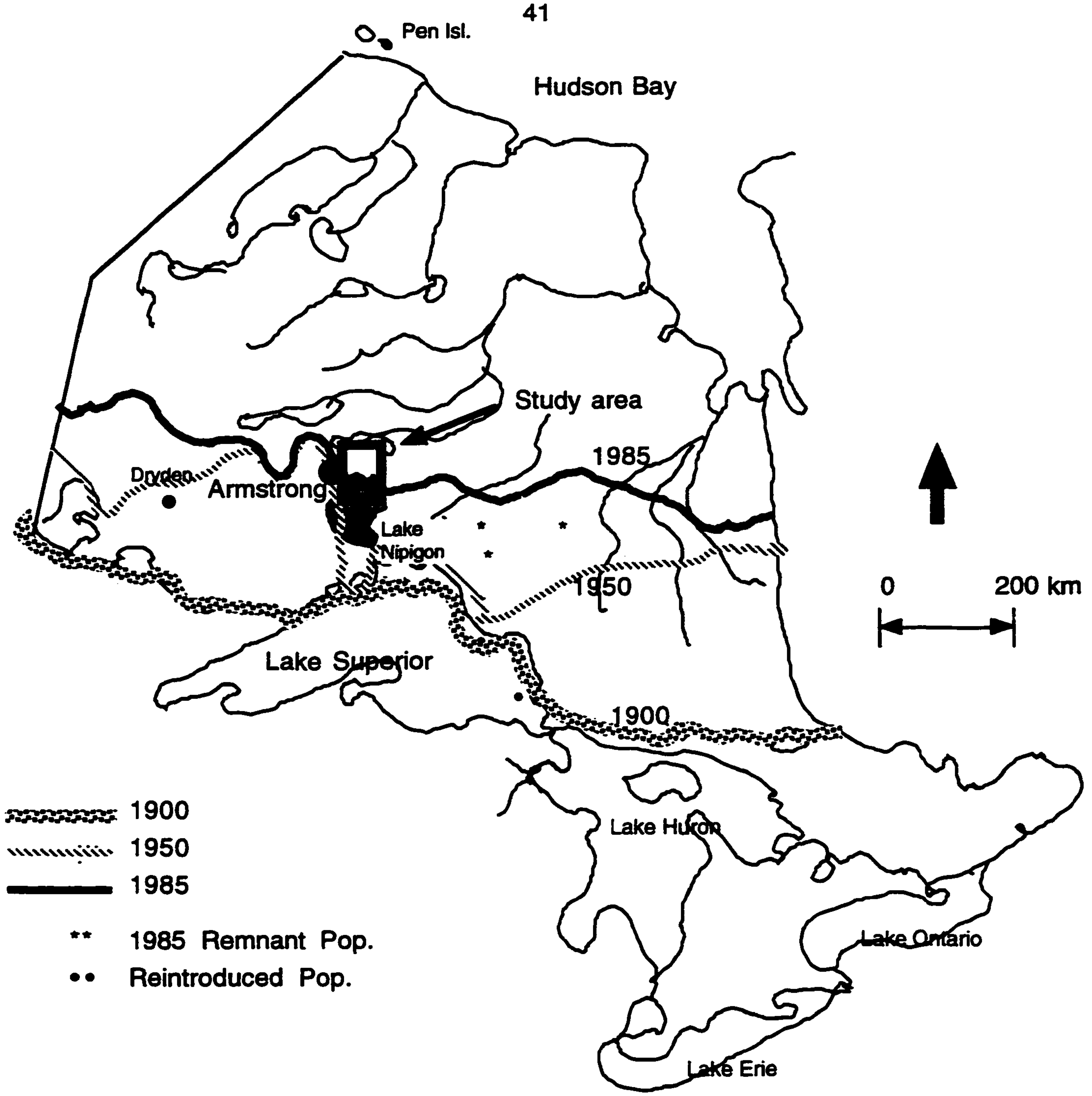


Fig. 3 Study area in relation to the historic southern lines of continuous distribution of woodland caribou in Ontario (after Darby and Duquette, 1986)

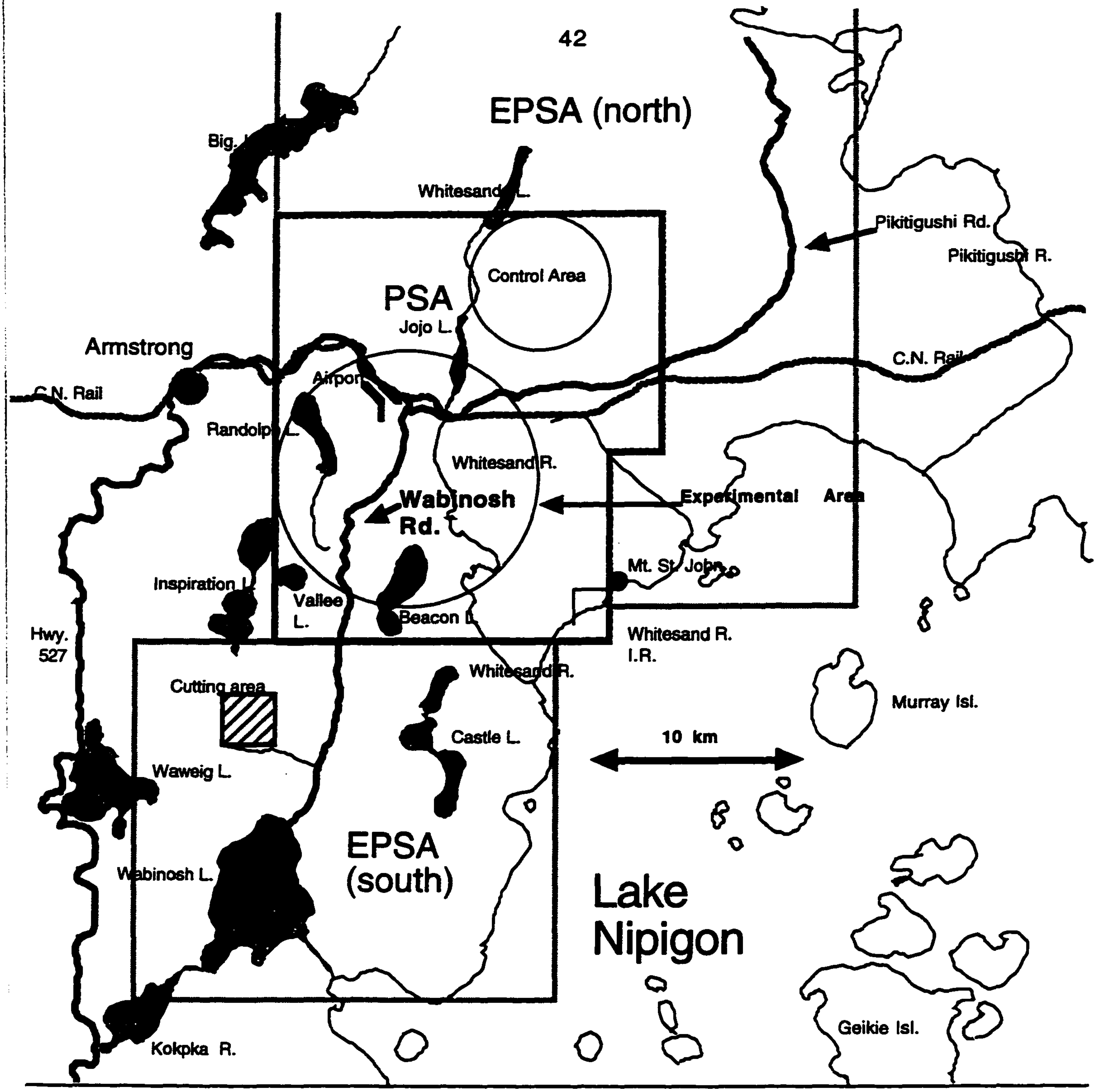


Fig. 4 Study Area, showing Wabinosh Road., Prime Study Area (PSA) and Extended Prime Study Area (EPSA)

Wildfires have left a mosaic of stands, primarily black spruce and jack pine, with a few mixed stands including trembling aspen (*Populus tremuloides* Michx.) and white birch (*Betula papyrifera* Marsh). Mosses, such as *Pleurozium schreberi* (Brid.) Mitt., cover much of the forest floor, but patches of ground lichens, e.g., *Cladina mitis* Sandst., *C. rangiferina* (L.) Wigg., and *C. alpestris* (L.) Rabenh, grow under poorly stocked stands of jack pines on sand flats and under scattered spruce on rock outcrops (Antoniak 1993). Tree lichens, e.g. *Usnea comosa* (Ach.) Röhl and *U. dasypoga* (Ach.) Röhl, are common but not especially abundant (Ahti and Hepburn 1967).

PRIMARY STUDY AREA (PSA)

The PSA is an area of 280 km^2, 14 km wide from Vallee Lake on the west to Mount St. John on the east and 20 km long from Mt. St. John on the south to Whitesand Lake on the north. The Armstrong airport and Jojo Lake are roughly in the centre of this area. In this area, deep but coarse sands support widely spaced jack pine with a ground cover rich in lichens (Antoniak and Cumming 1996).

EXTENDED PRIME STUDY AREA (EPSA)

Two extensions go beyond the original PSA (Fig. 4). One is to the north of the intensive area, bordered by Big Lake on the west and Pikitigushi Lake on the east, covering an area of approximately 800 km^2. The southern extension area includes Waweig, Wabinosh and Castle Lakes and covers approximately 400 km^2. These areas were added to the PSA for the following reasons:

1) they lie within 32 km of the Armstrong Airport.

2) they are contiguous to the intensive area, and are used by caribou which may indeed be some or all of the same animals/bands as in the intensive area.

3) there was some information that these areas encompassed likely emigration and immigration of caribou into and out of the PSA.

HIGH-LEVEL TELEMETRY AREA (HLTA)

The 2500 km^2 area called High-Level Telemetry Area (HLTA) encompassed all of the PSA, most of the EPSA, and all the Lake Nipigon islands north of 50 degrees latitude.

VII) METHODS

EXPERIMENTAL DESIGN

An experiment requires changing some aspect of a situation and comparing consequences with an unchanged control. Establishing control areas for operational-size field experiments involving wildlife is notoriously difficult (Walters and Holling 1990). Even the most carefully chosen controls in nearby, apparently comparable areas can differ significantly from treatment areas (Cumming 1989). In this study, it appeared that the nearest likely control area with caribou would be over 45 km distant (Wabakimi Provincial Park). In addition, it has more bedrock and black spruce, with little sand. For these reasons, a control in time rather than space was emphasized.

Year I of the experiment constituted a control year during which activities of caribou were mapped throughout their winter occupation of the study area while the road remained closed and little disturbance occurred (Table 1).

Year II was the experimental (treatment) year during which caribou activities were recorded before, during and after a period when trucks hauled logs through the caribou wintering area.

Year III provided a second control year during which the road was not plowed and disturbance was minimized.

Field work during the first winter revealed a second (at least partially segregated) aggregation of caribou only 6 km from the disturbance area (northeast of Jojo Lake, in an area of outwash sand

Table 1.

Design of log-hauling experiment: years I, III served as controls. In year II, logs were hauled through a traditional caribou wintering area (usually unplowed and unused in most winters) during Jan. 14 to Mar. 10.

Period	**Before Dec. 11**	**Dec. 11-Jan. 5**	**Jan. 6-7**	**Jan. 14 - Mar. 10**	**Mar. 11-Apr. 30**
Year I	Control period	Control period	Control period	Control period	Control period
Year II	Control period	Control period	**Road plowed**	**Log hauling treat-ments carried out**	No log hauling
Year III	Control period	Control period	Control period	Control period	Control period
Possible human disturbance in year II	Snowmo-biles	Snowmo-biles	Snow plow	Large machines moving in, diesel haul trucks, private vehicles	Private vehicles only

plains with open jack pine overstory and lichen understory). This second aggregation became a welcome control in space in addition to the control in time.

FIELD DATA COLLECTION

Capturing caribou

A previous study had shown that caribou in the study area migrated from islands in northwestern Lake Nipigon (Cumming and Beange 1987). As in the first study, caribou were driven from the islands by crews of up to 6 persons and 1 or 2 dogs. In the water, the caribou were approached by boat, restrained, and tagged. Fourteen caribou were fitted with radio transmitter collars (adults) or solar ear tags (calves) manufactured by Advanced Telemetry Systems in the summers of 1990 (1 cow) and 1991 (1 bull, 6 more cows, and 6 calves). All tagged (and released) animals were later relocated by aerial telemetry in the general vicinity of the study area, confirming our understanding, derived from the previous study, of the constancy of caribou traditions.

Telemetry

High-level winter flights to search for the collared animals covered the entire study area (or the area being used by the animals actively transmitting, if that area was smaller). Aircraft included a Cessna 185, a DeHavilland Turbo-Beaver, and a Champion 7EC. We used a transect width of 10 km (at 3,000-5,000' Above Ground Level (AGL); wider at higher altitudes). Twin directional yagi antennas were attached to the wing struts, angled outward and downward as per Gilmer *et al.* (1981). Altitudes ranged from ca. 3000' to 10,000' AGL (higher flights had wider range, covering more territory, but were less accurate for identifying locations). Weekly flights were made at times of likely significant movement (i.e. migration times, disturbance times) and flights were made at intervals of 2-4 weeks in mid-season when caribou movements were expected to be fewer. Wherever possible, caribou that were "found" during high-level telemetry were located as exactly as possible, by "dropping lower" and circling, while switching from one directional antenna to the other to "zero in" on the animals. Practice trials demonstrated that caribou could be located within a radius of about 200-500 m.

Radio transmissions also were recorded during low-level transect flights while primarily looking for tracks in snow in the PSA. A Lotek scanner was connected to a small (20 cm) whip antenna, which scanned the 14 frequencies (all VHF in the 164 MHz range) of collared or tagged animals, and fed the audio signal into the aircraft intercom. With a detection range (at that altitude, with just a whip antenna) of only about 2 km, any collared caribou was noted and location recorded. This was a supplement to, not a replacement for, high-level telemetry searches using the twin yagi antennae.

Mapping tracks

The main data collection tools for mapping tracks were fixed-wing aircraft using methods described by Cumming and Beange (1987). Except in year III when lack of aircraft and personnel reduced effort, flights were made at 1-2 week intervals, starting before the freeze-up of Lake Nipigon (late November or December) and ending when the caribou left their winter ranges to return to their summer calving grounds (always before ice-out). North-south transects were flown at 500'-1000' AGL, using the Champion 7EC with two people: a pilot/spotter and a spotter/recorder. The fore and aft seating of the Champion provided excellent visibility on both sides. The air speed of 50-85 Knot (93-158 km/hr) provided sufficient time for careful inspection of tracks. One observer spotted to the right, the other to the left, and the two communicated via a two-way intercom. Data were recorded on a 1:50,000 topographic map covered with acetate, using a Staedtler Omnichrome 108-2 marker. A photocopy of the data was made as soon as possible after each flight for a permanent data record, including the time and date of the flight. The acetate was then cleaned for re-use. The data were recorded as: C (live caribou), CT (caribou tracks), CB (caribou beds), CR (cratering), M (moose), MT (moose tracks), MB (moose beds), W (wolves), WT (wolf tracks), VT (vehicle tracks), and SS (snowshoe tracks). Where helpful and possible (e.g. on lakes) landings were made to confirm track types (or from the ground where accessible, e.g. along the roads in the airport area).

Three types of tracks made by caribou, moose, or wolf were recorded: individual, aggregate and linear. Individual tracks were recorded as discrete "CT" or "WT". However, in many places tracks were too numerous to be recorded individually. In these places, track aggregates were recorded as one or more "CT"or "WT", with a line drawn around the perimeter of the tracks, a practice that has become common in studies of moose (McNicol and Gilbert 1980). Linear tracks were drawn as lines, with direction noted where possible by an arrow (e.g. after ground-truthing, or where the animal was seen making the track). For the EPSA, transect width was 3 km, at a higher altitude (1000'-2000' AGL) to ensure transect coverage.

The first priority for winter aerial surveys was the PSA. Second and third priorities were the EPSA and the Overall Study Area, respectively. Air temperature, wind, and sun were recorded on days of flights or ground surveys.

GROUND SURVEYS

Ground-truthing

The primary means of collecting data was from the air. We also examined the Wabinosh Road, the Pikitigushi Road, and snowmobile trails on the ground to verify tracks spotted from the air, as to location, species, and completeness. Tracks under heavy canopy cover were examined where they were close to a road.

Snow depths

Due to the location of the study area, intensive investigation of snow conditions was not possible. However, in this northern location where winter snow melts do not usually occur, snow pits in late winter show records of the entire snow history up to that date each winter. Therefore dug snow pits were analyzed using a National Research Council snow kit in late March of early April of each year; snow depths, hardness and density were recorded. Plots were located in clearcuts 7 km south on the Wabinosh Road and also under jack pine stands used by the caribou as winter habitat 1 km south of the Armstrong airport. Under the jack pine stands, two pits per visit were dug: one pit was directly beneath tree cover (1 meter from the bole), and one was in a small unstocked space midway between trees. Two pits per plot were dug in the open clearcuts.

Supplementary snow depth information was obtained from an OMNR snow station at Flat Lake, near the centre of the study area. This station is one of a province-wide network of snow recording stations set up by OMNR in the 1960's for the purpose of measuring winter severity on white-tailed deer (Cumming pers. comm. 1990). These OMNR stations are located in hardwood stands (in this case trembling aspen) to measure snow conditions intermediate between those in open areas and those under conifers. At each location, 10 vertical measuring rods are placed in position before snowfall and mean snow depths for the station are recorded each Monday morning throughout the winter. Due to the complexities of measuring snow hardness and density, conditions are reported only in three classes: A - no crust, B - light crust, C - crust heavy enough to hold a person on snowshoes.

Traffic records

Apart from snowmobiles, there was no road traffic during year I, the first control year. In year II (1991-1992), the Wabinosh Road was unplowed until after the caribou had taken up residence in the airport area. The road was then plowed on January 6, 1992, and on January 7 hauling commenced from stands cut and slashed ca. 12 km southwest of the airport. Personnel from BFPL kept records of the haul dates and frequencies, and incorporated them into a report (Robinson and Bodie 1992). Traffic patterns for year III were similar to year I (some snow machine use of the road). Automatic pressure traffic counters were placed on the Wabinosh Road in year II, and on the Wabinosh and Pikitigushi Roads in year III. However, these counters did not distinguish types of vehicles; therefore, data recorded by BFPL (Robinson and Bodie 1992) were judged superior and are reported here (Tables 1 and 2) .

Table 2. Chronology of traffic on haul road during experimental period.

Date in Year II	Equipment movement	Personal vehicle travel (implied by number of shifts*)
Jan. 06	Snowplow opens Wabinosh Road	1
Jan. 07	Grading begins; feller buncher floated in	5
Jan. 08-13	Grapple skidder, delimber, bulldozer floated in	7
Jan. 15	Haul trucks begin; sand truck begins sanding road; loader, front end loader floated in	13 (25 haul trucks Mon. - Fri. until Jan. 16, haul in progress 24 hours)
Jan. 17	Loader, bulldozer, front end loader floated out; sand truck moves out	10 (no hauling until Jan. 23)
Jan. 23	2 loaders, front end loader, bulldozer floated in; sand truck driven in; haul trucks begin again	13 (hauling in progress once more)
Feb. 01-11	5 slashers floated in	15 - 21
Feb. 21	Cutting ceases	18
Feb. 29 - Mar. 1	Skidding, grading cease; four slashers, grapple skidder floated out	12 - 14
Mar. 2	Delimbing ceases	10
Mar. 4	Slashing ceases, delimber floated out	7
Mar. 6-10	Slasher, feller buncher, 2 bulldozers floated out; grader, sand truck, front end loader out	Haul operation personnel only
Mar. 11	2 loaders floated out, haul operations cease	Haul trucks finish

From: Robinson, L. and B. Bode. 1992. Chronological Report for BFPL's Valley Lake Operation, Winter, 1992. Internal Report for BFPL.

* Since no accommodation was available at the cutting location, workers used personal vehicles to go on and off shift.

Mortality of collared or tagged animals

Reception of a "mortality signal" (rapid beat) initiated a search by aircraft, followed by ground search (using a scanner and yagi directional antenna) to try to recover the collar or tag, and to attempt identifying the means of death if possible.

Measurement of disturbance factors

Any disturbance related to log hauling could have affected caribou through sight, scent or sound. Presumably direct vehicle sightings would not affect caribou other than those very close to the roads, because the entire area is heavily forested. Scent might have been disturbing, as reported in British Columbia (Simpson 1985), but appropriate experiments or measurements could not be devised. Investigation of scent possibilities was felt to be beyond the scope of this study.

Measurement of sound is difficult under any circumstances (Peterson and Gross 1974), and attempting to relate measurements to little known relevant physiology increases difficulties. What frequencies can caribou hear? From what is known of other animals, such as domestic dogs, they may hear frequencies far above those of human detection. Still, if logging trucks were found to constitute some kind of disturbance to caribou, we sought to document the types of truck sounds; it is possible that other trucks in other places might make different sounds initiating different caribou responses. After seeking advice from people who measure sound, I decided that the best approach was to record the vehicles on a high quality tape recorder and then analyze the recordings. Such equipment was available from the Faculty of Forestry at Lakehead University. The tape recorder was a Nagra IV - SJ with frequency response better than + 1 dB from 25 Hz to 35 KHz recording at 15 ips. The microphone was a cartridge Type 4165 condenser from Brüel & Kjaer with + 10 dB from 20 to 20,000 Hz. Since several people took the recordings, routines were established for each to follow, both for individual recordings and for daily records. Even when a good recording is obtained, difficulties continue. How should the sound be analyzed? Three major variables need to be simultaneously considered: intensity (dB); frequency (Hz); and duration (sec). Since all three variables interact, presentation of data for any single variable would risk complications from unknown effects due to changes in the other variables. A solution was found in a program Wave for Windows that produces 3-dimensional graphs of the changing variables. These graphs were examined for general understanding of the sound characteristics and for determining peak values of individual variables.

GIS AND STATISTICAL ANALYSES

Mapped results were first examined by visual inspection and by sketched composite maps. Subsequently, data were digitized using a Macintosh 6200 computer running a rastor-based Geographic Information System (GIS) called Map Factory. Free-hand digitizing from field maps to base maps in the computer was judged within acceptable limits of error because small errors are also inherent in free-hand location of tracks onto maps in the aircraft. Original mapping error was estimated to be within 100-1000 m for telemetry locations, 30-100 m for low-level mapping of tracks in the PSA, and 30-300 m in the EPSA. Pixel size for the base maps and data was 30 m, so the order of magnitude for accuracy for the original data, and for the GIS, were similar. Once entered, data could be combined in various ways, printed, and statistics tabulated.

Because caribou tracks frequently occurred in aggregates (i.e. polygons) in the small, heavily used wintering area, analysis of tracks as points (Cumming and Beange 1996) could not be attempted. Instead, the rastor pixel size was set at 30 m and the number (and percentage) of pixels showing "presence" or "absence" were counted, within cells of 300 by 300 m. These cells were arranged in buffers of rows of such cells at given distances from sources of disturbance (e.g. the Wabinosh Road, railroad, Pikitigushi Road). Observed track frequencies for the same periods (before Jan. 7; Jan. 7- March 11; after March 11) of the three years (two control years and one treatment year) were then compared using Chi-square tests. Spatial relations among caribou, moose and wolves were examined by establishing 900 m buffers around the presence in pixels for one species and counting numbers of occupied pixels within those buffers for other species. (Buffer width of 900 m was selected as a convenient width close to 1 km, but divisible by 100 m and also by the pixel size of 30 m.)

VIII) RESULTS

MEASURED DISTURBANCE FACTORS

Use of the Wabinosh Road

Disturbance during year I consisted of a few snowmobiles on special trails and along the haul road, mainly during the early winter when snow depths were not excessive.

The early part of year II was similar to year I, but on January 6 of year II the road was plowed and on January 7 company workers began to move in heavy equipment (Table 2). By January 13 a grader, grapple skidder, and several feller bunchers, delimbers, and bulldozers had been driven or floated in, through the PSA. On January 15 log hauling began. The haul consisted of 25 diesel trucks hauling 24 hours/day, from Monday to Friday. Workers began removing heavy logging equipment after cutting ceased on February 21. Except for a brief period in late January, hauling continued until March 11 of year II. In addition to the diesel vehicles, personal vehicles (e.g. half-ton to one-ton pickup trucks) contributed to the possible disturbance. Heavy-equipment operators drove to and from the cut site each day in personal vehicles for their shifts. Numbers of shifts increased through January as more heavy equipment was brought in, reached a high point of 21 shifts on the week of February 1 (Table 2), then gradually declined until in the last few weeks any disturbance would have come from truck traffic only. In addition to this work-related traffic, some people living nearby took advantage of the plowed road for winter outings.

Year III use of the Wabinosh Road was similar to year I.

Recordings of Vehicle Sounds

The sounds produced by the heavy equipment used for cutting could not be heard when they were operating, as they were too far south (in excess of 10 km) of the study area. However, diesel log hauling trucks could be heard by humans for several kilometres, depending on temperature and wind. Among the sounds produced by these trucks, low frequencies predominated; the highest frequencies were below 7150 Hz (Table 3). Loudest sounds were almost entirely in frequencies below 3000 Hz. No high frequencies were recorded above the range of human hearing. Frequencies of sounds produced by gravel trucks and smaller personal vehicles ranged slightly higher than the sounds of log hauling trucks.

Table 3.
Mean maximum frequencies of sounds made by vehicles passing through a traditional caribou wintering area.

Vehicle class	**Number of recordings**	**Mean maximum frequency in Hz**
Logging trucks loaded (all)	11	5318
Logging trucks loaded (High decibels only)	5	2976
Logging trucks unloaded (all)	8	4895
Logging trucks unloaded (High decibels only)	4	3075
Gravel trucks loaded	4	7150
Gravel trucks unloaded	3	6667
Pick up trucks	2	7000
Distant train	2	5500

TELEMETRY DATA

All 14 caribou fitted with radio transmitters on the islands of Lake Nipigon were relocated in or near the PSA in the late summer or fall of year II. However, only six of these caribou actually returned to the PSA close to the Wabinosh Road (i.e. within 8 km) prior to hauling in year II. All six left again after log hauling activities began (Fig. 5). Caribou 1 (Freq. 090) moved far north before returning to Lake Nipigon islands; caribou 2 (Freq. 310) moved to the control area, then to the islands; caribou 3 (Freq. 354) moved to a location 8 km east of the experimental area, then to the west shore of Lake Nipigon (a common staging location on the way to the wintering area), then to the islands constituting summer habitat; caribou 4, 5, and 6 (Freq. 533, 253, 333) moved almost directly to the islands. Four of the six caribou returned to summer range on Lake Nipigon islands before February 22 (Table 4). This is in contrast to a previous study (1976-1981), when the haul road was not open during winter, and spring movement from the Armstrong area began in early March and reached a peak in April (Cumming and Beange 1987).

Table 4. Locations of six radio-collared caribou during two winters.

Period	Date	Caribou 1) # 90	Caribou 2) # 310	Caribou 3) # 354	Caribou 4) # 533	Caribou 5) # 253	Caribou 6) # 333
Year II	Dec. 10/ 91		W. L. Nip	W. L.Nip	W. L. Nip		
Pre-	Dec. 19/ 91	< 8 km	< 8 km	< 8 km	< 8 km	E. > 8 km	< 8 km
haul	Dec. 28/ 91	E. > 8 km	< 8 km	< 8 km	< 8 km	< 8 km	< 8 km
period	Jan. 4/ 92	E. > 8 km		< 8 km	< 8 km		
Year II	Jan. 7/ 92	< 8 km	< 8 km	< 8 km	< 8 km		
haul	Jan. 14/ 92		< 8 km	E. > 8 km	E. > 8 km	Jojo Lake	W. L. Nip
period	Jan 24/ 92			E. > 8 km	E. > 8 km		W. L. Nip
	Feb 22/ 92	Islands		E. = 8 km	Islands	Islands	Islands
	Mar. 1/ 92			E. = 8 km	W. L. Nip	Islands	Islands
	Mar. 10/92	Islands		E. = 8 km	Islands		Islands
Year II	Mar. 30/92	Islands		E. = 8 km	Islands		Islands
Post-haul	Apr. 17-18/92	Islands		Islands	W.L. Nip	Islands	Islands
Year III	Oct. 22/92	Islands	Islands	Islands	Islands		Islands
Pre-"haul"	Dec. 22/92	Islands	Islands	Islands	Islands		Islands
Year III	Jan. 7/93	< 8 km					
"haul"	Jan. 14/93	< 8 km					
period	Jan. 19/93	< 8 km	Jojo Lake	Jojo Lake		Islands	Islands
	Jan. 27/93	< 8 km	Jojo Lake	Jojo Lake		Islands	Islands
	Feb. 4/93	< 8 km	Jojo Lake	Jojo Lake			
	Mar. 3/93	< 8 km	Jojo Lake	Jojo Lake			
Year III	Mar. 18/93		< 8 km				
Post-"haul"	Apr. 1/93	< 8 km	NW L. Nip.	Jojo Lake	Islands		Islands

Note: short forms indicate the following:
< 8 km (experimental area, < 8 km from Wabinosh Rd.)
> 8 km (experimental area, 8-60 km from Wabinosh Rd.)
= 8 km (experimental area, 8 km from Wabinosh Rd.)
E. > 8 km, etc. (East of experimental area, and > 8 km from Wabinosh Rd.
Jojo Lake (control area, ca. 8-12 km NE of Wabinosh Rd.)
Islands (islands in Lake Nipigon used for calving)
W., NW. Lake Nipigon (on the indicated shoreline area of L. Nipigon, often used as travel route going or coming from calving or wintering areas)

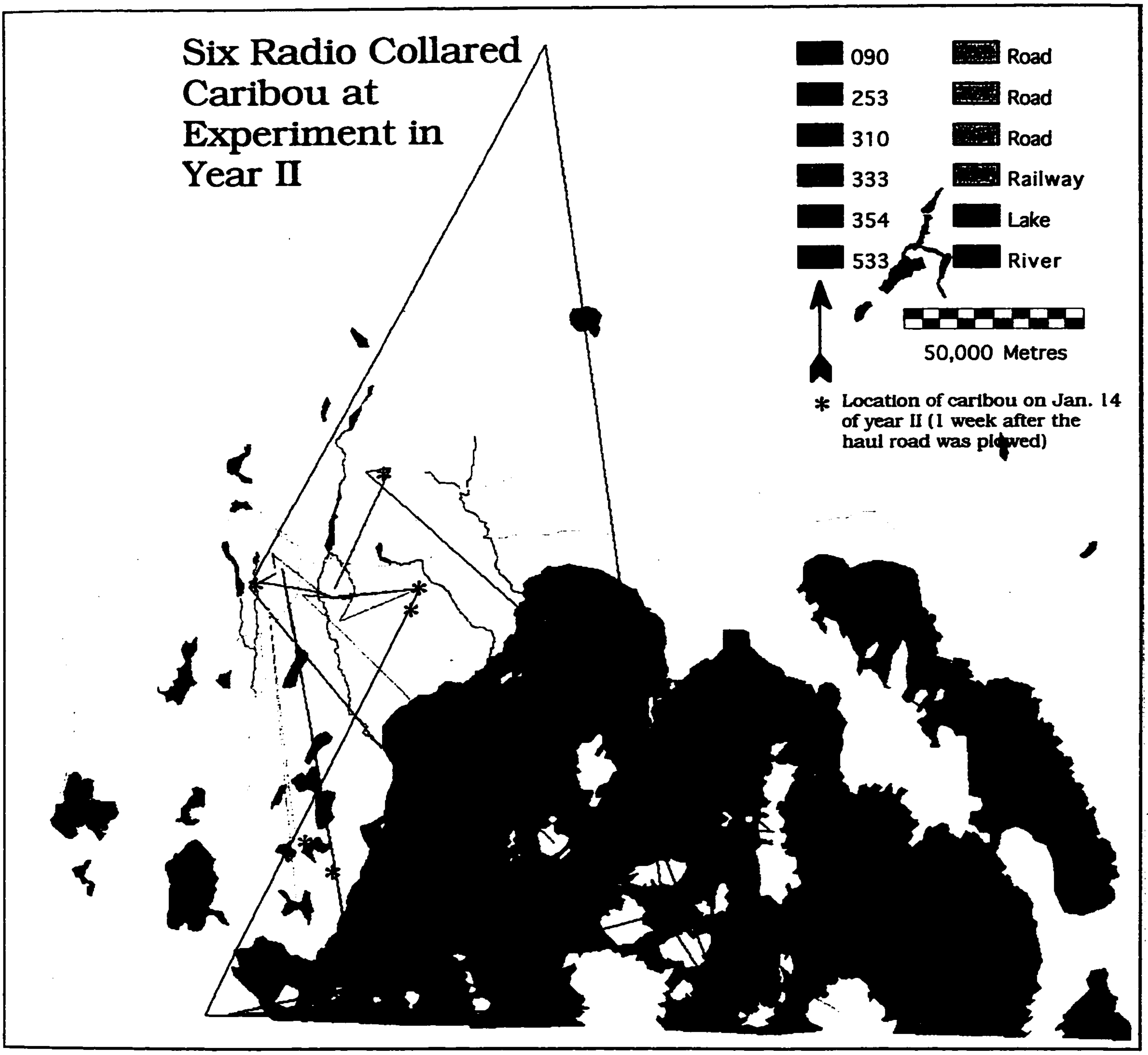


Fig. 5. Movements of 6 radio-colllared caribou during the winter of experimental log hauling from Dec. 10, 1991 to April 17, 1992. The red asterisks show the location of the caribou on Jan. 14, 1992 (1 week after plowing and hauling commenced). For date details see Table 4.

MAPPING TRACKS

Prime study area

Maps of tracks in the PSA showed caribou close to the haul road during early and mid winter of year I (tracks were not recorded for the late winter period of the first year). In fact, in year I caribou seemed preferentially to select the immediate vicinity of the haul road. Caribou returned to much the same areas before hauling commenced in year II, leaving many tracks close to the road during the pre-haul period (Fig. 6). On the day when the road was plowed (January 6, 1992), many highly linear tracks (as opposed to the typical overlapping circular patterns) were recorded at right angles to the road. Caribou tracks were found away from the road > 900 m during the haul period of year II; except for one small aggregation of tracks, caribou continued to use only areas remote (ca. 2-13 km) from the haul road through the post-haul period of year II. In year III (a second control year), some caribou arrived later than in previous years, but they did return to areas near the unplowed road that were similar to the areas used in previous years. They stayed in these places throughout the winter of year III (Fig. 6); fewer tracks in year III could have been due to reduced survey intensity.

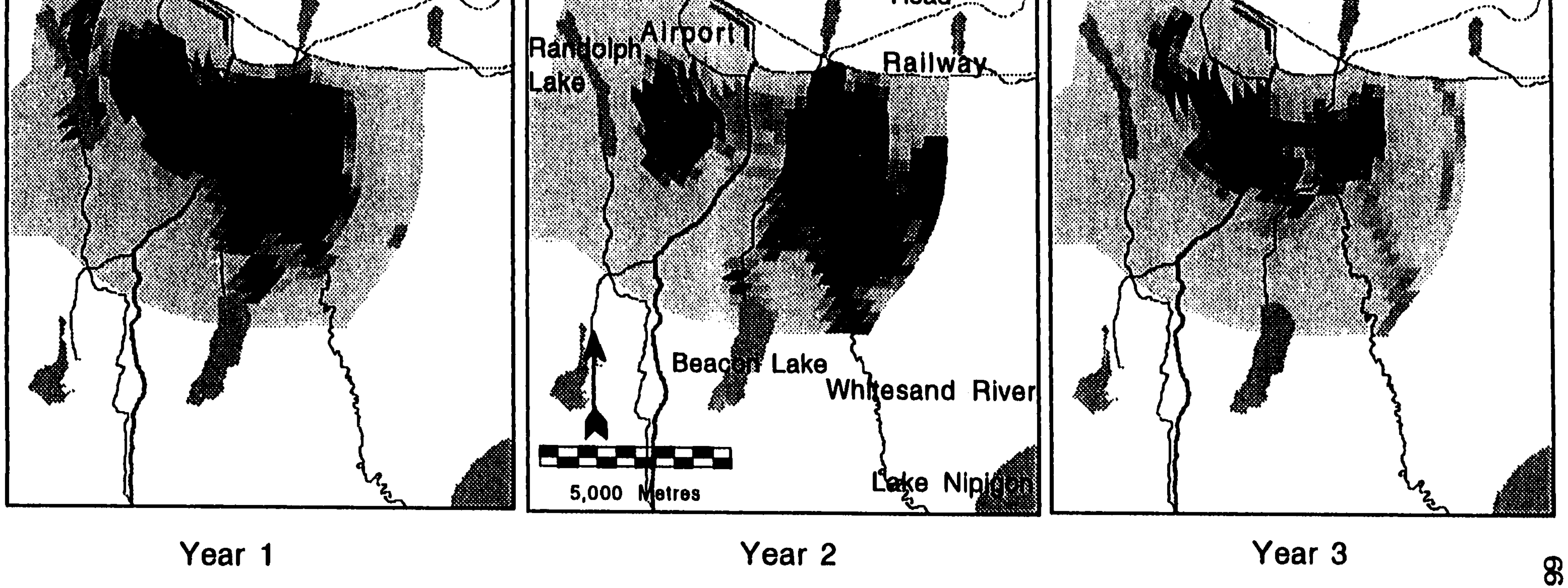


Fig. 6 "Contour" maps of track densities showing proportions of pixels with caribou tracks during the mid-winter period (Jan 7-Mar 11) when logs were hauled in year 2. The darker the area, the denser the tracks. The very light grey outer area indicates the extent of the prime study area.

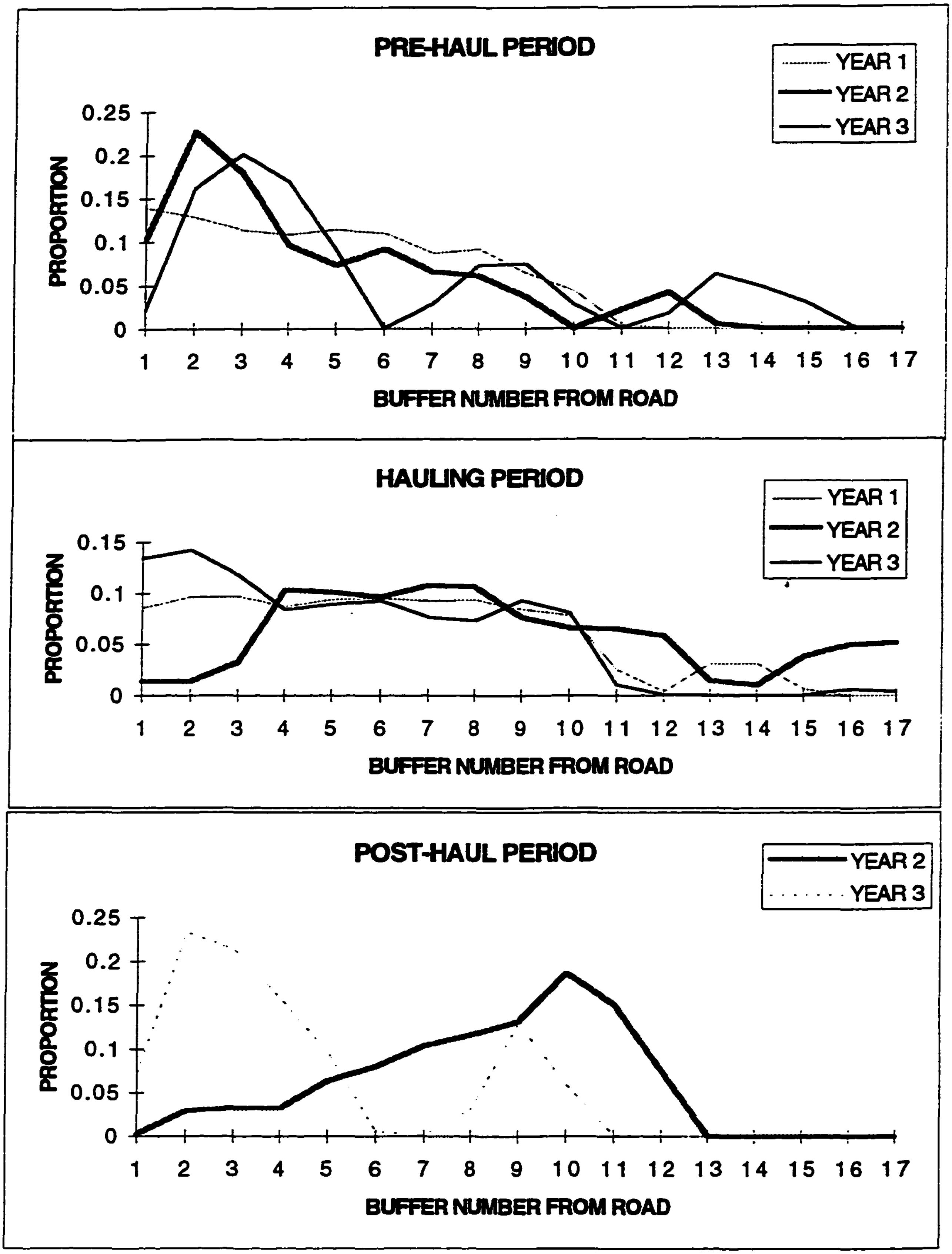


Fig. 7. Proportion of 300 x 300 m cells showing presence of caribou (based on tracks) in buffers numbered east and west from the Wabinosh Road.

"Contour" maps of caribou tracks showed proportions of occupied cells (GIS rastor polygons) concentrated in three preferred areas in year I: 1) the area directly south of the airport and from the Wabinosh Road ("haul road") to 2400 m west of that haulroad; 2) an area 1200-5400 m east of the haul road along the outlet from Beacon Lake; and 3) an area 2100-9900 m east of the haul road along the Whitesand River (Fig. 6). The area west of the haul road continued to be used in much the same way during year II, except for 600 m adjacent to the haul road which was used only lightly. The caribou virtually abandoned the area west of the haul road by late winter; areas east of the haul road were occupied later in years II and III. In year II, once logging began, caribou tracks showed almost no use of the area within 900 m of the haul road. Displacement away from the road during the post haul period was >2-3 km (for track data) and 8-60 km (for telemetry data). Caribou began to use the area along the Beacon Lake outlet in early winter, but discontinued its use during log hauling. In contrast, they continued to leave tracks in the Whitesands River area, farther from the haul road, even into late winter. Throughout the winter of year III, caribou used the area west of the haul road similarly to the use patterns of year I. However, east of the highway, the Beacon Lake area and the southern part of the Whitesand River area were little used. The northern section of the Whitesand River area, which was not favoured in years I or II, was used in year III. Most caribou left both eastern areas by late winter in year III.

The spatial distribution of areas used by caribou was graphed using data from 300 m buffer zones east and west of the road (Appendix 1). During year I (control year), caribou tracks were found on the road or close to the road throughout the winter; presence of tracks dropped with distance from the road (Fig. 7). In the year II hauling period, a large gap in use of cells within 1200 m of the road developed. During year III, a pattern similar to year I was re-established.

Chi-square tests showed significant differences among years for each of the 3 important periods of the experiment - before January 6 (pre-haul), January 7 - March 11 (hauling in year II) , and after March 11 (post-haul) (Table 5). No significant differences in caribou dispersions appeared between the pre-haul and hauling periods of year I. However, highly significant differences in dispersion were found for years II and III (chi-square = 50.92, 27.32, $P < 0.001, 0.002$). The differences in year II indicate that caribou changed their dispersion patterns at the time the road was plowed. The significant difference in year III might be accounted for by the later return of caribou to the PSA that year, as suggested from the maps, or from continued effects from the year II disturbance. No late-winter data were collected during year I. Post-haul dispersions did not differ from those during the hauling period in year II, whereas they did in year III. The lack of significant difference in year II suggests that the more remote (from the road) dispersions established by caribou during the haul period of year II carried through into the post-haul period. The change in year III could

Table 5.

Chi-square values and probabilities for percentages of pixels in cells indicating occupation by caribou and caribou tracks in nine 300m GIS buffers (total buffer width 2700 m). Six east-west rows of cells were chosen to avoid influences of north or south habitat changes. In year II, trucks hauled logs through the caribou wintering area. Years I and III were controls.

Test results:

	Winter periods and years		
	Comparison of pre-haul periods over all 3 years[1]	Comparison of haul periods over all 3 years[1]	Comparison of post-haul periods over years II, III
Chi-square	39.31	31.66	88.2
Probability	0.006	0.047	<0.001
	Pre-haul periods c.f. Years I, II[2]	Haul periods c.f. Years I, II[2]	
Chi-square	13.79	19.13	
Probability	0.183	0.039	
	Pre-haul period c.f. Haul period in year I[3]	Pre-haul period c.f. Haul period in year II[3]	Pre-haul period c.f. Haul period in year III[3]
Chi-square	5.5	50.92	27.32
Probability	0.856	<0.001	0.002
	Haul period c.f. Post-haul period in year II[4]	Haul period c.f. Post-haul period in year III[4]	
Chi-square	16.63	27.16	
Probability	0.083	0.003	

Notes:

1) All 3-year comparisons showed significant differences (including others not shown).

2) Pre-haul dispersion did not differ between years I and II, but dispersion during the hauling period did differ between years I and II.

3) Whereas dispersion in the periods before and during hauling did not differ significantly within the first (control) year, dispersion did differ significantly during the experimental year.

4) Dispersion during the hauling period did not differ significantly from the post-haul period in year II, but did in year III.

be due to heavier track densities during the January 6 - March 11 period, followed by reduced densities in the post-haul period as caribou began to move toward summer locations. Comparisons between years I and II showed no significant differences for the pre-haul period but a significant difference (chi-square = 19.13, P = 0.039) for the hauling period.

Control Area

Caribou were tracked entering the control area northeast of Jojo Lake from at least 10 km farther north during each of the three study years. However, some caribou also moved there from the Lake Nipigon islands, as indicated by radio-telemetry. Thus, the caribou in this wintering area came from at least two widely different summer locations (i.e. from an area well north of the study area, as well as from Lake Nipigon). Tracks of caribou in the control area showed that caribou occupied similar locations in all three years (Fig. 8). The only obvious shift in track distributions unique to year II constituted a filling-in of what had previously been an unoccupied strip near the northern end. Thus the caribou in the control area did not appear to be affected by the factors leading to changes in dispersion and movements during year II in the experimental area. Also, it appears that the study area in general did not have other factors (e.g. weather or snow) which might have caused the sort of effects seen in the experimental area in the treatment (haul) year.

POSSIBLE ALTERNATIVE EXPLANATIONS FOR CARIBOU DISTRIBUTIONS

Moose/Wolves

Moose tracks were not usually found near locations of caribou tracks (Fig. 7). An exception occurred in year II, when a southwestward extension of caribou tracks remote from the haul road coincided with a northward shift in moose tracks. This produced a small area near

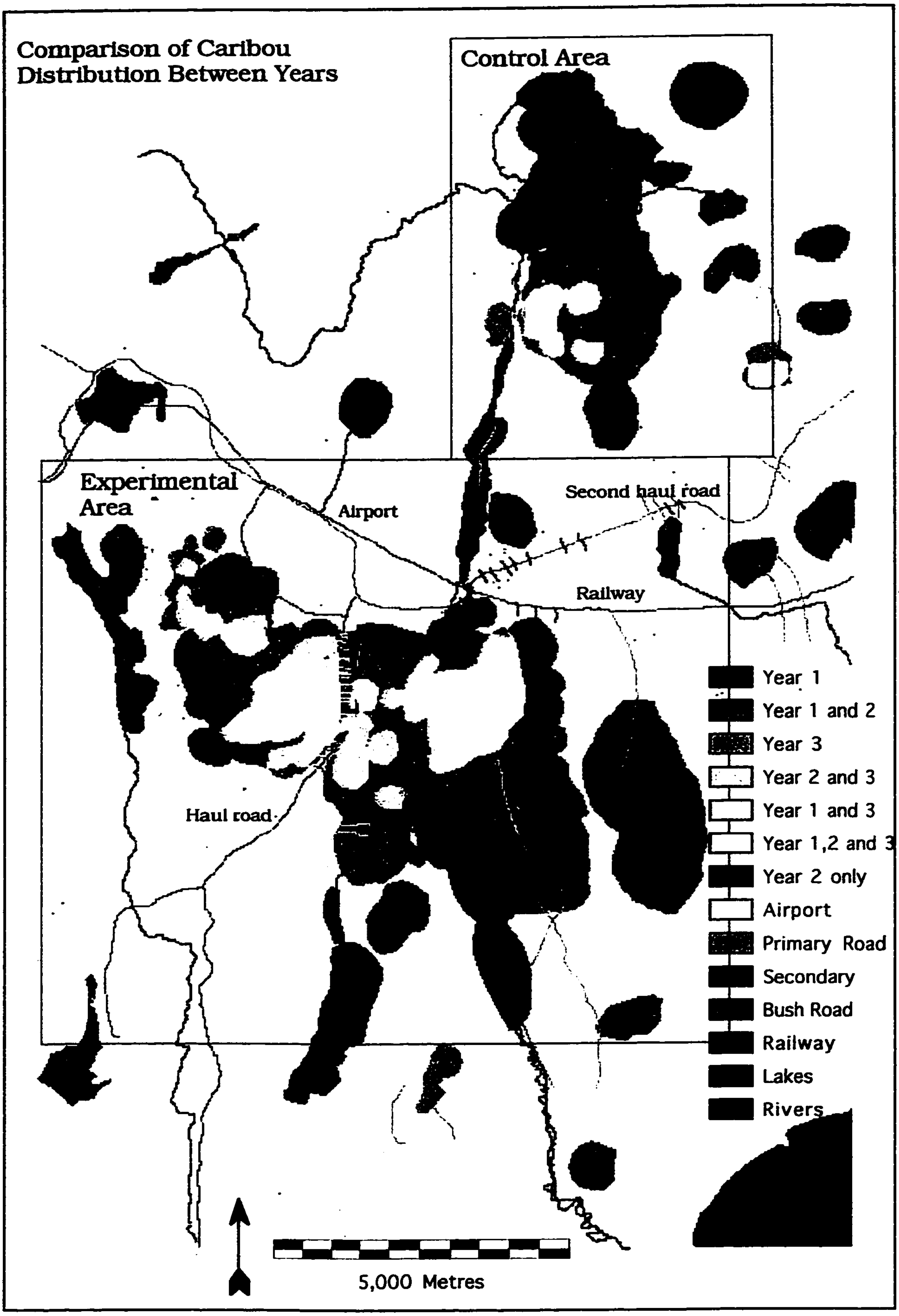


Fig. 8. Distribution of caribou tracks during three winters. Note the little change in distribution during experimental year II (red) in the control area (N.E. of Jojo Lake) compared to significant changes in the experimental area.

Randolph Lake in which caribou and moose tracks overlapped, the only such place in the three-year study. East of the haul road, caribou and moose were recorded in the same location, but in different years. Apart from snowmobile trails followed by wolves in portions of both the experimental area and the control area, wolf tracks were found primarily in the same locations as the moose. Few wolf tracks were observed at any time in the caribou winter refugia during the course of the study, even though they were frequently found where moose tracks were located. Wolf tracks were also common during ground investigations near the location of the timber harvesting operation (10 km to the south) in year II. Distances to nearest wolf were significantly greater for caribou than for moose in years I and II, but not significantly different in year III (Table 6).

Table 6.
Association of wolves with moose and caribou as indicated by numbers of pixels showing wolf presence within 900 m buffers of prey species.

Year	Prey species	Wolves present	No wolves	Totals	% used by wolves	Chi-square	Prob.
I	moose caribou total	3099 986 4085	8134 42883 51017	11233 43869 55102	27.6 2.2 7.4	8366.7	P<0.001
II	moose caribou total	11382 4064 15446	4580 41159 45739	15962 45223 61185	71.3 9.0 25.2	24279.9	P<0.001
III	moose caribou total	1362 2505 3865	11064 21294 32358	12426 23797 36223	11.0 10.5 10.6	1.679	P=0.1951

Mortality

In three winters of intensive flying, remains of only three dead caribou were found that had been fed upon by wolves, two of which were collared animals. The first caribou (#233) died 100 m from a snowmobile trail between Jojo and Whitesand Lakes sometime between Jan. 7 and Jan. 24, 1992. Interviews with a local hunter/trapper led to my suspicion that the animal might have been shot, and the remains subsequently eaten by wolves. Support for this belief, other than the impression gained during the interview, and the proximity of the snowmobile trail, came from caribou #293, the calf of caribou #233, which was not killed in year II and which lived through the remainder of the season. It would seem likely that the calf would have been killed (first, or also) if wolves had killed the mother.

The second kill was on Linklater Lake on Dec. 22, 1992, about 1.5 km from roads and cutting, on a travel route used by caribou approaching the control area from the north. Unsafe ice conditions made landing impossible to verify the identification, but the carcass lay on its back with intestines cleaned out, strongly suggesting a wolf kill.

The third kill was #293, the calf of #233. This calf survived the winter of year II, until October of year III, when it died on the shoreline of Lake Nipigon.

Not a single instance was observed of wolves or wolf tracks following a caribou or caribou tracks within the winter refugia, although these may have been missed. Wolves were frequently as close as 3 km from caribou in the airport area, yet no tendency for wolves to depart from human and moose trails was observed. There was no apparent interest by wolves in pursuing or stalking caribou in their winter refugia, in either the experimental area or the control area. This may be due to the ability of caribou to move relatively easily in deeper snow than can wolves. Peterson (1978) documented in great detail how wolves function poorly in deep snow. It may also be due to an apparent limitation of wolves to detect prey by scent (moose in this case) only up to 2.4 km, as reported by Mech (1966). In contrast, wolves were spotted in close association with moose, moose tracks, and roads and human trails (made by snowshoes, snowmobiles, and other vehicles) (Fig. 9).

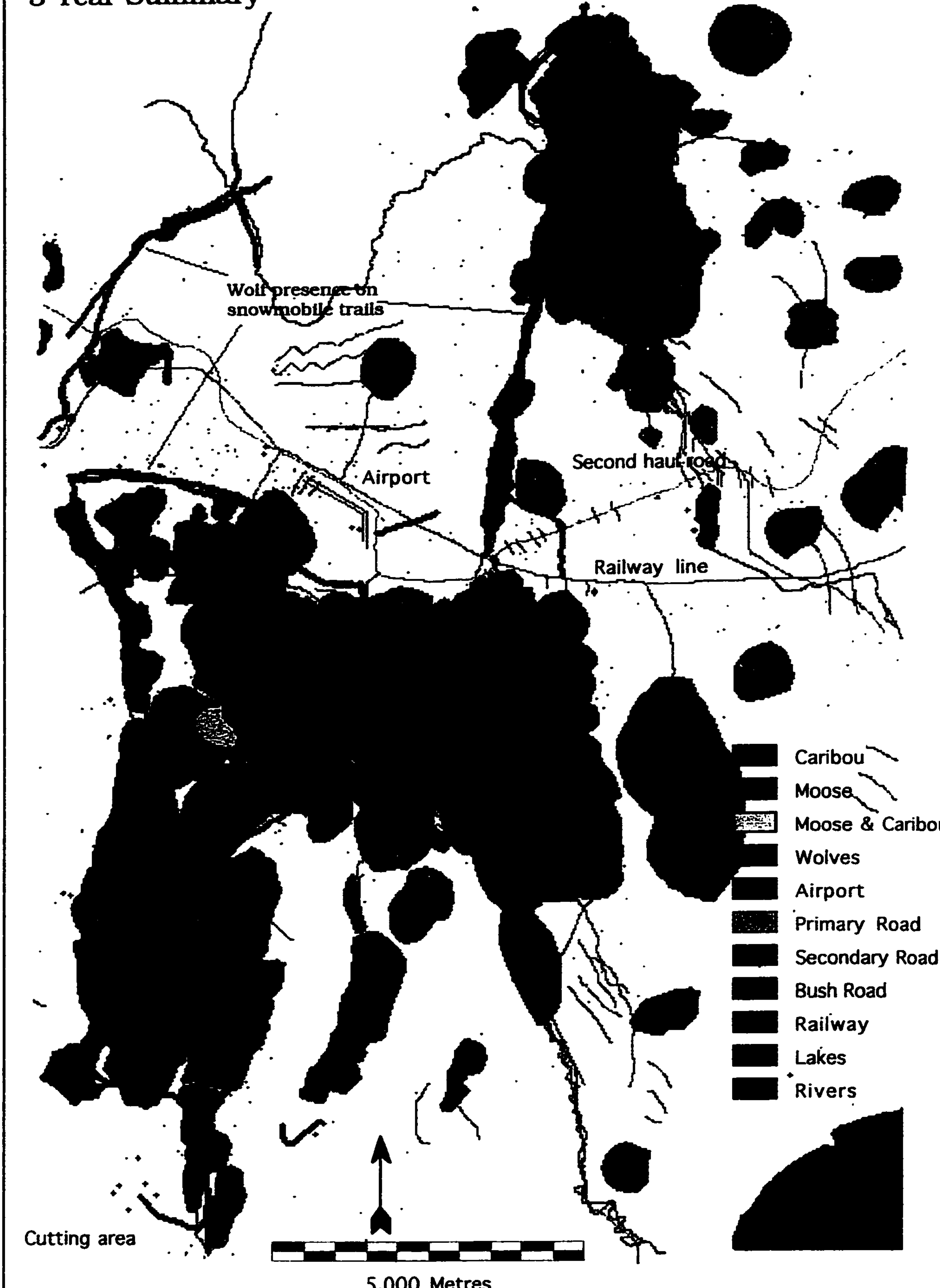


Fig. 9. Three years' combined track data showing habitat partitioning by caribou and moose (Note: moose and caribou overlap was in year 2 only). Wolves travelled mostly roads and snowmobile tracks, and were mostly associated with moose, rather than caribou.

Snow

Snow pits showed slightly deeper snow in year II than in years I and III (Table 7). Records from the OMNR snow station at Flat Lake confirmed the greater snow depths in the year II, but also showed greater snow depths in the year before the caribou study began (Table 7). Maximum reported snow depth was 71 cm in March of year II. The heaviest crusts were in year I when some layers of pure ice resulted from a brief rainfall; crusts were lightest in year III. Densities also averaged consistently highest in year I.

Stardom (1975) determined critical levels, i.e. levels that initiated emigration from an area, for caribou in Manitoba as follows:

depth	- 65 cm
hardness	- 80 g/cm^2 for jack pine ridge areas - 400 g/cm^2 for open bog areas - 700 g/cm^2 on lakes
density threshold	- 0.20-0.36 for jack pine ridges - 0.18-0.24 for bog areas - 0.25-0.33 for lakes

Snow depths in the jack pine winter habitat never exceeded Stardom's (1975) critical 65 cm snow depth. The snow hardness threshold was exceeded in up to four layers during year I, but rarely in the other years. Lowest density thresholds were exceeded in two snow pits dug in year I, and one snow pit in year II. Snow depths under the conifers in the winter habitat of the PSA were less than half the snow depths in nearby clearcuts. The tendency for snow depth and hardness

Table 7. **Snow conditions determined from pits dug as part of this study,and depths reported by the OMNR snow station at Flat Lake, Ont. Data from the treatment year are shown in bold.**

Year			**YEAR -1**	**YEAR I**	**YEAR II**	**YEAR III**
			1989-90	1990-91	**1991-92**	1992-93
				SNOWPIT DATA		
Dates				**16-Mar**	**(11-Mar) 8-Apr**	**11-Mar**
Snow depth (cm)						
Open location	Snowpit 1			61	**(69) 58**	48
	Snowpit 2			58	**79**	53
Forested location	Snowpit 1			62	**55**	55
	Snowpit 2			60	**n/a**	50
Comparable OMNR reported depths: Dates				11/18 Mar	**9/16 Mar**	8/15 Mar
		Depths		57/46	**71/73**	57/59
Snow hardness (g/cm^2)						
Open location	Snowpit 1	Mean		230	**(54) 74**	38
		Maximum		750	**(78) 100**	75
		# layers> 80		4	**(0) 2**	0
	Snowpit 2	Mean		1814	**47**	8
		Maximum		6500	**70**	10
		# layers> 80		4	**0**	0
Forested location	Snowpit 1	Mean		233	**35**	29
		Maximum		600	**67**	65
		# layers> 80		3	**0**	0
	Snowpit 2	Mean		1771	**n/a**	12
		Maximum		7000	**n/a**	35
		# layers> 80		1	**n/a**	0
Mean densities per snow pit						
Open location	Snowpit 1			0.22	**0.3**	0.12
	Snowpit 2			0.26	**0.16**	0.11
Forested location	Snowpit 1			0.25	**0.13**	0.16
	Snowpit 2			0.12	**n/a**	0.12

Snow depths recorded by OMNR personnel at Flat Lake snow station

Week 13 or 14 (includes January 6, the the date when the road was plowed in year II).				
Average depth (cm)	57	47	**59**	55
Crust	A	A	**C**	B
Week 22 or 23 (includes March 11, the last day of log hauling in Year II).				
Average depth (cm)	66	57	**71**	57
Crust	C	C	**C**	B
First recorded snow depth	6-Nov	26-Nov	**4-Nov**	9-Nov
No. of weeks of snow> 65 cm	8	0	**10**	0
Greatest depth (cm)	79	63	**76**	59
Last recorded snow depth	23-Apr	15-Apr	**25-May**	12-Apr

Notes: 1) Stardom (1975) reported 65 cm, 80 g/cm^2, 0.20-0.36 thresholds for jack pine ridges in Manitoba.

to be lower under conifer canopies than under either deciduous canopies or no canopy is well documented (e.g. Peterson (1978), who found that snow depths on Isle Royale under conifer canopies were about half that of snow depths in the open).

IX) DISCUSSION

Results of the log hauling experiment support the hypothesis that log hauling causes caribou to modify their winter dispersion and movements in measurable ways, and thus appear to confirm the results of Brousseau (1978) that disturbance by machinery associated with timber harvesting can affect caribou from as much as 2+ km distance. The first null hypothesis (that caribou would show no measurable reaction) was ruled out by the significant changes in caribou dispersion following initiation of log hauling in year II. When log hauling began, the six radio-collared caribou all left the experimental hauling area and fresh tracks of caribou became visible only beyond 2-5 km from the haul road. Dispersions differed significantly between the pre- and post-haul periods of year II. No similar changes were observed in the control area, and since the changes coincided with initiation of moving machinery and trucks through the caribou wintering area, the inference seems strong that the caribou moved as a result of the logging activities.

However, the second null hypothesis (that factors other than log hauling could cause the effects) needs to be considered, because coincidence by itself is not proof of causality. Other possible factors affecting dispersion and movement might also have coincided with the initiation of logging activities, and these other factors might have caused the caribou to change their dispersions, rather than any disturbance from the log hauling itself. It is difficult to rule out all other possibilities, but those that appear most likely were examined.

Neither moose nor wolves seem to have been likely agents of change in year II since neither spent any appreciable time in areas occupied by the caribou. The small overlap between areas showing tracks of caribou and moose in year II appeared to result from changes in caribou dispersions. The observations that wolf tracks were located with moose tracks rather than caribou tracks, along with the virtual absence of wolf tracks or observations from areas occupied by caribou, strongly suggest that wolves did not cause the caribou to change dispersions in year II.

Changes in snow depths might have affected the caribou since deepest snows occurred in year II. However, depths in the winter refugia never exceeded critical thresholds for caribou reported for Manitoba by Stardom (1975), nor were they unusual for the study area; similar snow depths were recorded the year before the study began, and by Cumming and Beange (1987) in my study area and surrounding country in two of four winters in a previous study. Snow consistency did not appear to be a factor either since the heaviest crusts, hardness values, and densities, factors that might make digging in snow difficult and therefore force caribou to move, all were more adverse in year I. Furthermore, the absence of similar changes in caribou dispersion in the control area during year II suggested that differences in general snow conditions would not likely explain the experimental results.

While snow depths did not appear to be a significant stressor to caribou, it is interesting to note that Nasimovich (1955, cited in

Peterson 1978) found that wolves had difficulty pursuing ungulates in uncrusted snow over 41 cm deep, and that "with depths greater than 50-60 cm pursuit through untracked snow was almost impossible", thus helping to explain why wolves did not attempt accessing or chasing caribou in their Armstrong winter refugia. Peterson (1978) found that wolves did most of their killing of moose within 0.8 km of a trail, or shoreline, where snow depths were less or snow hardness was greater. Further evidence of wolf ineffectiveness in soft snow is their inability to outrun foxes in most (uncrusted) snow conditions (Peterson 1978).

Although changes in habitat due to fire occurred some 5 km or more distant to the southeast during the summer of 1991, fires did not occur in the winter refugia. No other habitat changes that could have accounted for the caribou movements were recorded.

No changes in poaching or native hunting were noted. Snowmobiles showed some disturbance potential, but at a lower magnitude, showing caribou displacements of 200-300 m. Klein (1971) reported similar snowmobile disturbance of reindeer (*Rangifer tarandus tarandus*) in Scandinavia, stating that if approached too closely the reindeer may panic and become unmanageable. Perhaps the human activity most likely to have affected results would be use of the haul road by private vehicles after the hauling period in year II. This continued activity might have extended the disturbance period.

From these results, I rule out the listed possible disturbance factors other than log hauling. I had hoped to include an experiment to determine whether human scent was involved, as Simpson (1985) suggested in British Columbia, but no possible approach seemed practical. Therefore, I conclude that in this instance, hauling logs through a caribou wintering area caused caribou to change their behaviour by shifting their winter dispersion from areas near the road to areas farther from the haul road. Jackson (1990) reported a similar move from the same caribou wintering area during December, 1989, when trucks were hauling logs on the same road.

Some might argue that such a shift in winter location would be of little consequence. However, observations associated with this study suggest otherwise. The caribou killed or scavenged by wolves outside the major wintering areas, and the one killed by wolves on an approach to the control study area, suggest that the immunity to predation enjoyed by caribou in their wintering refugia (Cumming *et al.* 1994) may not extend elsewhere.

Consider the possible fates of the radio-collared caribou. The one that moved to the control area might have been equally safe in that refuge once there, but faced hazards en route. The two collared caribou that moved to the north would almost certainly have faced higher predation risk. The caribou that moved back to the Lake Nipigon islands did so in the face of poorer habitat conditions and increased wolf presence. Bergerud *et al.* (1990) concluded that winter food on the Lake Nipigon islands was scarce, and pointed out that the protection from predators enjoyed by caribou on these islands during summer was removed by the presence of winter ice.

As an example of how returning early to the islands increases risk of predation, a caribou was found killed by wolves near one of the islands during the winter of 1989 (Beange pers. comm. 1990). Furthermore, some movements resulting from the log hauling brought caribou into close contact with moose, and presumably wolves, within the study area. Cumming and Beange (1993) suggested that the best explanation for disappearance of caribou bands in Ontario was displacement from their wintering areas by logging, thus forcing them into places having reduced protection from wolves, poaching, and accidents. The results of this study suggest that displacement due to winter traffic might have similar effects.

Cumming *et al.* (1994) showed that habitat partitioning by caribou and moose resulted in caribou putting greater distances between themselves and their predators, producing implicit refuges (Holt 1984). This result seems to have been supported by the patterns of caribou, moose and wolf tracks in the present study. The virtual absence of wolves from the caribou wintering area may have been due to habitat partitioning similar to that described by Cumming *et al.* (1994). The tendency for wolves to follow human trails (snowmobiles, trucks) documented elsewhere (Fritts *et al.* 1984) was confirmed in this study.

Bergerud *et al.* (1984) stated a hypothesis that "viable caribou herds cannot survive on ranges frequented by a high number of wolves (maintained mainly by moose prey) unless there are special (summer) habitat features providing escape for cows with young calves." I believe that this hypothesis would become much more useful and supportable if the following components were added to it:

- adequate buffers around winter refugia to allow habitat partitioning to segregate moose and wolves from caribou, and
- freedom from human activities or mechanized sounds, or other human sources of disturbance, within 2-3 km of important winter caribou habitats.

Bergerud (1974) suggested that one might expect to find caribou exhibiting adaptive modification to human activities when food or weather are the primary influences on caribou behaviour. Would caribou become habituated to traffic if the road were plowed every year? The return of caribou to the PSA in the third year suggests some degree of resilience after disturbance (also reported for an unknown disturbance to another band by Cumming and Beange) (1987), but if the apparent reduction in numbers in the third year was real, it would suggest otherwise. If the road were travelled every winter, the observed displacement of caribou might continue in a way similar to that of caribou in the control area. Although small groups of caribou frequently cross the Pikitigushi Road where they are sighted by local people and truckers, aerial surveys indicate that the sightings of caribou on the roads result from linear movements at right angles to it. Although it might appear to observers limited to the ground that the area along the road was utilized (albeit rarely), the actual concentration of most caribou in the control area remains 2-3 km from the Pikitigushi Road. The extent to which this displacement may have reduced caribou numbers in that band is not known. Therefore, long-term effects of disturbance remain uncertain.

Without disputing the validity of either or both of the two other major theories attempting to explain caribou declines in certain situations, one can speculate that the third possibility - severe or chronic disturbance to caribou - might also cause or contribute to range reduction or population decline. Unlike moose, caribou are not strong enough to fight off predators successfully (Gollat pers. comm. 1997). Caribou occupying traditional winter habitats may be sensitive to predation, or to the perceived risk of predation. Consequently, they may also be extremely sensitive to sounds that are unfamiliar, or that may hide the sounds of wolves. Therefore, habituation such as that reported in British Columbia (Johnson and Todd 1977) and Newfoundland (Hill 1985) may be more likely where predators on winter range are rare or nonexistent. Where predators are present in or near winter range, caribou may abandon, temporarily or permanently, otherwise suitable habitat if stressed chronically by noise or other stimuli (e.g. sight, smell) that may put them on "predator alert". Thus, they may be forced into habitats with increased metabolic demand, decreased quality or quantity of food, and increased susceptibility to predation. The response to disturbances may differ between different age and gender categories of caribou. Messier (pers. Comm. 1997) indicates that mature females, particularly those with calves, may be the most hypersensitive.

Researchers and the lay public have observed how caribou sometimes tolerate human influences. One possible explanation for this may lie with different responses by different age or sex categories of caribou. Another potential explanation for the apparently contradictory observations as to how sensitive species sometimes seem to habituate to human activities, while at other times (or even at the same time) put large distances between themselves and similar human activities, has been proposed for osprey by D'Eon and Watt (1994). Their studies indicate that osprey reproductive success is usually high far from human activities, but sometimes is also high for habituated populations in suitable habitats with constant disturbance. However, reproductive success is extremely low for habitats that are usually remote, but with moderate or intermittent disturbance (Fig. 10). Therefore, it is possible in some circumstances to have no effect from disturbance in some (habituated) situations, yet have large effects with the same species at greater distances. Similar reactions may help to explain the apparently contradictory observations of caribou behaviours.

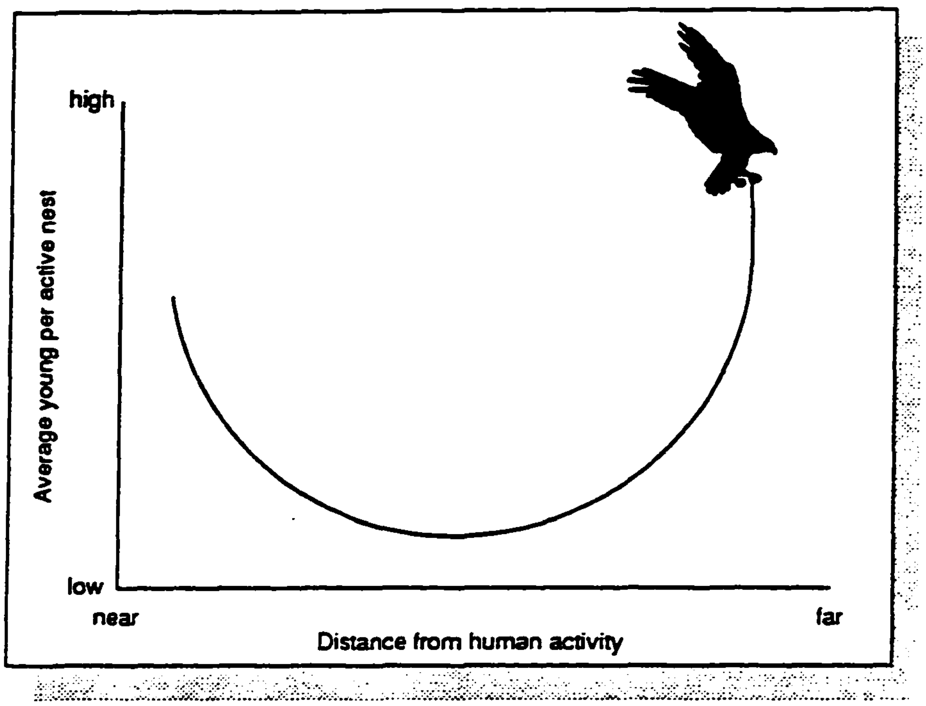


Fig. 10. Relationship between osprey nest productivity and nest distance from human disturbance (based upon data from Van Daele and Van Daele, 1982) (*In* D'Eon and Watt 1994).

X) MANAGEMENT IMPLICATIONS

This study indicates that log hauling through caribou wintering areas in northwestern Ontario has a potential for substantial adverse effects to caribou. Evidence suggests that the caribou may be encouraged to move to other areas where predator protection is less effective, in ways similar to movements when wintering areas are logged (Cumming and Beange 1993). Cutting and hauling are probably the most important factor, but roads also allow access by non-logging vehicles as indicated by the sample of vehicles in our sound study. This increased access to the wintering area by the general public could increase vehicular accidents, poaching, and access by wolves (c.f. guidelines for reducing road impacts in British Columbia by Johnson and Todd) (1977).

The return of caribou to the study area during year III suggests that some of the effect of log hauling may have been short term. However, there was some suggestion that returning numbers were fewer. If that is the case, it might be possible to haul through caribou wintering areas on an occasional basis without permanent abandonment by caribou. However, if the local caribou band were already barely maintaining numbers against predators, accidents, and poachers, this addition of new stress factors could be significant. It may also be that a "critical mass" of disturbance may be reached where disturbance is sufficiently intense or repetitive to cause range abandonment, as reported by Brousseau (1978). Once the knowledge of that winter refuge were lost, it might be difficult indeed for small numbers of caribou in a large landscape to regain knowledge of the area and reoccupy it.

Although a complete ban on hauling through caribou wintering areas may not always be possible, these considerations suggest that use of such roads in winter (i.e. Mid-November to mid-April) should be avoided. Thus, management action should aim at minimizing locations of roads through or near caribou wintering areas, and restricting the use of existing roads. Furthermore, movements of caribou relative to the logging road in this study, and placement of moose and wolves relative to caribou, seem to support the suggestion by Cumming (1996) that a 3 km no-disturbance buffer should be established around caribou wintering areas.

REFERENCES

Ahti, T. and R.L. Hepburn. 1967. Preliminary studies on woodland caribou range, especially on lichen stands, in Ontario. Ontario Dept. Lands and For. Toronto. Res. Rep. #74 (Wildl.). 134 pp.

Anderson, R.C. 1972. The ecological relationship of meningeal worm and native cervids in North America. J. Wildl. Dis. 8(4): 304-310.

Antoniak, K. 1993. Forest analyses and modelling of wintering areas of woodland caribou in northwestern Ontario. M. Sc. F. Thesis, Lakehead Univ. Thunder Bay. 97 pp.

Baldwin, K.A., J.A. Johnson, R.A. Sims, and G.M. Wickware. 1990. Common landform toposequences of northwestern Ontario. OMNR, N.W. Ont. For. Tech. Dev. Unit. Thunder Bay. Rep. 49. 26 pp.

Banfield, A. W. F. 1955. A provisional life table for the barren ground caribou. Can. J. Zool. 33:143-147.

Banfield, A.W.F. 1961. A revision of the reindeer and caribou genus *Rangifer*. Mus. Of Canada Bull. 177. 137 pp.

Beange, D.B. 1979. Great West Timber cutting request. Sept. 13 memo to G.T. Marek. OMNR Nipigon Distr. Nipigon, Ontario.

Bergerud, A. T. 1961. Reproduction of Newfoundland caribou. M. Sc. Thesis. Univ. of Wisconsin. Madison,WI.

Bergerud, A. T. 1963. Aerial winter census of caribou. J. Wildl. Manage. 27:438-449.

Bergerud, A. T. 1969. The population dynamics of Newfoundland caribou. Ph.D. Thesis. Univ. of British Columbia. Vancouver.

Bergerud, A.T. 1971. Abundance of forage on the winter range of Newfoundland caribou. Can. Field-Nat. 85:39-52.

Bergerud, A.T. 1974a. The decline of caribou in North America following settlement. J.Wildl. Manage. 38:757-770.

Bergerud, A.T. 1974b. The relative abundance of food in winter Newfoundland caribou. Oikos 25:379-397.

Bergerud, A. T. 1974c. The role of the environment in the aggregation, movement and disturbance behaviour of caribou. Pages 552-584: In V. Geist and F. Walther. The behaviour of ungulates and its relation to management. IUCN, Calgary

Bergerud, A. T., and H. E. Butler. 1974. Wildlife investigations on the Slate Islands: June 15- July 14 and September 30- November 21, 1974. Unpubl. OMNR Report, Terrace Bay, Ont.

Bergerud, A.T. and H.E. Butler. 1975. Some rambling thoughts on caribou distribution and abundance in the Armstrong-Nipigon Region. Unpub. OMNR, Nipigon Dist. 53 pp.

Bergerud, A. T. 1978. Caribou. pp. 83-101. In: Schmidt, J. L.and D. L. Gilbert, ed. Big Game of North America: Ecology and Management. Stackpole Books, Harrisburg, Pa. 494 pp.

Bergerud, A.T. 1979. Status of *Rangifer* in Canada (*Rangifer tarandus caribou)* pp. 748-753 In: Reimers, E. *et al.*, Proc. 2nd Int. Reindeer/Caribou Symp. Roros, Norway. 1979. 799 pp.

Bergerud, A. T. 1980. A review of the population dynamics of caribou and wild reindeer in North America. In: Reimers, E. *et al.*, Proc. 2nd Int. Reindeer/Caribou Symp. Roros, Norway. 1979. 799 pp.

Bergerud, A. T. 1982. Caribou. *In:* D. E. Davis, (ed.) CRC Handbook of Census Methods for Terrestrial Vertebrates. 268-270.

Bergerud, A.,T. 1983a. Prey switching in a simple ecosystem. Sci. Amer. 249:130-141.

Bergerud, A. T. 1983b. The natural population control of caribou. Pages 14-61 *In:* Bunnell, F. L, .D. S. Eastman, and J. M. Peek, (eds.) Symposium on Natural Regulation of Wildlife Populations. 14-61.

Bergerud, A. T., M. J. Nolan, K. Curnew, and W. E. Mercer. 1983. Growth of the Avalon Peninsula, Newfoundland, caribou herd. J. Wildl. Manage. 47:989-998.

Bergerud, A.T., R.D. Jakimchuk and D.R. Carruthers. 1984a. The buffalo of the north: caribou (*Rangifer tarandus*) and human developments. Arctic 37(1): 7-22.

Bergerud, A.T., H.E. Butler, and D. R. Miller. 1984b. Antipredator tactics of calving caribou: dispersion in mountains. Can. J. Zool. 62:1566-1575.

Bergerud, A.T. 1985. Anti-predator strategies of caribou: dispersion along shorelines. Can. J. Zool. 63(6):1324-1329.

Bergerud, A. T., and J. P. Elliot. 1986. Dynamics of caribou and wolves in northern British Columbia Can. J. Zool. 64:1515-1529.

Bergerud, A.T., and R.E. Page. 1987. Displacement and dispersion of parturient caribou at calving as antipredator tactics Can. J. Zool. 65:1597-1606.

Bergerud, A.T. And W.B. Ballard. 1988. Wolf Predation on caribou: the Nelchina herd case history; a different interpretation. J. Wildl. Manage. 52:344-357.

Bergerud, A.T. 1989a. Aerial census of caribou and wolves in Wabakimi Provincial Park. March, 1989, OMNR Unpubl. Report Bergerud and Assoc. Fulford harbour, B.C. 41 pp.

Bergerud, A. T. 1989b. The abundance, distribution and behaviour of caribou in Pukaskwa National Park, 1972-1988. Bergerud and Associates, Contract # 88-CPS-PUK, Scientific Review of Caribou Management Activities in Pukaskwa National Park. 57 pp + tables + figures.

Bergerud, A. T., and W. E. Mercer. 1989. Caribou Introductions in Eastern North America. Wildl. Soc. Bull. 17:111-120.I
Bergerud, A. T. 1990. Rareness as an antipredator strategy to reduce predation risk. Pages 15-25 In Trans. 19th IUGB Congress, Trondheim 1989.

Bergerud, A. T., R. Ferguson, and H.E. Butler. 1990. Spring migration and dispersion of woodland caribou at calving. Anim. Behaviour. 39 : 360-368.

Bloomfield, M. 1980. The impact of development, settlement and associated activities on mountain caribou in central British Columbia. Pages 705-715: *In* E. G. Reimers *et al.* Proc. 2nd Int. Reindeer/Caribou Symp., Roros, Norway. 1979. 799 p.

Brousseau, C. 1978. Trends in the woodland caribou (*Rangifer tarandus*) population in the Cliff Lake area of the Dryden District 1972-1978. OMNR Unpubl. Report 25 pp.

Brown, W.K., J. Huot, P. Lamothe, S. Luttik, M. Pare', G. St. Martin, and J.T. Theberge. 1986. The distribution and movement patterns of four woodland caribou herds in Quebec and labrador. Rangifer Spec. Issue. 31:(42-49).

Buss, M.E. and J.M. Barboski. 1974. Winter habitat utilization by woodland caribou in the Hudson Bay Lowlands. OMNR Unpubl. 12 pp.

Butler, H. E., and A. T. Bergerud. 1978. The unusual story of the Slate Island caribou. Nat. Can. (Ottawa) 7:37-40.

Calef, G.W., E.A. Debock and G.M. Lortie. 1976. The reaction of barren ground caribou to aircraft. Arctic. 29(4): 210-212.

Carrol, S.B. and L.C. Bliss. Jack pine-lichen woodland on sandy soils in northern Saskatchewan and northeastern Alberta. Can. J. Bot. 60:2270-2282.

Chubbs, T.E., L.B. Keith, S.P. Mahoney, and M.J. McGrath. 1993. Responses of woodland caribou (Rangifer tarandus caribou) to clear-cutting in east-central Newfoundland Can. J. Zool. 71:487-493.

Clarke, C.H.D. 1948. Caribou on the islands of Lake Nipigon, Res. Mgmt. Report, Ont. Dept. Lands and Forests, Toronto.

Cringan, A. T. 1957. History, food habits and range requirements of the woodland caribou of continental North America. Pages 481-501 In Trans. North Am. Wildl. Conf. 22.

Cumming, H.G. 1975. Clumping behaviour and predation with special reference to caribou. Pages 474-479 *In:* Proc. First Int. Reindeer/Caribou Symp. Fairbanks, AK 1975. U. Alaska

Cumming, H.G. 1981. Caribou Country. Seasons, Summer: 16- 30.

Cumming, H.G. And D. B. Beange. 1987. Dispersion and movements of woodland caribou near Lake Nipigon, Ontario. J. Wildl. Manage. 51(1):69-79.

Cumming, H.G. 1989. First year effects of moose browse from two silvicultural applications of glyphosate in Ontario. Alces. 25 : 118-132.

Cumming, H.G. 1991. Report on Two Summers' Caribou Tagging for Partnership Caribou Res. Project. unpubl.

Cumming, H.G. 1992. Woodland caribou: facts for forest managers. For. Chron. 68 (4) : 481-491.

Cumming, H.G. and Beange, D.B. 1993. Survival of woodland caribou in commercial forests of northern Ontario. For. Chron. 65: 579-588.

Cumming, H.G., D.B. Beange, and G. Lavoie. 1994. Habitat partitioning between woodland caribou and moose in Ontario: the potential role of shared predator risk. Rangifer. Special Issue no. 9 : 81-94.

Cumming, H.G. 1996. Managing caribou in a partitioned habitat. Rangifer, Special Issue No. 9: 171-180.

Curatolo, J.A. and S.M. Murphy. 1986. The effects of pipelines, roads, and traffic on the movements of caribou, *Rangifer tarandus*. Can. Field Nat. 100:218-224.

Darby, W.R. and W.O. Pruitt. 1984. Habitat use, movements, and grouping behaviour of woodland caribou (*Rangifer tarandus caribou*) in southeastern Manitoba. Can. Field-Nat. 98:184-190.

Darby, W.R. and L.S. Duquette. 1986.Woodland caribou and forestry in northern Ontario, Canada. Rangifer, Special Issue #1:87-93.

Darby, W.R., H.R. Timmermann, J.B. Snider, K.F. Abraham, R.A. Stefanski, and C.A. Johnson. 1989. Woodland caribou in Ontario. Background to a policy. Ontario Ministry of Natural Resources. Unpubl. 37 pp.

Dau, J. R., and R. D. Cameron. 1986. Effects of a road system on caribou distribution during calving. Rangifer 95-101.

Dauphine, T.C. Jr. 1975 The disappearance of caribou re-introduced to Cape Breton Highlands National Park. Can. Field-Nat 89(3): 299-310.

D'Eon, R.G. and W.R. Watt. 1994. Osprey Management guidelines in northeastern Ontario; a review. OMNR, Northeast Sci. & Technol. Timmins, Ont. TR-108. 24 pp.

De Vos, A. 1948. The former and present distribution of the woodland caribou (*Rangifer caribou*) in northern Ontario, with suggestions for its management. Dept. of Lands and Forests, Ontario. Paper presented to Tenth Midwest Wildlife Conf. Ann Arbor, Mich. Dec. 9-11. Mimeo.

DeVos, A. and R.L.Peterson. 1951. A review of the status of woodland caribou (Rangifer caribou) in Ontario. J. Mamm. 32 (2) : 329-337.

Dobbs, A. 1744. An Account of the countries adjoining to Hudson's Bay, *In:* J. Robinson, London. Old Fort William Resource Library, Thunder Bay.

Dugmore, A.A.R. 1913. The romance of the Newfoundland caribou. J.P. Lippincott Co., Philadelphia. 186 pp.

Dugmore, A.A.R. 1930. In the heart of the northern forests. Chatto and Windus, London. 243 pp.

Edmonds, E. J., and M. Bloomfield. 1984. A study of woodland caribou (*Rangifer tarandus caribou*) in west central Alberta 1979- 1983. Alberta Energy and Natural Resources, Fish and Wildl. Div., Edmonton, Alberta. 203 pp.

Edmonds, E. J. 1988. Population status, distribution, and movements of woodland caribou in west central Alberta. Can. J. Zool. 66 : 817-826.

Edwards, R. Y. 1954. Fire and the decline of a mountain caribou herd. J. Wildl. Manage. 18 : 512-526.

Ekholm, R. 1972. Caribou in area face competition. Bush Beat, Thunder Bay Chron. Journ. Date uncertain.

Elliott, J. P. 1989. Wolves and ungulates in British Columbia's northeast. 97-123 In Wolf-prey dynamics and management, Vancouver, B. C., B. C. Ministry of Environment, Victoria.

Elsey, C.A. 1975 Woodland Caribou-Armstrong Airport Area. Unpubl. Memo Feb. 10, OMNR Thunder Bay Dist.

Euler, D.L., B.Snider, and H.R. Timmermann. 1976. Woodland caribou and plant communities on the Slate Islands, Lake Superior. Can. Field-Nat. 90:17-21.

Fancy, S. G., and R. G. White. 1985. Energy expenditures by caribou while cratering in snow. J. Wildl. Manage. 49:987-993.

Fawcett, D.A. 1979. Proposed Indian Reserve-Wagaming Station Area. Jan 15 memo Reg. Lands Coord. OMNR North Central Region.

Ferguson, S. H., A.T. Bergerud, and R. Ferguson. 1988. Predation risk and habitat selection in the persistence of a remnant caribou population. Oecologia (Berl.) 76:236-245.

Fletcher, J.L. 1978. Effects of Noise on Wildlife. Academic Press, N.Y.

Fort William Journal. 1823-4. *In* Old Fort William Resource Library, Thunder Bay, Ont.

Fort William Report. 1824. *In* Old Fort William Resource Library, Thunder Bay, Ont.

Freddy, D. J. 1979. Distribution and movements of Selkirk caribou, 1972-74. Can. Field-Nat. 93 (1) : 71-74.

Fritts, S. H., W.J. Paul, and L.D.Mech. 1984. Movements of translocated wolves in Minnesota. J. Wildl. Manage. 48 (3) : 709-721.

Gauthier, D.A. and J.B. Theberge. 1986. Wolf predation in the Burwash caribou herd, southwest Yukon. Rangifer. Special Issue No. 1 : 137-144.

Geraldton (Ontario) Local Citizens' Committee (LCC). 1995. Response to the OMNR Proposed Caribou Mosaic.

Gilmer, D. S., L.M.Cowardin, R.L.Duval, L.M.Mechlin, C. W. Shaiffer, R. Kuechle, and R. Gollat. 1976. A preliminary investigation into the fish and wildlife values of the islands of Lake Nipigon. Unpubl. Rep. OMNR, Thunder Bay.

Godwin, L. 1990. Woodland caribou in northern Ontario: Why are they so different? OMNR. NW Ont. For. Tech. Dev. Unit, Thunder Bay. TN-07. 7 pp.

Gray, Paul A. 1978. Native Peoples harvest of woodland caribou (Rangifer tarandus caribou) in the West Patricia Area, 1960 to 1978. OMNR Unpubl. Rep.

Hagan, D. 1968. Aerial caribou survey: Irregular Lake study area. OMNR Sioux Lookout District.

Hamilton, G. D. 1978. Aerial census of woodland caribou in the West Patricia Planning Area (December). OMNR Unpubl. Rep. 14 pp.

Harris, A.G. 1991. Woodland caribou habitat inventory: West Caribou, east caribou, Brightsand, Abitibi-Spruce River, and Domtar-Armstrong Forests. OMNR Unpubl. Rep. 9 pp. + 40 maps.

Harris, A.G. 1996. Post-logging regeneration of reindeer lichens (*Cladina* spp.) as related to woodland caribou winter habitat. OMNR Northwest Region Sci. and Technol. Report TR-69. 40 pp.

Hayes, R., A. Baer, R. Farnell, R. Sumanik, and D. Larsen. 1989. Wolf/prey studies in the Yukon Territory, 1983-88. Pages 70-81 In Wolf-prey dynamics and management, Vancouver, B. C., B. C. Min. of Environment, Victoria.

Hearn, B. J., S. N. Luttich, M. Crete, and M. B. Berger. 1990. Survival of radio-collared caribou (Rangifer tarandus caribou) from the George River herd, Nouveau-Quebec - Labrador Can. J. Zool. 68:276-283.

Heinselman, M. 1996. The Boundary Waters Wilderness ecosystem. U. Minn. Press. Mpls.

Hill, E. L. 1985. A preliminary examination of the behavioural reaction of caribou to the Upper Salmon hydroelectric development in Newfoundland. 85-94 In Meredith, T.C. and A.M. Martell. Second North American Caribou Workshop, Val Morin, Quebec, Centre for Northern Studies and Research, McGill University.

Hind, H. 1860. August, 1857, On the Kaministiquia River; Narrative of the Cdn. Red River exploring expedition of 1857. Longman Green London. *In* Old Fort William Resource Library, Thunder Bay, Ont.

Holt, R. D. 1984. Spatial heterogeneity, indirect interactions, and the coexistence of prey species. Amer. Natur. 124 (3) : 377-406.

Jackson, B. 1990. Winter observations of the Armstrong caribou herd with special reference to the effects of active logging roads.Buchanan Forest Products Ltd. Unpub. 14 pp.

Jackson, G. 1981. Woodland caribou (*Rangifer tarandus caribou*) Summary: Information of woodland caribou in Geraldton District. OMNR Unpubl. report

Johnson, D.R. and Todd, M.C. 1977. Summer use of a highway crossing by mountain caribou. Can. Field-Nat. 91 (3) : 312-314.

Johnson, D.R., D.R. Miller, and J.M Peek. 1977. Guidelines for human activity within the range of mountain caribou, southern Selkirk Mountains. Forest, Wildlife and Range Experiment Station, Univ. Idaho. Publ. # 3. Contr. # 22. Rev. June 1981. 7 pp.
Kelsall, J.P. 1968. The migratory barren-ground caribou of Canada. Can. Wild. Serv. Dept. Indian Aff. and N. Devel. 340 pp.

Kenward, R. 1987. Wildlife radio tagging: equipment, Field techniques, and data analysis. Biol. Tech. Series., Instit. of Terrestrial Ecology. Wareham, Dorset. 203 pp.

Klein, D. R. 1971. Reaction of reindeer to obstructions and disturbances. Science. 173 : 393-398.

Klein, D. R. 1979. Reaction of reindeer to obstructions - a reassessment. Pages 519-527 In Proc. Sec. Int. Reindeer/Caribou Symp. Roros, Norway. 1979. 799 pp.

Klein, D. R. 1982. Fire, lichens, and caribou. J. Range Manage. 35 (3) : 390-395.

Koistinen, G. 1975. Domtar Cutting Approval South of Armstrong Airport. June 6 memo to Regional Director. OMNR Nipigon District.

Lankester, M.W. 1976. A protostrongylid nematode of woodland caribou and implications in moose management. Pages 173-190 In Proc. N. Am. Moose Conf. and Workshop 12.

Lankester, M.W., V.J. Crichton, and H.R. Timmermann. 1976. A protostrongylid nematode (*Strongylida: Protostrongylidae)* in woodland caribou (*Rangifer tarandus caribou*) Can. J. Zool. 54:680-684.

Leopold, A. 1933. Game management. Charles Scribner's Sons New York. 481 pp.

McNicol, J. D. and Gilbert, F. F. 1980. Late winter use of upland cutovers by moose. Wildl. Manage. 44: 363-371.

McNicol, J. G., and H. R. Timmermann. 1981. Effects of forestry practices on ungulate populations in the boreal mixedwood forest. Pages 141-154 In Proc. Boreal Mixed Wood Symposium. Can For. Serv., Ottawa.

Mech, L.D. 1966. The Wolves of Isle Royale. U.S. Nat. Park Serv. Faunal Series # 7. 210 pp.

Mercer. E., S. Mahoney, K. Curnew, and C. Finlay. 1985. Distribution and abundance of insular Newfoundland caribou and the effects of human activities. Nfld. And Labr. Wildl. Div. St. John's, Nfld. 32 pp.

Messier, F. 1995. Trophic interactions in two northern wolf-ungulate systems. Wildl. Res. 22: 131-146.

Messier, F. and Crete, M. 1985. Moose-wolf dynamics and the natural regulation of moose populations. Oecologia 65:503-512.

Messier, F., J. Huot, D. Le Henaff, and S. Luttich. 1988. Demography of the George River caribou herd: evidence of population regulation by forage exploitation and range expansion. Arctic 41 (4) 279-287.

Millais, J.G. 1907. Newfoundland and its untrodden ways. Longmans, Green and Co. 340 pp.

Monk, C.E. 1967 One Caribou Less... Ont. Dept. Lands & Forests Wkly Report March 4. Port Arthur Dist. , Port Arthur, Ont. (now Thunder Bay).

Morash, P.R., and G.D. Racey. 1990. The Northwestern Ontario Forest Ecosystem Classification as a descriptor of woodland caribou (*Rangifer tarandus caribou*) range. OMNR Report NWOFTDU Tech. Report #55. North Central Rgn. 22 pp.

OMNR. 1972 Sensitive Area Report W-3 Nipigon District

OMNR. 1978. Forest Resource Inventory Procedure for Ontario. 3rd Ed. 31 pp.

OMNR. 1990. Policy 6.04.01. Wildlife Branch Prog. Toronto. 1990.04.01.

OMNR. 1991. Timber Mgmt. Guidelines for the Provision of Woodland Caribou Habitat (Draft). Wildl. Policy Branch. 15 pp.

OMNR. 1993. Wildlife management program: woodland caribou. Policy and Programs Div. 69 pp.

OMNR. 1994. Northwest Region interim management direction: March 14, 1994. Site Region Planning, NW Region, Thunder Bay, Ont.

OMNR. 1994. Management guidelines for woodland caribou habitat. NW Region caribou task Team. August 15, 1994 (+ 5 p. Appendix by J.H. Young April 24, 1995.) 17 pp.

Penak, B. 1983. Management guidelines and recommendations for ospreys in Ontario. OMNR Wildlife Br.,Toronto, Ont. 28 pp.

Peterson, A. P. G. and E. E. Gross, J. 1974. Handbook of noise management. GenRad, Concord, Mass. 322 pp.

Peterson, R.L. 1955. North American moose. Univ. Toronto Press, Toronto. 280 pp.

Peterson, R.O. 1978. Wolf ecology and prey relationships on Isle Royale. Nat'l. Park Service Sci. Monog. # 11. 210 pp.

Plonski, W.L. 1981. Normal Yield tables (metric) for major forest species of Ontario. OMNR. 40 pp.

Racey, G.D., K. Abraham, W.R. Darby, H.R. Timmermann, and Q. Day. 1992. Can woodland caribou and the forest industry coexist: The Ontario scene. Pages 108-115 In S. Skjenneberg. Proceedings of the Fifth American Caribou workshop, Yellowknife, Northwest Territories, Canada., Rangifer, No. 1, 1992 (Vol. XII, Harstad, Norway).

Racey, G.D., A.G. Harris, and R.F. Foster. 1996. Caribou winter habitat in the new forest: lessons from Lucy Lake. OMNR NW Sci. And Technol., Thunder Bay, Ont. TR-103. 9 pp.

Rayner, M. R., and K. J. Bennett. 1985. Ecological land classification based wildlife habitat evaluation in west-central Alberta: woodland caribou winter habitat suitability. Canadian Wildl. Serv. Environment Canada, Ecological Land Classification Series. No. 22:33-40.

Ritcey, W. R. 1988. Provincial approach by Ministry of Environment to caribou habitat management. Pages 9-12: in Page, R. Caribou research and management in British Columbia: proceedings of a workshop, Victoria, B. C., Wildlife Branch, B. C. Ministry of Environment.

Robinson L. and Bodie, B. 1992 Chronological Report for Buchanan Forest Products Vallee Lake Operation, Winter, 1992. Internal report, Buchanan Forest Products Limited, Thunder Bay.

Royal Commission on the Northern Environment (RCNE). 1985. North of 50; An Atlas Of Far Northern Ontario. J.E.J. Fahlgren, Commissioner (Ont. Min. Of Att. Gen.)
Royal Commission on the Northern Environment (RCNE). 1985. Final Report and Recommendations of the RCNE. J.E.J. Fahlgren, Commissioner (Ont. Min. Of Att. Gen.)

Schaefer, J.A. and W.O. Pruitt. 1991. Fire and woodland caribou in southeastern Manitoba. Wildl. Monogr. 116:1-39

Schrader, H. 1982. A discussion on the effects of logging on woodland caribou (*Rangifer tarandus caribou*) with specific reference to the Armstrong airport herd. Unpubl. Report March, 1982. OMNR Regional Office, Thunder Bay, Ontario. 22 pp.

Scotter, G. W. 1972. Fire as an ecological factor in boreal forest ecosystems in Canada. Pages 15-24 In Fire in the Environment, Denver, Colo., U. S. Forest Serv.

Seip, D.R. 1989. Caribou-moose-wolf interaction in Central British Columbia. B.C. Min. Env. Wildl. Working Rep. #40: 57-69.

Seip, D.R. 1990. Ecology of woodland caribou in Wells Gray Provincial Park. British Columbia Ministry of Environment. 43 pp.

Seip, D.R. 1992. Factors limiting woodland caribou populations and their interrelationships with wolves and moose in southeastern British Columbia Can. J. Zool. 70:1494-1503.

Seton, E.T. 1909. Life histories of northern animals. 2 Vol. Charles Scribner's Sons, N.Y. 1267 pp.

Shoesmith, M. W., and D. R. Storey. 1977. Movements and associated behaviour of woodland caribou in central Manitoba. Pages 1-16 In XIIIth Congress of Game Biologists, Atlanta, Georgia, USA. Wildl. Soc. & Wildl. Manage. Institute, Wash. D.C.

Simkin, D.W. 1965. A preliminary report of the woodland caribou study in Ontario. Ont. Lands and Forests Section Report (Wildl.) #59. 76 pp.

Sims, R.A., W.D. Towill, K.A. Baldwin, and G.M. Wickware. 1989. Field Guide to the Forest Ecosystem Classification for Northwestern Ontario. OMNR, Toronto, Ont. 191 pp.

Simpson, K. 1985. The effects of snowmobiling on winter range use of mountain caribou. Pages 59-70 In Page, R. Caribou research and management in British Columbia. Kamloops, B. C., B. C. Ministry of Forests, B. C. Min. of Environment, Victoria, B. C.

Simpson, K., K. Hebert, and G.P. Woods. 1987. Critical habitats of caribou (*Rangifer tarandus caribou*) in the mountains of southern British Columbia. B.C. Ministry of Environment and Parks, Wildlife Branch, Nelson, B.C. 12 pp.

Stardom, R. R. P. 1975. Woodland caribou and snow conditions in southeast Manitoba. 324-334 In J.R. Luick, D.R. Klein, and R.G. White. First Int. Reindeer and Caribou Symp., Fairbanks, Alaska, Univ. Alaska Biol. Pap.

Stardom, R.R.P. 1977. A study of the winter ecology of woodland caribou (*Rangifer tarandus caribou*) and comparison with some aspects of the winter ecology of moose (*Alces alces andersoni*) and whitetail deer(*Odocoileus virginianus dacotensis*) (Mammalia: Cervidae) in southeastern Manitoba. M.Sc. Thesis, U. Manit., Wpg, Manitoba. 147 pp.

Stevens, K.M. and D.R. Storey. 1977. A scoresheet method of woodland caribou habitat evaluation. Manit. Dept. Renewable Resources. and Trans. Services, Wildlife Research, M.S. Report #77- 36. 33 pp.

Stevenson, S.K. and D. F. Hatler. 1985. Woodland Caribou and their habitat in southern and central British Columbia. Pages 21-228 In B.C. Min. of For., Victoria, B.C. Land Mgmt. Rep. # 23. 2V.

Swant, G.R. 1989. GWT request to extend operating period in Vallee Block (835). Letter to Nipigon Dist. OMNR. 2 pp.

Tanner, J.T. 1975. The stability and intrinsic growth rates of prey and predator populations. Ecology 56(4) 855-867.

Telfer, E.S. 1974. Logging as a factor in wildlife ecology in the boreal forest. For. Chron. 55 (5) 186-189.

Thomson, J.W. 1967. The lichen genus *Cladina* in North America. Univ. Of Toronto Press. Toronto. 172 pp.

Timmermann, H.R. 1967 "Caribou Food Study-Armstrong Airport" Unpubl. Memo OMNR Thunder Bay District 3 pp + map.

Timmermann, H.R. 1990. Population dynamics of the Lake Nipigon caribou herd. Research proposal, July, 1990. OMNR Thunder Bay Rgn.

Van Ballenberghe, V. 1985. Wolf predation on caribou: the Nelchina herd case history. J. Wildl. Manage. 49 (3) : 711-720.

Van Ballenberghe, V. 1986. Wolf predation on caribou: the myth of the Nelchina herd. Rangifer 374.

Van Daele, L.J., and H.A. Van Daele. 1982. Factors affecting the productivity of ospreys nesting in west-central Idaho. Condor. 84:292-299

Van Daele, L.J., and D.R. Johnson. 1983. Estimation of arboreal lichen biomass available to caribou. J. Wildl. Manage. 47:888-890.

Varrin, P.W. 1977. Caribou and moose surveys and tagging: Lake Nipigon Islands, summer 1976. OMNR Unpubl. Rep.

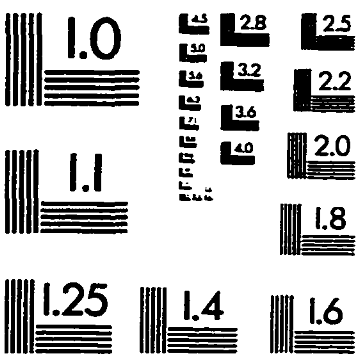
Walters, C.J. and C.S.Holling, 1990. Large-scale management experiments and learning by doing. Ecology. 71: 2060-2068.

Zoltai, S.C. 1965. Thunder Bay Surficial Geology; Map S265. Ont. Lands and Forests, Lands and Surveys Branch. Toronto.

Appendix 1. Counts of occupied 30X30 m pixels by 300 m buffers east and west of the Wabinosh Road, near Armstrong, Ontario.

Number of metres	Number of	Prior to Jan. 6			Jan. 7 - Mar. 11 (log hauling period)			After Mar. 11	
from road	Plots Counted	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 2	Year 3
Metres east of road									
300	2418	1258	355	46	833	110	551	13	49
600	2413	1135	984	208	995	98	521	26	124
900	2431	867	851	360	1082	135	392	22	7
1200	2417	956	159	382	1317	677	366	25	5
1500	2432	968	17	247	1380	967	610	79	4
1800	2445	749	4	0	1392	1322	609	460	171
2100	2519	327	1	123	1419	1375	581	808	108
2400	2518	585	1	405	1368	1330	608	995	20
2700	2492	831	5	392	1421	1340	659	1020	273
3000	2476	608	1	108	1385	1408	420	1006	183
3300	2435	191	0	0	872	1358	19	993	17
3600	2440	0	0	0	192	1281	19	628	10
3900	2422	0	0	0	1	699	15	43	1
4200	2413	0	0	0	0	624	0	0	16
4500	2387	0	0	0	0	809	0	0	7
4800	2364	0	0	0	0	788	58	0	0
5100	2361	0	0	0	51	854	41	0	1
Metres west of road									
300	2737	1417	422	97	879	133	781	13	262
600	2525	1020	792	400	939	104	874	134	774
900	2650	895	712	439	908	267	677	158	767
1200	2698	1121	643	344	834	721	553	169	610
1500	2669	1254	537	171	1026	801	615	348	372
1800	2630	1140	624	0	970	801	377	55	19
2100	2584	1076	434	0	839	849	160	1	4
2400	2543	671	390	0	787	720	152	0	100
2700	2591	24	296	1	642	336	358	36	130
3000	2639	0	38	1	561	73	364	252	0
3300	2664	0	116	0	309	1	69	89	0
3600	2580	0	243	68	267	2	2	0	0
3900	2401	0	33	264	589	0	3	0	0
4200	2302	0	0	217	506	0	2	0	0
4500	2166	0	0	111	88	1	0	0	0
4800	1941	0	0	0	1	0	0	0	0
5100	1742	0	0	0	0	1	0	0	0

IMAGE EVALUATION TEST TARGET (QA-3)



150mm

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