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Source: Wildlife Biology, 13(1) : 66-74

Published By: Nordic Board for Wildlife Research

URL: https://doi.org/10.2981/0909-6396(2007)13[66:EOMDOW]2.0.CO;2

Effects of mine development on woodland caribou *Rangifer tarandus* distribution

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Weir, J.N., Mahoney, S.P., McLaren, B. & Ferguson, S.H. 2007: Effects of mine development on woodland caribou *Rangifer tarandus* distribution. - Wildl. Biol. 13: 66-74

Knowledge of the effect of mining developments on caribou *Rangifer tarandus* is fragmentary. We examined the impact of the Hope Brook gold mine, southwestern Newfoundland, on the La Poile woodland caribou herd on a section of their year-round range. We examined the impact of the mine on caribou distribution during three phases of mine activity (pre-disturbance, construction and open-pit mining and underground mine and mill operation) in five seasons (winter, late winter, pre-calving, calving and autumn). Aerial surveys were conducted on a monthly basis from September 1985 to July 1991. Following initiation of the mine construction, caribou abundance increased with distance from the mine site in all seasons, and caribou avoided areas within 4 km of the site in most seasons. Within 6 km of the mine centre, group size and the number of caribou decreased as mine activity progressed in late winter, pre-calving and calving seasons. Although the impact of the mine was most prominent in the pre-calving and calving seasons, caribou responded to mine disturbance in all seasons. This highlights the importance of evaluating the year-round impact of human-induced environmental change.

Key words: Avoidance, distribution, disturbance, mining, Rangifer, woodland caribou

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Received 22 August 2005, accepted 9 January 2006

Associate Editor: Marco Festa-Bianchet

The expansion of human settlements and land developments have been implicated in the decline of caribou *Rangifer tarandus* across their geographical range, but the extent to which specific activities affect their demography and movements is still disputed (Klein 1980, Bergerud et al. 1984, Miller & Gunn 1985, Cronin et al. 1998, Nellemann et al. 2003, Noel et al. 2004). Direct links between caribou declines and human activities or development are often difficult to isolate, but some intermediate and long-term impacts of disturbance have been reported.

Reduction in the abundance of caribou in the vicinity of disturbed areas has been documented repeatedly, often with an avoidance zone of 1-5 km (Cameron et al. 1992, Smith et al. 2000, Dyer et al. 2001, Nellemann et al. 2001, Vistnes & Nellemann 2001, Mahoney & Schaefer 2002, Cameron et al. 2005). Females with calves are less tolerant and more likely to avoid disturbance, than are other caribou (Roby 1978, Cameron et al. 1979, Smith & Cameron 1983, Dau & Cameron 1986, Chubbs et al. 1993, Nellemann & Cameron 1998, Nellemann et al. 2001), and caribou are most sensitive to disturbance during the calving season (Cameron et al. 1979, Cameron et al. 1992, Dyer et al. 2001, Nellemann et al. 2001). Group size also affects the response to disturbance. Large groups usually avoid disturbed areas more than smaller groups (Cameron et al. 1979, Curatolo & Murphy 1986, Murphy & Curatolo 1987, Nellemann et al. 2003). Furthermore, the timing and direction of migration may be altered by disturbance (Cameron & Whitten 1980, Curatolo & Murphy 1986, Mahoney & Schaefer 2002).

While isolated developments, affecting a small fraction of a population's range, seem to have few obvious effects on herd demographics, progressive industrial activity and habitat alteration can exert a serious cumulative effect, including reduction in available range and population size (Nellemann & Cameron 1998, Vistnes et al. 2001), decreased reproductive rates and population fragmentation (Nellemann et al. 2003).

Perhaps the greatest impact of development on caribou has come from indirect effects of disturbance. Greater access to caribou created by linear corridors, such as roads and seismic lines, has led to increased harvest by humans (Bergerud 1974, Edmonds 1991, Rettie & Messier 1998) and predation (James 1999, James & Stuart-Smith 2000, James et al. 2004) which are suspected of contributing to caribou population declines. Widespread logging in western Canada has increased the availability of early successional stages of vegetation, increasing range suitability for moose *Alces alces*, creating an alternate prey base for wolves *Canis lupus*, and possibly large reductions in caribou numbers (Edmonds 1991, Seip 1991, 1992, Wittmer et al. 2005).

Newfoundland has been the site of substantial habitat alterations, and the effects of logging, hydroelectric development and road construction on caribou have been addressed in several studies (Mercer et al. 1985, Chubbs et al. 1993, Mahoney & Schaefer 2002); these results broadly concur with patterns observed elsewhere. Although the impacts of such industrial activities are well studied, little is known about the effects of mining on caribou and other ungulates.

In this paper, we report on the effects of the Hope Brook gold mine on a portion of the La Poile woodland caribou herd in southwestern Newfoundland. This herd, one of the largest on the island, was the subject of a comprehensive study during 1985-1991, which examined caribou distribution in the vicinity of the mine site before disturbance, after the initiation of construction and throughout the operation of the mine during five seasons. We predicted that the disturbance created by the development and operation of the mine would result in a shift in the distribution of caribou away from the mine site, and we expected this response to be evident in all seasons.

Material and methods

Study area and caribou herd

The Hope Brook gold mine occupied an area of about 2 km^2, in the southwest corner of Newfoundland, within an important winter and calving/post-calving habitat for the La Poile caribou herd (Fig. 1). Our study focused on the impact of mine development and operation on a variable section of the La Poile caribou herd located within a 195 km^2 survey block centered on the mine site.

The total range of the La Poile caribou herd is approximately 7,000 km^2 (Mahoney 2000a) and is predominantly barren land interspersed with partially forested river valleys, rocky outcrops, bogs, fens and ponds. The coastline is generally rugged, and inland the region shows gentle relief with summits rising to 650 m above mean sea level and average elevations of 300 m a.s.l. In the barren regions, heath vegetation is characterized by alpine azalea *Loiseleuria procumbens*, diapensia *Diapensia lapponica*, pink crowberry *Empetrum eamesii* and sheep laurel *Kalmia angustifolia*. Forested areas are composed of black spruce *Picea mariana*, balsam fir *Abies balsamea* and occasionally yellow birch *Betula lutea*.

The climate is strongly influenced by the ocean, particularly in the south (0-20 km inland; Maritime Barrens) where elevations are generally below 300 m a.s.l. Average annual temperature is about 7.5°C with mean minimum and maximum temperatures of

Figure 1. Study area and location of the Hope Brook gold mine within the La Poile caribou herd range boundary.

around 2.0°C in February and 18.1°C in August. The mean duration of the frost-free season is 157 days near the coast and 101 days inland. Total annual snowfall is 266 cm near the coast and 339 cm inland (Mahoney 2000b).

Based upon 16 stratified random block, transect and mark-recapture surveys, the La Poile caribou herd increased from 500 animals in 1960 to a high of 11,210 in 1988, falling to 4,300 in 2004 (Mahoney 2000a, S.P. Mahoney, unpubl. data). Moose, the only other ungulate in the study area, are widespread in forested areas. Wolves *Canis lupus* have been absent from Newfoundland since about 1922, but lynx *Lynx canadensis* are present in low abundance and black bears *Ursus americanus* are common. Both species prey on caribou calves (Mahoney et al. 1990). Coyotes *Canis latrans* reached the island of Newfoundland in 1985 but were not sighted in the area, and no coyote kills were reported during the course of our study. More detailed descriptions of the climate, soils, flora and fauna of southwestern Newfoundland can be found in South (1983).

Mine development

Construction of the Hope Brook gold mine began in July 1986, and the mine reached peak daily operating capacity in April 1991. In May 1991, the mine was closed due to economic and environmental problems. Royal Oak Mines Incorporated bought the property in April 1992, and commercial operations were re-

Table 1. Time line of the development and operation of Hope Brook gold mine during 1985-1991. Mine activities were categorized into three phases of mine activity. Numbers and dates of flight surveys included in each season are presented for each phase of mine activity.

Year	Mine activity	Phase of activity	Season	Survey dates	Number of surveys
September 1985-June 1986	No known disturbances		Autumn	3-29 November 1985	2
			Winter	12 December 1985-11 February 1986	4
		Pre-disturbance	Late winter	11-26 April 1986	2
			Pre-calving	16-23 May 1986	2
			Calving	4-27 June 1986	3
July 1986-September 1988	Road, dock construction and site preparation for camp, plant, crusher and portal (July 1986)				
	Excavation, heap leach pad construction, concrete pouring for dock (November 1986)				
	Underground development (February 1987)		Autumn	8 November 1986, 9 November 1987	2
	Heap leach process, development of open pit mining and mill construction (April 1987)	Construction/ Open pit mining	Winter	13 January-21 February 1987, 4 December 1987-16 February 1988	7
	Hydro line and dock construction (June 1987)	(Construction)	Late winter	3 March-25 April 1987, 19 March-24 April 1988	7
	Permanent camp/dock operation (November 1987)		Pre-calving	6 May 1987, 18 May 1988	2
	All operations shut down (December 1987)		Calving	2 June 1987, 9 June 1988	2
	Excavations, open pit resume (March 1988)				
	Heap leach process resumes (April 1988)				
October 1988-July 1991	Mill and crusher in operation (October 1988)		Autumn	5 November 1988, 9 November 1989	2
	Underground mine in operation and heap leach process suspended (February 1989)	Mill operation/underground mine	Winter	14 January 1989, 10 January-1 February 1990	3
	Heap leach process resumes (June 1989)		Late winter	26 April 1989, 30 March 1990	2
	Peak production (April 1991)	(Operation)	Pre-calving	24-31 May 1989, 25 May 1990	3
	Operations shut down (23 May 1991)		Calving	9-24 June 1989, 11 June 1990, 4-18 June 1991	5

sumed in July 1992 and continued until 1997. Our study focused on the period of the mine's history during 1985-1991 (Table 1).

Data collection

Caribou survey periods and observations

Caribou groups were observed, and their size and locations were plotted on 1:25,000 map sheets during 81 helicopter flights during 27 September 1985 - 18 July 1991. Surveys were conducted over the mine site area using Bell 206 helicopters, and the number of flights varied between three and 22 per year and between one and three per month. Two rear seat observers counted caribou within a 0.5 km strip (total width = 1.0 km) while flying east-west transects at an altitude of 135 m above ground level. During each flight, there was 100% coverage of a rectangular block (13 × 15 km; 195 km^2) centered over the mine.

We used the GIS software Terrasoft (1990, Digital Resource Systems Ltd.) to process caribou location data. All groups of caribou were located with respect to the centre of the mine activity in 10 concentric circles such that, excluding large ponds and the ocean, each circular area was 10 km^2. Because of the squared relationship between area and distance, the radii to the outer distances of the concentric circles were not uniform. These radii were 1.78, 2.52, 3.09, 3.57, 3.99, 4.40, 4.78, 5.13, 5.48 and 5.82 km, respectively, from the centre of mine activity. We recorded the location and number of caribou in each group observed within each circle.

Data analysis

Few caribou (mean: 3.86 ± 1.63 S.E.) were observed in the mine survey area from July to October in any year and, therefore, flights (N = 28) which occurred during this period were not included in the analyses. Furthermore, we omitted five other surveys because of limited data (only four to 22 caribou were observed in the 100-km^2 study area). These five surveys occurred throughout the study period (1 March, 28 November and 17 December 1986, 12 December 1989 and 30 March 1990). Data from the remaining 48 survey flights were separated by flight dates in consecutive years into five distinct 'seasons': winter (December-February), late winter (March-April), precalving (May), calving (June) and autumn (November; see Table 1). The five seasons closely approximate published accounts of woodland caribou biology (Bergerud 1975). We averaged multiple caribou counts for each season each year during 1985-1991 (see Table 1). We categorized years of mine activity into three phases: pre-disturbance, construction and open-pit mining (i.e. construction) and underground mine and mill operation (i.e. operation; see Table 1). For each season, we had one to three years of data for each phase of mine activity, and we averaged data across years in the same phase.

We used SPSS version 11.5 for all data analyses. Linear regression analysis was used to determine the relationship between number of caribou in each of the 10 concentric circles and the distance from the mine. We compared linear relationships for each phase of mine activity and for each season separately. All linear regression analyses were repeated using average group size as the test variable. We explored the trend in number of caribou, within the 100-km^2 study area, between phases of mine activity for each season. We used ANOVA to examine the effect of phase of mine activity on average group size, within the 100-km^2 study area, for each season separately. We used Tukey's *post-hoc* tests for multiple comparisons.

Recent research on the effect of disturbance on caribou populations in Newfoundland and elsewhere reported a possible threshold avoidance zone out to approximately 4 km from the source of the disturbance (Nellemann & Cameron 1998, Vistnes & Nellemann 2001, Nellemann et al. 2003, Cameron et al. 2005). To directly test this hypothesis, we compared the proportion of caribou distributed within and beyond 4 km of the mine centre during three phases of mine activity. We summed the number of caribou within the first five concentric circles (0-3.99 km) and the remaining five circles (4-5.82 km) and created two distance categories (0-4 km and 4-6 km) from the centre of mine site. We used χ^2 analysis to determine if the observed distribution of caribou between the two distance intervals, during construction and operation phases, differed significantly from what was expected based on the proportion of caribou in each distance interval in the pre-disturbance phase.

Results

Caribou distribution, in the pre-disturbance phase, was not related to distance from the mine centre in either season (Fig. 2). However, the number of caribou increased with distance during construction in all seasons, and this trend continued during the operation in all seasons except late winter (see Fig. 2). Between 51 and 92% of the variation in caribou distribution was accounted for by distance from the mine centre. There was an overall reduction in the number of caribou, within the 100-km^2 study area, as the mine activity progressed. During late winter, pre-calving and calving seasons, the number of caribou within 6 km of the mine centre declined progressively from pre-disturbance to operation, and only 17-27% of the number of caribou seen during pre-disturbance remained in the study area during operation in these seasons (see Fig. 2)

Group size increased with distance from the mine site during construction in the autumn ($R^2 = 0.54$, $P = 0.015$), pre-calving ($R^2 = 0.48$, $P = 0.032$) and calving seasons ($R^2 = 0.75$, $P = 0.001$), but not in the winter or late winter seasons ($R^2 \leq 0.02$, $P \geq 0.7$). There was no relationship between distance and group size in either season during operation $R^2 \leq 0.21$, $P \geq 0.18$), but the average group size, within the 100-km^2 study area, decreased from pre-disturbance to operation during the late winter, pre-calving and calving seasons (Fig. 3).

In comparison with the pre-disturbance phase, most caribou avoided the area within 4 km of the mine centre during mine construction and operation (Table 2). This behavioural response was most evident during the winter, late winter and pre-calving

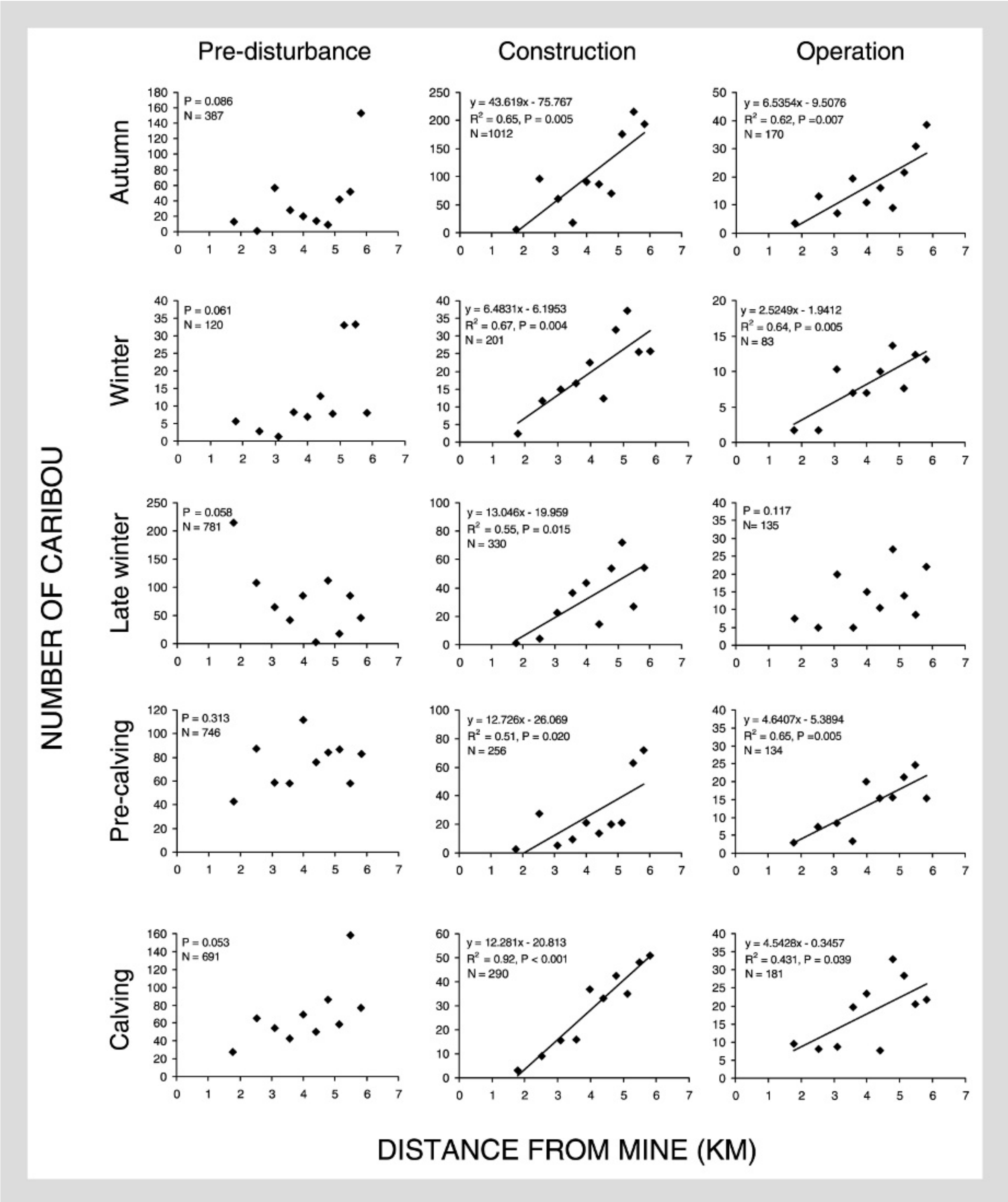

Figure 2. Relationship between caribou abundance and distance from the mine centre for each of the five phases of mine activity. Regression lines are shown for significant (α = 0.05) relationships only. The numbers of caribou (N) observed within the study area (100 km^2) are averaged for each phase of mine activity within each season.

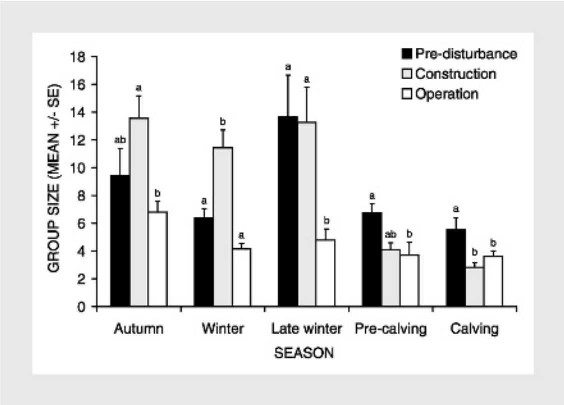

Figure 3. Changes in caribou group size (mean ± S.E.) as a function of the five phases of mine activity for each season. The letters above the bars represent significant differences between phases using Tukey's *post-hoc* tests.

seasons. During the autumn and calving seasons, fewer caribou occupied the area within 4 km during construction than during operation, but there was no difference in the distribution of caribou across the two distance zones between pre-disturbance and operation (see Table 2).

Discussion

Opportunities to quantitatively assess the impact of mining activities on ungulates have been limited (Oehler et al. 2005). To our knowledge, this is the first study to investigate the effect of mining on the distribution of woodland caribou, over multiple seasons, using pre-development control data.

Overall, mining affected the distribution of caribou. Prior to initiation of the Hope Brook gold mine development, caribou were dispersed throughout the study area, but during construction and mine operation, the number of caribou increased linearly with distance from the mine in all five seasons. Furthermore, there was avoidance or diminished use of the area within 4 km of the mine centre, which confirms the findings of numerous studies, which have reported lower abundance of animals near human disturbance, often with a diminished range use or avoidance within 4 km of the disturbed area (Nellemann & Cameron 1998, Vistnes & Nellemann 2001, Mahoney & Schaefer 2002, Nellemann et al. 2003, Cameron et al. 2005).

We provided evidence for the negative impact of mine disturbance on caribou distribution; however, evidence for demographic responses to mine activity was limited. While there was a decline in the number of caribou within the 100-km^2 study area as mine activity progressed during the late winter, pre-calving and calving seasons, this local decline was confounded by a wider population-level decline which was likely due to negative density-dependent effects (Mahoney 2000a, S.P. Mahoney & J.N. Weir, unpubl. data). The degree, if any, to which the Hope Brook gold mine may have precipitated these changes in the La Poile herd was unknown, but any loss of available habitat to a population experiencing food shortages is a cause for concern.

In addition to distributional changes, we detected changes in the structure of caribou groups with mine activity. Average group size, as far as up to 6 km from the mine centre, declined as mine activity progressed and increased with distance from the mine centre during the autumn, pre-calving and calving seasons. It is difficult to know whether the observed decline in group size, as the mine activity progressed, was an artifact of a reduction in the number of caribou in the study area, or whether large and small groups differentially avoided the mine area. Other researchers have reported that larger caribou groups avoided disturbed areas more than small groups (Cameron et al. 1979, Curatolo & Murphy 1986, Murphy & Curatolo 1987, Nellemann et al. 2003), and that the small groups, which occupy areas in the vicinity of the disturbance, are usually composed of bulls and yearlings who are more tolerant of disturbance (Cameron et al. 1979, Smith & Cameron 1993, Chubbs et al. 1983, Nellemann & Cameron 1998, Nellemann et al. 2003). Although we did not classify group composi-

Table 2. Percentage of caribou distributed between the two distance intervals 0-4 km and 4-6 km from the mine centre. χ^2 was performed comparing caribou distribution during the pre-disturbance (PD) phase to their distribution during the construction (C) and operation (O) phases.

	Autumn			Winter			Late winter			Pre-calving			Calving		
Interval	PD	C	O	PD	C	O	PD	C	O	PD	C	O	PD	C	O
0–4 km	30.1	26.8	31.8	20.9	34.0	33.3	66.2	32.8	39.0	48.1	25.8	31.3	37.6	27.8	38.4
4–6 km	69.9	73.2	68.2	79.1	66.0	66.7	33.8	67.2	61.0	51.9	74.2	68.7	62.4	72.2	61.6
χ^2	-	6.32	0.13	-	20.59	8.38	-	197.3	53.94	-	50.90	14.99	-	11.89	0.04
P-value	-	0.013	0.718	-	< 0.001	0.004	-	< 0.001	< 0.001	-	< 0.001	< 0.001	-	0.001	0.845

tion during survey flights, researchers conducting the reconnaissance flights and mine workers generally reported an absence of females with calves near the mine site.

Mahoney & Schaefer (2002) called for land and wildlife managers and policy developers to consider a likely habitat loss of 1-4 km following industrial developments. The Hope Brook gold mine resulted in a direct habitat loss of 1.78 km^2 due to actual mine infrastructure and gravel overlay of vegetation during mine construction. However, by assuming a circular avoidance radius of 4 km from the mine centre, the construction and operation of the mine resulted in direct and indirect habitat loss of 50 km^2.

Although the loss of 50 km^2 from an annual home range of 7,000 km^2 may seem insignificant, it may have important ramifications depending on the location of the loss (i.e. if it is along a migration route, the impact may be substantial) and can contribute to cumulative effects of development. While significant localized impacts of hydroelectric development, forestry and road construction on caribou abundance, distribution and migration patterns have been reported for Newfoundland caribou herds (Mercer et al. 1985, Chubbs et al. 1993, Mahoney & Schaefer 2002), no study has addressed the cumulative effects of these industrial activities. However, cumulative and progressive development has led to significant habitat loss and fragmentation, resulting in reduced reproductive rates and increased predation risk for woodland caribou in Alaska and Alberta (Nellemann & Cameron 1998, James 1999, James & Stuart-Smith 2000, James et al. 2004) and wild reindeer in Norway (Vistnes et al. 2001, Nellemann et al. 2003).We argue that future environmental impact assessments of proposed industrial development must focus on the cumulative effects of the proposed activity and historical habitat alterations. This is especially relevant for woodland caribou given that most herds are experiencing population declines (COSEWIC 2002, Mahoney 2000a).

Although we focused on the effect of mine disturbance, Newfoundland may provide a unique environment for future caribou disturbance studies. A major argument explaining caribou avoidance of linear industrial features, such as roads and seismic lines, is that linear disturbances may enhance the ability of wolves to prey on caribou (James 1999, James & Stuart-Smith 2000). Because wolves were extirpated, Newfoundland is an ideal place to test predictions of habitat avoidance in response to linear disturbance in the absence of wolves. We would expect results to differ greatly from areas where caribou are limited by wolf predation, if caribou truly avoid these features because of increased predation risk.

Acknowledgements - we thank the many members of the Newfoundland and Labrador Wildlife Division who contributed to this work over the years, especially Conservation Officers Mr. Bill Greene, Mr. Eric Menchenton and Mr. Lloyd Russell. Thanks also to the various pilots with Universal Helicopters and Canadian Helicopters. Special thanks to Marlene Dredge who worked tirelessly on GIS mapping of caribou locations. We also acknowledge the Newfoundland and Labrador government's continuing commitment to wildlife science.

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