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Experimental log hauling through a traditional caribou wintering area

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Abstract: A 3-year field experiment (fall 1990-spring 1993) showed that woodland caribou (*Rangifer tarandus caribou*) altered their dispersion when logs were hauled through their traditional wintering area. Unlike observations in control years 1 and 3, radio-collared caribou thar had returned to the study area before the road was plowed on January 6 of the experimental year 2, moved away 8–60 km after logging activities began. Seasonal migration to Lake Nipigon islands usually peaked in April, bur by February 22 of year 2, 4 of the 6 had returned. The islands provide summer refuge from predarion, but not when the lake is frozen. Tracks in snow showed that some caribou remained but changed locations. They used areas near the road preferentially in year 1, early year 2, and year 3, but moved away 2–5 km after the road was plowed in year 2. In a nearby undisturbed control area, no such changes occurred. Caribou and moose partitioned habitat on a small scale; tracks showed gray wolf (*Canis lupus*) remote from caribou but close to moose tracks. No predation on caribou was observed within the wintering area; 2 kills were found outside it. Due to the possibility of displacing caribou from winter refugia to places with higher predation risk, log hauling through important caribou winter habitat should be minimized.

Key words: *Rangifer tarandus caribou*, disturbance, moose, gray wolf, predation.

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Introduction

Increasing concern for the viability of remnant woodland caribou (*Rangifer tarandus caribou*) herds along the southern limits of their range in North America has led to recommendations for more restrictive forest harvesting practices where these caribou still occur (e.g., Freddy, 1979; Bloomfield, 1980; Ritcey, 1988). In Ontario, where the geographic range of caribou has been dramatically reduced over the last hundred years (Fig. 1), similar concern has been expressed (DeVos & Peterson, 1951; Cringan, 1957; Darby *et al*, 1989; Racey *et al.,* 1991; Cumming & Beange, 1993). The widespread caribou declines have traditionally been attributed to habitat disturbance or direct mortality factors. A third factor, disturbance of caribou themselves by human activities, has been less thoroughly investigated. Several studies have examined effects of human disturbance on barren-ground caribou mostly in connection with oil pipeline construction (e.g. Klein, 1979; Cameron & Whitten, 1980; Fancy, 1983; Curatolo & Murphy, 1986), but the relevance of these studies to woodland caribou is questionable. Relatively few studies have concentrated on disturbance of woodland caribou.

Those that have been reported have proven somewhat contradictory. Most have concerned caribou in Newfoundland. Bergerud (1974b) maintained that caribou have no 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 a construction period; caribou returned to pre-construction locations after the development was completed. Hill (1985) found caribou in Newfoundland more alert and less inclined to intake energy while construction of a hydroelectric development was in progress, though they eventually became sensitized 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 1 has ever been recorded killed by vehicles on Newfoundland highways compared with 200-300

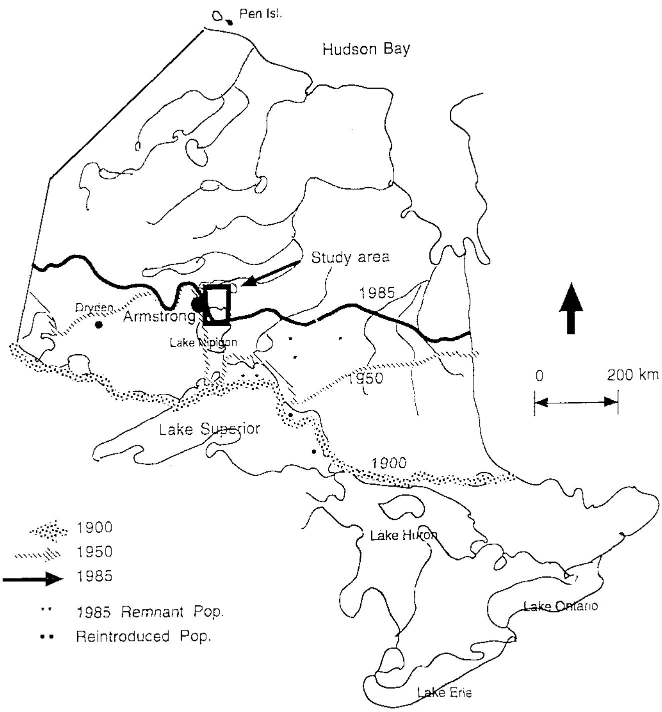


Fig. 1. Study area in relation to the historic lines of continuous distribution for woodland caribou in Ontario (after Darby & Duquette, 1986).

moose (*Alces alces*) killed annually. He suggested that caribou may avoid the roads. Mercer *et al.* (1985) also drew attention to the fact that centres of year-round ranges for all caribou herds, especially calving grounds, are at maximum distances from roads and population centres, and that distributions of several herds have changed with the placement of high use roads and railways within their ranges. Bergerud (1974b) 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 (1974b) made his observations. Mercer *et al.* (1985) reported that both flushing and flight distances have been reduced on the Avalon Peninsula since the 1960's.

In British Columbia, Johnson *et al.* (1977) found that mountain caribou near Kootenay Pass became habituated to the presence of highway traffic and continued to use traditional routes, but Simpson (1985) discovered 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 large group movements.

Based on contemporary knowledge, the Ontario Ministry of Natural Resources (OMNR) viewed with concern plans by a local forest company, Buchanan Forest Products Limited (BFPL), to haul logs through a known caribou wintering area while the caribou were present (the cutting could not be carried out at any other time of year). To answer some of the questions regarding possible effects on caribou, a research partnership was formed in 1990 among OMNR, BPFL, and Lakehead University .

The major goal of the three-year study was to examine the direct and indirect effects of log hauling on caribou use of this traditional wintering area. The hypothesis to be tested was that transporting machinery and logs through a traditional woodland caribou wintering area would cause caribou to leave, or to modify their movements and dispersion within the wintering area in measurable ways. We identified 2 null-hypotheses: (1) caribou will not measurably alter their occupancy, dispersion, or movements when logs are hauled through their traditional wintering area; (2) caribou will alter these parameters coincident with log hauling, but by chance - the changes will be caused by concomitant alterations in other environmental influences, most likely in view of previous studies, wolf presence (e.g., Simkin, 1965; Bergerud, 1974a; Bergerud, 1985a; Bergerud, 1985b; Elliott, 1985; Page, 1985; Edmonds, 1988; Archibald, 1989; Bergerud, 1989; Elliott, 1989; Gasaway, 1989; Hayes *et al*, 1989; Seip, 1991), or snow depths (e.g., Formozov, 1946; Prnitt, 1959; Bergerud, 1974; Lent, 1979; Darby & Pruitt, 1984; Edmonds & Bloomfield, 1985; Fancy & White, 1985; Simpson *et al*, 1985; Vandal & Barrette, 1985).

Study area

The study required several related study areas, surveyed at varying intensities. Overall Study Area (2500 km^2) included all forested land within a radius of 32 km from the Armstrong airport (200 km north of Thunder Bay, Ontario) and islands in the north half of Lake Nipigon (north of 50 degrees latitude), which lies 20-70 km east of the Prime

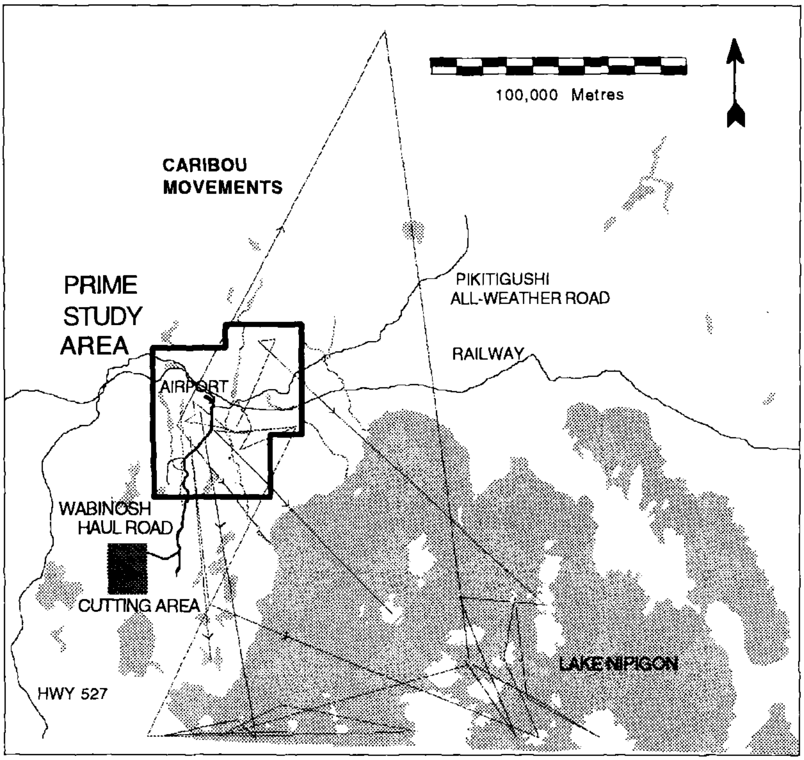


Fig. 2. Movement of radio-collared caribou during the winter of experimental log hauling from Dec. 10 until Apr. 17. For date details see Table 3.

Study Area (Fig. 2). In the Overall Study Area, sand, gravel and till thinly cover the Archean granitic uplands, typical of the heavily glaciated Precambrian shield. Summer temperatures are cool (mean daily temperature 16 °C), winters cold (mean daily January temperature -20 °C). Total precipitation (750 mm/year) and snow depths are moderate (highest weekly average depth during the study 76 cm). Wildfires have left a mosaic of stands, primarily black spruce (*Picea mariana*) and jack pine, (*Pinus banksiana*) with a few mixed stands including trembling aspen (*Populus tremuloides*) and white birch (*Betula papyrifera*). Mosses, such as *Pleurozium schreberi* cover much of the forest floor, but patches of ground lichens, e.g., *Cladonia mitis, C. rangiferina,* and *C. alpestris,* grow under poorly stocked stands of jack pines on sand flats and under scattered spruce on rock outcrops. Tree lichens, e. g., *Usnea comosa* and *U. dasypoga,* are common but not especially abundant (Ahti & Hepburn 1967). Ground access is provided by an east-west railway, highway 527 from Thunder Bay, the all-weather Pikitigushi Road running north from the railway, and the seasonal (experimental) Wabinosh Road running south. The forest has been cut back some 10+ m from the railway and highway, but along other roads it grows within about 3–7 m.

A Prime Study Area, centered on Armstrong airport and Jojo Lake, encompassed 280 km², 14 km wide from Vallee Lake on the west to Mount St. John on the east and 20 km long from Mt. St. John

Table 1. Design of log-hauling experiment: years 1, 3 served as controls; in year 2 logs were experimentally hauled through a traditional caribou winrering area during January 14-March 10.

Period	Before Dec 11	Dec 11-Jan 5	Jan 6-7	Jan 14-Mar 10	Mar 11-April 30
Year 1	Control period	Control period	Control period	Control period	Control period
Year 2	Control period	Control period	Road plowed	Log hauling experiment carried out	No log hauling
Year 3	Control period	Control period	Control period	Control period	Control period
Possible human disturbance in year 2	Snowmobiles		Snow plow	Large machines trucks, private moving in, vehicles	Private vehicles only

on the south to Whitesand Lake on the north. In this area deep but poor sands support widely spaced jack pine with a ground cover rich in lichens (Antoniak & Cumming, 1998). A Northern Extension of this Prime Study Area was bordered by Big Lake on the west and Pikitigushi Lake on the east, covering an additional area of approximately 800 km^2. A Southern Extension, approximately 400 km^2, included Waweig, Wabinosh and Castle Lakes.

Methods

Experimental design

Since the nearest potential control area was 25 km distant (Wabakimi Provincial Park), a location that differed in soils and landform, we turned to a control in time rather than space. Year 1 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 2 was the experimental year during which caribou activities were recorded before, during and after a period when trucks hauled logs through the caribou wintering area. Year 3 provided a second control year during which the road was not plowed and disturbance was minimized. However, the picture was changed when field work during the first winter revealed a second (at least partially segregated) aggregation of caribou only 6 km north of the disturbance area. This second aggregation provided a suitable control in space and was added to the study as such.

Field data collection

Capture techniques followed methods reported by Cumming & Beange (1987). Caribou were captured by crews of up to 6 men and 1 or 2 dogs driving them from islands into the water where they were approached by boat, lassoed, and tagged. Fourteen caribou (one cow in 1990; 1 bull, 6 cows, and 6 calves in 1991) were fitted with battery powered radio transmitter collars (adults) or solar ear tags (calves), from Advanced Telemetry Systems, running at 164 Mh.

High level winter flights to search for caribou covered the entire study area (or the area being used by the animals actively transmitting, if smaller); we did not search for missing signals beyond the borders of the study area, but reception range from high altitudes covered a substantial surrounding band. Aircraft included a Cessna 185, a DeHaviland Turbo-beaver, and an Aeronca Champion. Altitudes ranged from ca. 1800 to 6000 m above ground level (AGL). We used a transect width of 10 km at 1 800 to 3 000 m 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). We flew weekly at times of likely significant movement (i.e. migration times, disturbance times) and at intervals of 1-3 weeks in mid-season when movements were expected to be fewer. Wherever possible, caribou that were roughly "found" during high level telemetry were located as exactly as possible, by "dropping lower" and circling, while switching from one antenna to the other to "zero in" on the animals. Practice trials demonstrated that transmitters could be located within a radius of about 200-500 m.

Radio transmissions were also monitored during low level transect flights to look for tracks in snow. 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 beeper into the aircraft intercom. With a detection range (at that altitude, with just a whip antenna) of only about 2 km, any collared caribou were noted and recorded as to location. This was a supplement to, not a replacement for, high level telemetry searches using twin yagi antennae.

The main tools for mapping tracks in the Prime Study Area and Extension Area were fixed wing aircraft, using methods described by Cumming & Beange (1987). Except in year 3 when lack of aircraft and personnel reduced effort, flights were made at 1-2 week intervals, from before the freeze-up of Lake Nipigon (late November or December) to whenever the caribou left their winter ranges to return to their summer calving grounds, always before ice-out. North-south transects flown at 300-600 m (AGL) aimed at total coverage of the Prime Study Area. For the Extension Areas, transect width was 3 km, at a higher altitude (600 to 1200 m AGL) to ensure transect coverage. A Champion 7EC provided excellent visibility on both sides for two people, a pilot/spotter and a spotter/recorder, seated fore and aft. The air speed of 90 km/hr to 155 km/hr provided sufficient time for careful inspection of tracks. One observer spotted to the right, the other to the left, and communicated via a two way intercom. Data recorded on a 1:50 000 scale topographic maps, included live caribou, caribou tracks, caribou beds, cratering, moose, moose tracks, moose beds, wolves, wolf tracks, vehicle tracks, and snowshoe tracks. Where helpful and possible (e.g. on lakes) landings were made to confirm track types. Tracks were also examined on the ground where accessible, e.g. along the roads in the airport area.

In view of the null-hypothesis that caribou might move due to changes in wolf behaviour, we recorded tracks of wolves as well as caribou. Suspecting that moose dispersion and movements might influence wolf behaviour which in turn might affect caribou dispersion, we recorded moose tracks along with caribou and wolf tracks. Three types of track records were recorded: individual, aggregate and linear. Individual tracks were recorded as discrete caribou, moose, or wolf tracks. However, in many places tracks were too numerous to be recorded individually. In these places, track aggregates were recorded as caribou, moose, or wolf tracks, with a line drawn around the perimeter of the aggregate, a practice that has become common in studies of moose (e.g., McNicol & Gilbert, 1980). Linear tracks were drawn as lines, with direction noted by an arrow where possible (e.g. after ground truthing, or where the animal was seen making the track).

The priorities for winter aerial surveys were first, the Prime Study Area; second, the North and South Extension Areas; third, the Overall Study Area. Temperature, wind, and sun were recorded on days of flights or ground surveys.

Ground surveys

Although the most important means of collecting data was by surveys with aircraft, we also examined the Wabinosh Road, the Pikitigushi Road, and snow machine trails on the ground to verify tracks spotted from the air, as to location, species, and completeness.

Tracks under heavy canopy cover were examined on snowshoes where they lay close to a road.

To examine the null-hypothesis that snow depths would affect caribou movements, we measured snow depth and consistency throughout the study. But the remote location of the study area made any intensive (e.g., weekly) investigation of snow conditions impossible. Instead we dug snow pits late in each winter; in this northern location where snow melts rarely occur, snow pits in late winter record the entire snow history to that date each year. A National Research Council snow kit was used to measure snow depths, hardness and density. Plots were located in clear-cuts 7 km south on the Wabinosh Road, and under jack pine stands used by the caribou as winter habitat about 1 km south of the Armstrong airport. Under the jack pines, two pits per visit were dug; one directly beneath tree cover (1 meter from the bole), and one in a small "open" (unstocked) space midway between trees. Two pits per outing were dug in the open clear-cuts.

To supplement these data, snow depth information was obtained from the OMNR snow station at Flat Lake, near the centre of the study area. The station is located in a trembling aspen stand to measure intermediate conditions between those in open areas and those under conifers. At each location, 10 measuring rods were placed in position before snowfall and mean snow depths for the station were recorded each Monday morning throughout the winter. Due to the complexities of measuring snow hardness and density, they were reported in only 3 classes: A - no crust, B - light crust, C - crust heavy enough to hold a man on snowshoes.

To document the nature of any perceived disturbance from the logging trucks we attempted to record traffic on the experimental road. Traffic counters were placed on the Wabinosh Road in year 2, and on the Wabinosh and Pikitigushi Roads in year 3. However, these counters did not distinguish types of vehicles. On the other hand, movements recorded by BFPL (Robinson & Bodie, 1992) identified all types of forest harvesting equipment. Since these data were judged superior they were reported here.

Important also for evaluation of the second null-hypothesis were records of caribou killed by wolves or as a result of deep snow. Reception of a "mortality signal" (rapid beat) initiated a search by aircraft, followed by ground search (using a scanner and yagi directional antenna) to recover the collar or tag, and to identify means of death if possible.

GIS and statistical analyses

Results from mapping tracks were first examined manually. Subsequently, they were digitized into a Macintosh computer running a rastor based Geographic Information System (GIS) called Map Factory . 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 Prime Study Area, and 30-300 m in the extensive study areas. Due to the frequency of caribou aggregates in this small, heavily used wintering area, analysis of tracks as points (Cumming *et al.,* 1996) was not possible. Instead, the rastor pixel size was set at 30 m and the computer counted numbers of pixels

Table 2. Chronological time chart of traffic on haul road during experiment.

Date Year 2	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 Monday-Friday until January 16, haul in progress 24 hrs.
Jan 17	Loader, haul bulldozer, front end loader floated out; sand truck moves out	10 No hauling until Jan 23
Jan 23	2 loaders, front end loader, haul bulldozer floated in; sand truck driven in; haul trucks begin again	13 Hauling in progress once more.
Feb 01-11	Five slashers floated in	15-21
Feb 21	Cutting ceases	18
Feb 29 -Mar 1	Skidding, grading cease 4 slashers, grapple skidder floated out	14-12
Mar 02	Delimbing ceases	10
Mar 04	Slashing ceases, delimber floated out	7
Mar 06 - 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 trucks finish	Haul operations cease

From: Robinson, L. & B. Bodie, 1992.
* Since no accomodation was available at the cutting location, workers used personal vehicles to go on and off shift.

showing presence or absence of tracks. Observed track frequencies were then compared using chi-square. Spatial relations among caribou, moose and wolves were examined by establishing 900 m buffers (the closest to 1 km that Map Factory could easily handle) around each species and counting numbers of pixels within the buffer showing fresh tracks of other species.

Results

Disturbance during year 1 consisted of a few snowmobiles on special trails and along the Wabinosh haul road, mainly during the early winter when snow depths were not excessive. The early part of year 2 was similar. On January 6 of year 2, the road was plowed and on January 7 company workers began to move in heavy equipment (Table 2). The haul consisted of 25 trucks hauling 24 hours/day, Monday - Friday. The sounds produced by the harvesting equipment used in the actual logging operation could not be heard by humans from the caribou wintering area, as they were too far south; however, large trucks and other pieces of equipment could be heard for several kilometers, depending on temperature and wind, and these passed right through the occupied area. Among the sounds produced by these trucks low frequencies predominated. The highest frequencies recorded fell below 10 000 Hz (Hyer, 1997). In addition to this work-related traffic, some people living nearby took advantage of the plowed road for winter outings, but they were not counted.

Telemetry data

All 14 of the caribou fitted with radio transmitters on western islands of Lake Nipigon were relocated in or near the Prime Study Area during year 2. However, only 6 of these caribou actually returned close to the haul road prior to the experimental hauling in year 2. All 6 left again after initiation of logging activities (Fig. 2). Caribou 1 moved far north before returning to Lake Nipigon islands. Caribou 2 moved to the control area, then to the islands.

Table 3. Locations of radio collared caribou during 2 winters.

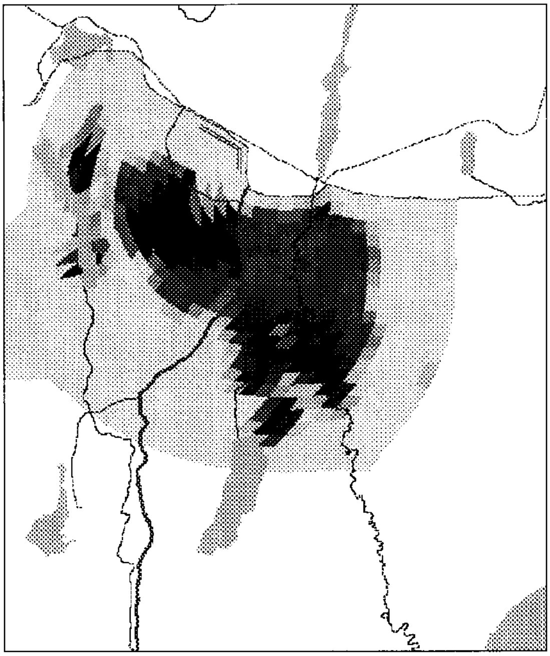
		Caribou collar frequency					
Year	Date	cow 90	310	354	533	253	333
Year2	Dec. 10/91		W L.NIp	W L.NIp	W L.NIp		W L.NIp
pre-	Dec 19/91	Expt. area	Expt. area	Expt. area	Expt. area	E. Expt. area	W L.NIp
haul	Dec 28/91	E. Expt. area	Expt. area	Expt. area	Expt. area	Expt. area	
period	Jan 4/92	E. Expt. area		Expt. area	Expt. area		
hauling	Jan 7/92	Expt. area	Expt. area	Expt. area	Expt. area		
period	Jan 14/92		Expt. area	E. Expt. area	E. Expt. area	Control area	
	Jan 24/93			E. Expt. area	E. Expt. area		
	Feb 22/92	Islands		Expt. area	Islands	Islands	Islands
	Mar 1/92			Expt. area	W L.NIp	Islands	Islands
	Mar 10/92	Islands		Expt. area	Islands		Islands
post-haul	Mar 30/92	Islands		Expt. area	Islands		Islands
period	Apr 17,18/92	Islands		Islands	W shore	Islands	Islands
Year3	Oct 22/92	Islands	Islands	Islands	Islands		Islands
pre-haul	Dec 22/92	Islands	Islands	Islands	Islands		Islands
hauling	Jan 7/93	Expt. area					
period	Jan 14/93	Expt. area					
	Jan 19/93	Expt. area	Control area	Control area		Islands	Islands
	Jan 27/93	Expt. area	Control area	Control area		Islands	Islands
	Feb 4/93	Expt. area	Control area	Control area			
	Mar 3/93	Expt. area	Control area	Control area			
post-haul	Mar 18/93		Expt. area				
period	Apr 1/93	Expt. area	NW L. Nip	Control area	Islands		Islands

Note - abbreviations indicate the following:
Expr. area - the experimental area south of the railway within 8 km of the road on which logs were hauled.
Control area - the undisturbed winter area north of the airport near Jojo Lake.
Islands - the islands of Lake Nipigon used as calving and summer habitat.
E., NE. Expt. area - within the prime study area but beyond 8 km from the haul road.
W., NW L. Nip - on the indicated shores of Lake Nipigon where they are usually found enroute to or from calving or wintering areas.

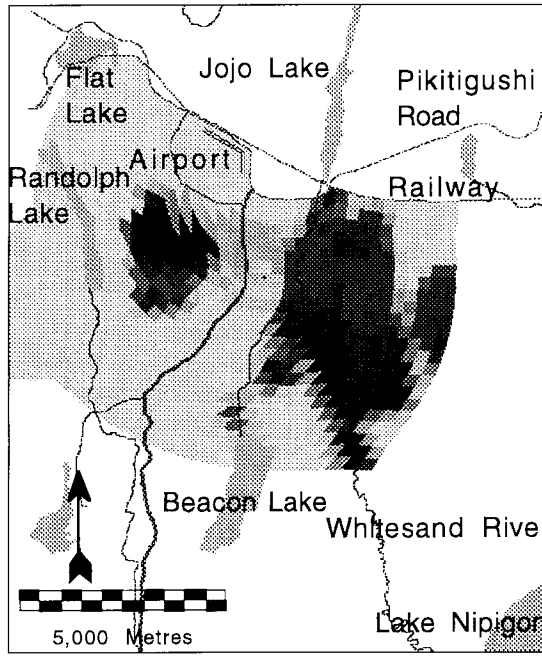
Caribou 3 moved to a location 2-8 km east of the experimental area, then to the west shore of Lake Nipigon (a common staging location on the way to the wintering area), then to the islands constituting summer habitat. Caribou 4, 5, and 6 moved almost directly to the islands. Four of the 6 caribou returned to Lake Nipigon islands before February 22 (Table 3), an exceptional early date, for a previous study during a period when the haul road was not open in winter, found that spring movement from the Armstrong area began in early March and reached a peak in April (Cumming & Beange, 1987).

Mapping tracks

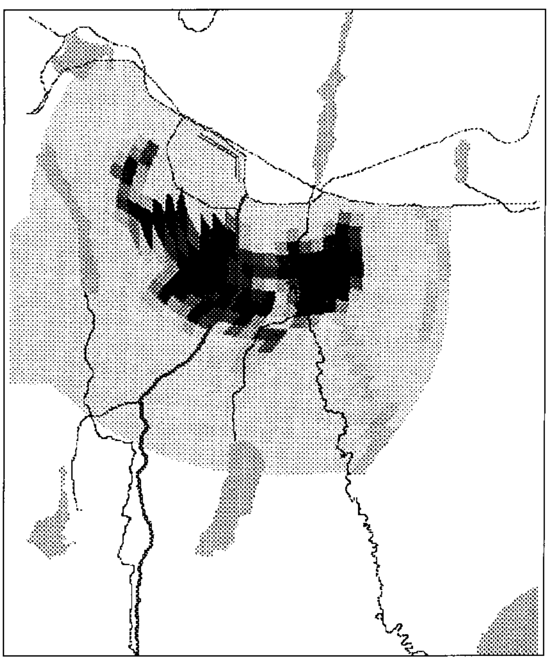
Maps of tracks in the Prime Study Area showed caribou close to the haul road during the pre-haul, and hauling periods of year 1 (tracks were not recorded for the post-haul period of the first year). Caribou returned to much the same areas in year 2, leaving many tracks close to the road during the pre-haul period (Fig. 3). On the day when the road was plowed, many linear tracks were recorded oriented at right angles to the road. Caribou tracks continued to be found in the Prime Study Area, even though all collared animals had left, but they were found spaced away from the road > 900 m during the haul period of year 2. Except for one small aggregation of tracks 300 m from the road, caribou continued to use only areas remote (>900 m) from the haul road through the post-haul period of year 2. In year 3, caribou arrived later than in previous years, but did return to areas near the unplowed



Year 1



Year 2



Year 3

Fig. 3. "Contour" maps of track densities showing proportions of pixels with caribou tracks during the mid-winter period (Jan 7–Mar 11) wven logs were hauled in year 2. The darker rhe area, the denser the tracks. The very light gray outer area indicates the extent of the prime study area. Conrour width 300 m.

road and continued to track these places throughout the winter (Fig. 3). The fewer tracks recorded in year 3 could have been due to reduced effort due to problems with aircraft availability.

"Contour" maps of caribou tracks showed proportions of occupied computer cells concentrated in 3 preferred areas in year 1: the area directly south of the airport, from the haul road to 2400 m west; an area 1200-5400 m east of the haul road along the outlet from Beacon Lake; and an area 2100-9900 m east of the road along the Whitesand River (Fig. 3). The same area west of the haul road continued to be used during year 2, except for a strip 600 m wide adjacent to the haul road which was used only lightly. The caribou virtually abandoned this stretch by late winter. Areas east of the haul road were occupied later in years 2 and 3. In year 2, caribou tracks showed little use of the area within 900 m of the haul road once logging began; some moved closer to the railway tracks. In the post-haul period largest track aggregations were located 2-3 km from the road. Caribou began to use the area along the Beacon Lake outlet in early winter, but discontinued its use during logging. In contrast, they continued to leave tracks in the Whitesands River area, far-

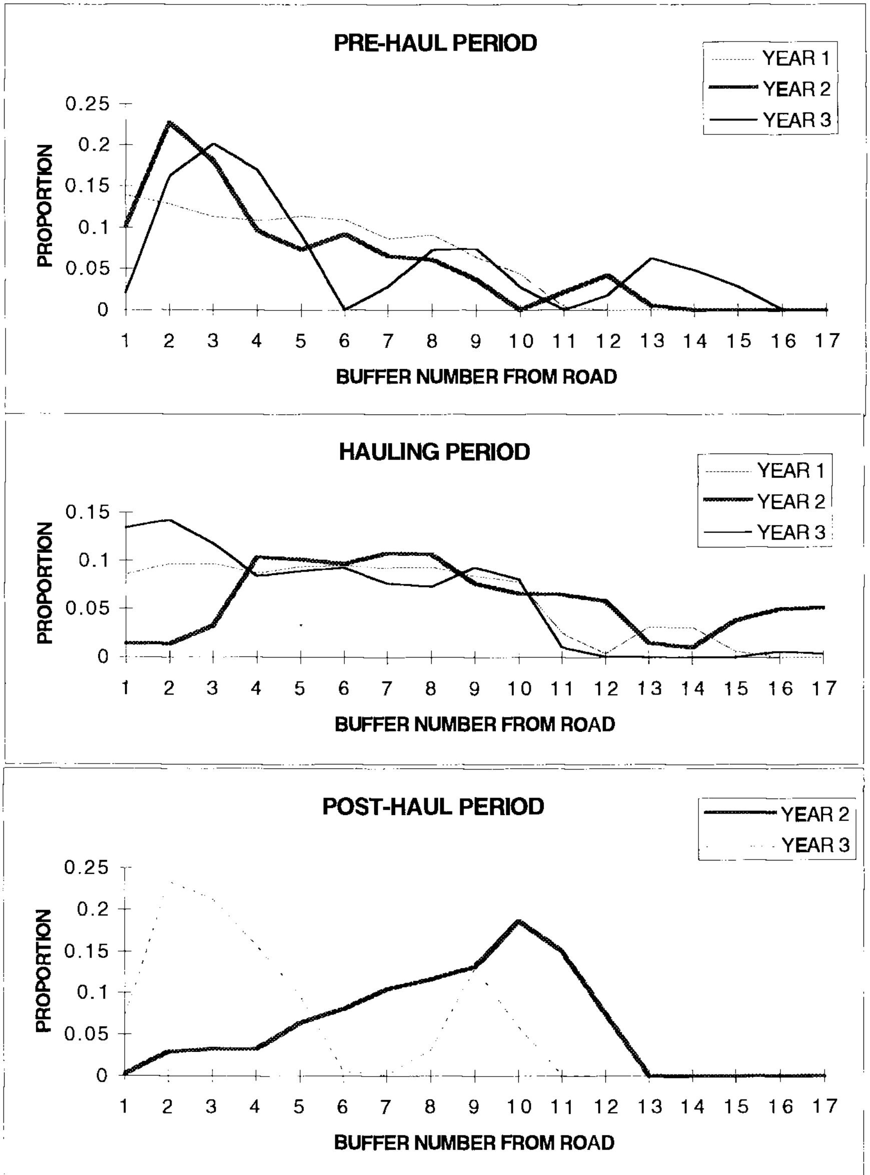


Fig. 4. Proportions of 300x300 m cells showing presence of caribou for 3 winters in buffers numbered east and west from the Wabinosh Road.

ther from the haul road, even into late winter. In year 3, caribou used the area west of the haul road in ways similar to year 1 throughout the winter. However east of that road, the Beacon Lake area was used very lightly, and caribou left tracks in only a northern section of the Whitesands River area, a section that was not favoured in years 1 or 2. Most caribou left both eastern areas by late winter in year 3.

Proportions of occupied computer cells were graphed using data from 300 m buffer zones east and west of the road. During year 1, the control year, caribou tracks were found on the road or close to the road throughout the winter; presence of tracks decreased with distance from the road (Fig. 4). In year 2, the hauling year, only small proportions of tracked cells were located within 1200 m of the road. During year 3, a pattern similar to year 1 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 2), and after March 11 (post-haul) (Table 4). No significant differences in caribou dispersion appeared between the pre-haul and hauling periods of year 1, but highly significant differences were found before and after the experimental hauling in year 2. These differences indicated that caribou changed their dispersion patterns about the time the road was plowed. A similar significant difference in year 3 probably arose from the later return of many caribou to the prime study that year, making the early period different from the period after the main body arrived. Post-haul dispersions did not differ significantly from the experimental hauling period in year

Table 4. Chi-square values and probabilities for proportions of cells occupied by caribou or caribou tracks in 1-9 300 m GIS buffers from "the Wabinosh Road, near Armstrong, Ontario. Six east-west rows of cells" were chosen to avoid influences of north and south habitat changes. In "year 2, trucks hauled logs through the caribou wintering area. Years" "1,3 were controls."

Test results	Winter periods and years		
	Comparison of pre-haul periods over all 3 years	Comparison of hauling periods over all 3 years	Comparison of post-haul periods over years 2,3
Chi-square	39.31	31.66	88.2
Probability	0.006	0.047	<0.001
	Pre-haul periods - c. f. years 1,2	Haul periods - c. f. years 1,2	
Chi-square	13.79	19.13	
Probability	0.183	0.039	
	Pre-haul period c. f. haul period in year 1	Pre-haul period c. f. haul period in year 2	Pre-haul period c. f. haul period in year 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 2	Haul period c. f. post-haul period in year 3	
Chi-square	16.63	27.16	
Probability	0.083	0.003	

1) All 3-year comparisons showed significant differences (including others not shown).
2) Dispersion in the periods before and during the first (control year), bur it did during the experimental year.
3) The hauling period did not differ significantly from the post-haul period in year 2, but did in year 3.
4) Pre-haul dispersion did not differ berween years 1, 2, but during the hauling period it did.

2. This lack of significant suggests that the more remote (from the road) dispersions established by caribou during the haul period of year 2 carried through into the post-haul period. In contrast, track locations did differ significantly between the hauling and post-hauling periods of year 3, perhaps due to the change from normally heavy track densities during the January 6 - March 11 period to reduced densities in the post-haul period as caribou began to move toward summer locations. Comparisons of pre-haul periods between years showed no significant differences between years 1 and 2, but similar comparisons for the hauling period did show a significant difference, supporting the idea that the change did not occur until hauling began.

At the control area in year 1, tracks indicated ingress of caribou along a water course from a start at least 10 km north. Similar movements were tracked in each succeeding year suggesting that this might be a traditional travel route. At the same times, radio-telemetry showed that some caribou also moved there from the Lake Nipigon islands. Thus, the caribou in the Control Area appeared to come from at least 2 widely spaced summer locations. During winter, tracks of caribou in the Control Area showed similar patterns for all 3 years (Fig. 5). The only obvious shift in track dispersion unique to year 2 constituted a filling-in of what had previously been an unoccupied strip near the northern end. Thus track locations of caribou in the control area changed little during the experimental year 2 compared with other years.

Possible alternative explanations

Moose tracks were not usually found near locations of caribou tracks (Fig. 6). A small exception occur-

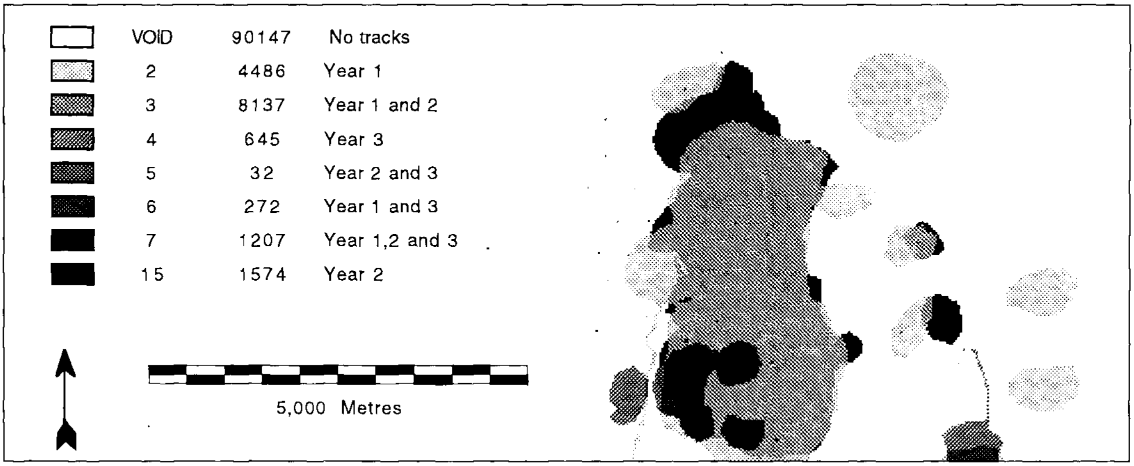


Fig. 5. Locations of caribou tracks at the control area (north of the railway and west of the Pikitigushi Road) during 3 winters. Note that the largesr single area was that used by caribou in both year 1 and year 2 (light grey). Year 2 (black) was uniquely used in only a few small places. Thus changes from year to year were small. Column 2 indicates grey scale of category. Column 3 provides a pixel count indicating area.

Table 5. 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	No wolves	Totals	% used by wolves	Chi-square	Probability
1	moose	3099	8134	11233	27.6		
	caribou	986	42883	43869	2.2		
	Total	4085	51017	55102	7.4	8366.7	$P<0.001$
2	moose	11382	4580	15962	71.3		
	caribou	4064	41159	45223	9.0		
	Total	15446	45739	61185	25.2	24279.9	$P<0.001$
3	moose	1362	11064	12426	11.0		
	caribou	2503	21294	23797	10.5		
	Total	3865	32358	36223	10.6	1.679	$P=0.1951$

red in year 2, when a southwestward extension of caribou tracks remote from the haul road coincided with a notthward shift in moose tracks producing a small area near Randoph Lake where caribou and moose tracks overlapped, the only such place in the 3-year study. East of the haul road, caribou and moose were occasionally recorded in the same location, but in different years. Apart from snowmobile trails followed by wolves in portions of both the Prime Study Area and the Control Area, wolf tracks were found close to those of moose. Few wolf tracks were observed at any time during the course of the study in the parts of the Prime Study Area tracked by caribou, but they were frequently found in other parts where the moose tracks were located. Distances to nearest wolf were significantly greater for caribou than for moose in years 1, 2, but not significantly different in year 3 (Table 5). Both aerial and ground investigations located moose tracks and wolf tracks, but not caribou tracks, in and around the cutting area 2.8 km to the south.

In three winters of intensive flying, only 2 caribou were found fed on by wolves. 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 suspicion that the animal might have been shot, and the remains scavenged by wolves. Support for this belief, in addition to the impression gained from the interview and the proximity of the snowmobile trail, came from caribou #293, the calf of caribou #233, which was not killed

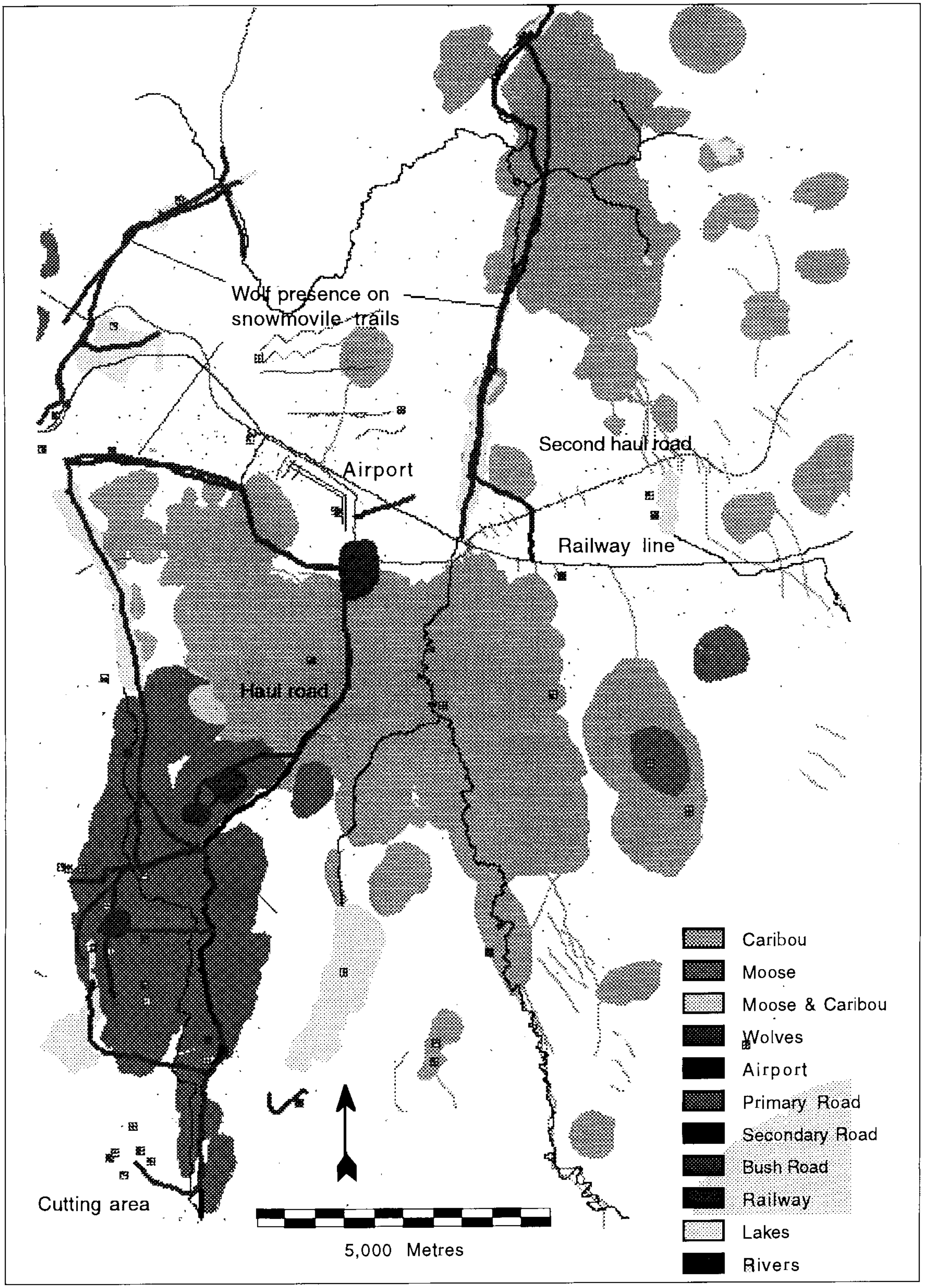


Fig. 6. Three years' combined track data showing habitat partitioning by caribou and moose, with wolves, traveling roads and snowmobile tracks, mostly associated with moose rather rhan caribou.

but lived till the end of the study. If wolves had been doing the killing, the calf would likely have been killed first.

The only other dead caribou was found on Dec. 22, 1992, on the travel route used by caribou approaching the Control Area from the north. Unsafe ice conditions made landing to verify the identification impossible, but the carcass lying on its back with intestines removed, out strongly suggested a wolf kill.

Not a single instance was observed of wolves, or wolf tracks, following live caribou or caribou tracks, although some wolf tracks may have been missed, as Jackson (1990) suggested after a previous winter of ground surveys in the area. Wolf tracks were frequently found within 3 km of caribou tracks in the airport area, yet we never observed any tendency for wolves to depart from human and moose trails to follow caribou.

In contrast, wolves and wolf tracks were recorded closely associated with live moose and moose tracks on many occasions (Fig. 6). During the 3 years, wolves were seen on 3 fresh moose kills in the Prime Study Area, but always at locations remote from areas occupied by caribou.

Snow pits showed slightly deeper snow in year 2 (mean open depth on 16 March of 64 cm) than in years 1 (60 cm) and 3 (50 cm, Table 6). Further, records from the OMNR snow station at Flat Lake showed greater snow depths in year 2 also (maximum depth 76 cm, compared with 63 in year 1 and 59 in year 2). To find if the second year depth was unusual in the area, OMNR records for 1989 were also examined; these depths equaled or exceeded (maximum 79 cm) snow depths in year 2 (Table 6).

The heaviest crusts were in year 1 when some layers of pure ice resulted from a brief rainfall; crusts were lightest in year 3. Densities also averaged consistently highest in year 1. Stardom (1975) determined critical levels (i.e. levels that initiated emigration from an area) for woodland caribou. Snow depths at the study area never exceeded Stardom's (1975) critical snow depth level of 65 cm. The snow hardness threshold was exceeded in up to 4 layers during year 1, but rarely in the other years. Lowest density thresholds were exceeded in 2 snow pits in year 1, and 1 snow pit in year 2.

Discussion

An experiment requires changing some aspect of a situation and comparing consequences with an unchanged control. But establishing control areas for operational-size field experiments involving wildlife is notoriously difficult (Walters & Holling, 1990). Even the most carefully chosen controls in nearby, apparently comparable, areas can differ significantly from treatment areas in ways unrelated to the treatments (Cumming, 1989). For this reason, the experiment was set up with controls in time rather than space. We examined the status quo, changed the vehicular traffic pattern and observed consequences; then we allowed traffic to return to its original, minimally disturbing condition, once more observing results. This control worked well. Caribou showed behaviour in year 2 different from either of the other 2 years. The discovery of a previously unknown additional caribou wintering area north of the railway tracks, provided an opportunity to add a spatial control as well. The changes found in the experimental area were not observed in the control area. Therefore the evidence seems substantial that the change in caribou behaviour occurred only at the time of log hauling and only near the road on which the logs were hauled. Further, during the experimental period of year 2, the 6 radio-collared caribou all left the experimental area; fresh track aggregates of remaining caribou could be found only beyond 2-5 km from the haul road. Caribou dispersions differed significantly between periods of log hauling and no hauling. No similar changes were observed in the control area, nor near the contiguously used railway and all weather road. Null-hypothesis #1 that there would be no change was disproved, and the hypothesis at least to some degree supported.

The most likely alternative explanation for changes in caribou dispersion and movements was the presence of wolves. Presumably, caribou harassed by wolves would be sensitive to changes in behaviour or abundance of the latter and might have moved out during year 2 for that reason coincident with the log hauling. Yet results indicated that wolves did not in any year spend appreciable time in areas occupied by the caribou, rather their tracks were found in areas frequented by moose, and these areas were usually spaced some distance from those used by caribou. The small over-lap between areas showing tracks of caribou and moose in year 2 appeared to result from independent changes in dispersion by each species that brought them closer together. In the most intensively used and observed areas near the Wabinosh Road wolf tracks were virtually absent. Furthermore, no evidence suggested that

Table 6. Snow depths from the Ministry of Narural Resources snow station at Flat Lake, Ontario, and from" snow pits dug in this study. Data for rhe log hauling experimental year are shown in bold.

Years			1989-90	1990-91	1991-92	1992-93
Snow depths recorded by OMNR personnel at Flat Lake snow station						
Week 13-14	"(includes January 6,7)"					
Average depth (cm)			57	47	59	55
Crust			A	A	C	B
Week 22-23	(includes March 11)					
Average depth (cm)			66	57	71	57
Crust			C	C	C	B
Entire winter						
First recorded snow depth			6-Nov	26-Nov	4-Nov	9-Nov
No. of weeks snow depth >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
Snowpit data						
Dates				16-Mar	(Mar 11) Apr 8	11-Mar
Snow depth						
Open locations	Snowpit 1			60	(68) 58	48
	Snowpit 2			58	79	53
Forested location	Snowpit 1			61	55	55
	Snowpit 2			60		50
Comparable OMNR reported depths		Dates		11/18-Mar	9/16-Mar	8/15-Mar
		Depths		57/ 46	71/73	57/59
Snow hardness						
Open location	Snowpit 1	Mean g/sq. cm.		230	(54) 74	38
		Max. g/ sq.cm.		750	(78) 100	75
		No layers>80		4	(0) 2	0
	Snowpit 2	Mean g/sq. cm.		1814	47	8
		Max. g/ sq.cm.		6500	70	10
		No layers>80		4	0	0
Forested location	Snowpit 1	Mean g/sq. cm.		233	35	29
		Max. g/ sq.cm.		600	67	65
		No layers>80		3	0	0
	Snowpit 2	Mean g/sq. cm.		1771	n/a	12
		Max. g/ sq.cm.		7000	n/a	35
		No layers>80		1	n/a	0
Mean density per snow pit						
Open locations	Snowpit 1			0.22	0.30	0.12
	Snowpit 2			0.26	0.16	0.11
Forested locations	Snowpit 1			0.25	0.13	0.16
	Snowpit 2			0.12	n/a	0.12

1) Road was plowed and log hauling began on January 6,7, 1991-92. Hauling ceased March 11.
2) 65 cm was found to be a critical snow depth for caribou in Manitoba (Stardom, 1975).
3) A crust is very light, B medium, C heavy enough to hold a man on showshoes.

wolf abundance or behaviour had changed noticeably. Therefore, the results make impact of wolves an unlikely alternative explanation for caribou movements.

Snow depths were greater in year 2, than in either the previous or subsequent year, supporting the null-hypothesis that caribou might have moved in year 2 because of the snow. However, depths never exceeded critical thresholds that initiate movement for caribou in Manitoba (Stardom, 1975). Nor could they be considered unusual for the study area; similar snow depths were recorded at Flat Lake the year before the study began, and were reported previously in the general area by Cumming and Beange (1987). Likewise, changes in snow consistency did not appear to be a factor since heaviest crusts, hardness values, and densities, factors that might make digging in snow more difficult and so spur caribou to move, were most adverse in year 1, not in year 2. Furthermore, similar behavioral changes were not detected among caribou at the northern control area during year 2 where snow depths could be presumed to be similar to those in the nearby study area (they were not measured because of inaccessibility). Thus all evidence suggested that differences in snow conditions would not likely explain the experimental results.

Other factors not measured might have affected the caribou. Although habitat change due to fire occurred some 5 km distant during the summer of 1991, none occurred in the occupied winter range. 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 disturbance potential by displacing caribou up to 200-300 m. Furthermore, Klein (1971) reported snowmobile disturbance of reindeer (*Rangifer tarandus tarandus*) in Scandinavia, stating that if approached too closely the reindeer may panic and become unmanageable. But in this study the snowmobiles stayed on roads and established trails where their effects on caribou seemed similar to but less than impact from roads. Apart from log hauling, the human activity most likely to have affected results was use of the haul road by private vehicles. We considered use of private vehicles during the hauling period as part of the overall impact of the hauling operation. But use of private vehicles after the hauling period in year 2 might have extended the length of disturbance time. We concluded 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 locations farther from the haul road, some returning all the way to summer habitat. Jackson (1990) reported similar movements of caribou from the same wintering area during December 1989, a time when trucks were also hauling logs.

Long term effects of the log hauling could not be determined from this study. Possible habituation was suggested by the continued presence of caribou in the area despite the presence of the railway and permanent all-weather roads. Further, the return of caribou to the Prime Study Area the third year suggested some degree of resilience after disturbance. If the road were traveled every winter, the observed displacement of caribou might decline or the caribou continue to occupy more remote areas in a way similar to caribou in the control area. Although small groups of caribou some time cross the Pikitigushi Road where they are sighted by local people and truckers, our aerial surveys showed major concentrations 2-3 km remote from the road, perhaps avoiding it in a way similar to caribou in Newfoundland (Mercer *et al.,* 1985). Bergerud (1974b) suggested that caribou might exhibit adaptive modification to human activities when food or weather were the primary influences on their behaviour. Perhaps that could happen here if hauling continued. Still this possibility is not reason for complacency about the impacts of roads on caribou. The number of caribou that became habituated to disturbance after several winters of displacement from favoured winter refugia might be considerable fewer than the number of caribou originally displaced.

Without disputing the validity of either or both of the major theories attempting to explain caribou declines, we speculate that a third possibility - severe or chronic disturbance to caribou - might also cause range reduction or population decline. When caribou occupy traditional winter habitats, they may be very sensitive to predation, or to the perceived risk of predation. Consequently, they may also be extremely sensitive to sights and sounds that are unfamiliar, sounds that may cover the approach of wolves. Therefore, habituation such as that reported in British Columbia (Johnson & Todd, 1977) and Newfoundland (Hill, 1985) may be more likely where predators on winter range are rare or nonexistent. Where predators are present, caribou may abandon, temporarily or permanently, otherwise suitable winter habitat if stressed chronically by noise or other stimuli (e.g. sight, smell) that may put them on "predator alert". They would also be less likely to move adjacent to disturbance areas during their normal patterns of winter habitat use. Thus, they may be forced into habitats with increased metabolic demand, decreased quality or quantity of food, and increased susceptibility to predation. Caribou displacement from wintering areas may result from various agents: humans, predators, climate, fires; the fact of displacement may be more important than the absolute effect of a single cause.

Management implications

It might be argued that shifts in winter location would be of little consequence for management of animals as notable for their wandering as caribou, but suitable wintering areas may not be in unlimited supply (Cumming *et al.,* 1996). This suggestion is supported by a comparison of the population estimates by Simkin (1965) with contemporary estimates of population potential by Ahti & Hepburn (1967). Caribou numbers in the Hudson Bay Lowland regions amounted to only 19% and 32% of their estimated carrying capacity. But in the Nipigon-Superior and Central Regions they reached 80% and 50% of their habitat potentials. Habitat loss in the former case presumably would be of little consequence, but in the forest loss of winter habitat through logging or disturbance might result in decreased caribou numbers. The mechanism could be simple food shortage, but it seems more likely to involve the need fot winter refugia from predation. Even within the study area, movements of caribou and moose during rhe time of log hauling brought the two species together, possibly increasing predation risk for the caribou. The finding of caribou killed or scavenged by wolves outside the major wintering areas suggests that immunity to predation may not extend beyond the traditional winter range boundaries. Movements of radio-collared caribou support this suggestion. The caribou that moved to the control area might have been equally safe once there, but the 2 collared caribou that traveled north, probably into areas with more moose and wolves, would likely face higher predation risks as a result. Caribou that returned to Lake Nipigon islands did so in the face of poor winter habitat conditions and increased wolf presence (Bergerud *et al.,* 1990). A caribou found killed by wolves near one of the islands during the winter of 1989 (Beange, pers. comm.) provided supporting evidence. Cumming & Beange (1993) suggested that the best explanation for disappearance of caribou bands in Ontario was displacement by logging from their wintering areas that forced them into places with reduced protection from wolves, poaching, and accidents. The results of this study suggest that displacement of caribou by winter traffic might have similar effects.

The observation of recreational driving on the logging road suggests possible consequences for roads through caribou wintering areas beyond direct disturbance. The presence of more roads may provide better access for wolves; more vehicles increase the risk of caribou being killed in road accidents; more people heighten the risk that some may be poachers. Even when caribou are not displaced, the presence of roads may increase all usual hazards.

The multiple increased risks to caribou from the use of winter roads, whether for logging or otherwise, argues for a complete ban on roads through caribou wintering areas. In Ontario caribou have been threatened by human activities throughout this century. Now even small bands are important to retain linkages for genetic exchange. Increased mortality due to displacement from favoured wintering areas should be avoided. However, a complete ban may not always be possible e.g., in places where roads have already been built; in these cases, winter use of roads should be reduced as much as possible. In summary, management action should aim at minimizing location of roads through caribou wintering areas, and restricting winter where there are such roads.

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