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Hydroelectric development and the disruption of migration in caribou

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Abstract

We investigated the effects of hydroelectric development on the movements and space-use of caribou (*Rangifer tarandus caribou*) in west-central Newfoundland, Canada. We compared patterns of range use, site fidelity, and timing of migration before, during, and after project construction. Coincidental with the first year of project construction, caribou were less likely to be found within 3 km of the site; this persisted at least 2 years after construction was completed. Relative timing of migration was individual-specific; the rank order of spring arrival on, and autumn departure from, the calving and summer grounds tended to be consistent year-to-year. This is the first report of such individual-specific consistency in migration for a non-avian species. This predictability disappeared during development: the year-to-year consistency of fall and spring migration among individuals was apparent before and after construction, but not during construction. Variation in calving site fidelity was correlated to year-to-year differences in snowfall. We conclude that the development caused a disruption of migrational timing during construction and longer-term diminished use of the range surrounding the project site. Long-term studies of individually marked animals can aid in environmental assessments for migratory animals. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Anthropogenic effects; Avoidance; Migration; Movements; Philopatry

1. Introduction

Gauging the effects of human developments on migratory species can be difficult. While demographic responses are arguably the most poignant signal of negative impacts (Bergerud et al., 1984; Caughley and Gunn, 1996; Gill et al., 2001), the mobility of large mammals like caribou (*Rangifer tarandus*) has tended to hamper our ability to detect human-caused impairments to survival and reproduction. At the same time, the need for space suggests that disruption of movement may be particularly serious for migratory species (Bergerud et al., 1984). For caribou, assessments generally have relied on documenting population-level changes in distribution (Mahoney et al., 1991; Nellemann and Cameron, 1998; James and Stuart-Smith, 2000; Smith et al., 2000) or short-term changes in behaviour (Murphy and Curatolo, 1987; Harrington and Veitch, 1991; Duchesne et al., 2000). Radiotelemetry provides an opportunity, however, to evaluate potential human-caused effects, such as the timing of migration, by examining long-term responses by individuals.

Despite a large literature (reviewed by Cronin et al., 1998; Klein, 2000; Wolfe et al., 2000), predicting anthropogenic effects on caribou—due to roads, seismic lines, pipelines, hydroelectric dams, and transmission lines—remains problematic, in part because of the complex ecology of *Rangifer*. Furthermore, the vast scales of occupancy by each population tend to constrain experimental designs. Controls in space are often prohibitive, and thus comparisons in time are essential for gauging potential effects. Nonetheless, few studies of *Rangifer* (Bradshaw et al., 1997) have included observations of before, during, and after development.

We investigated the effects of a hydroelectric development on the space use and movements of the Buchans Plateau Caribou Herd (BPCH) in west-central Newfoundland, Canada. The Star Lake project was constructed in the heart of the herd's migratory pathway, between its calving and summer range, situated north of

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the development, and its winter range, located to the south (Fig. 1). Our inferences regarding anthropogenic effects were based on comparisons in migration and space use, before, during, and after development. We searched for changes in population distribution, site fidelity, and the relative timing of migration of radio-collared animals.

2. Methods

2.1. Study area and population

The BPCH occupied 12,000 km^2 in west-central Newfoundland (Fig. 1). Most individuals were migratory and the majority utilized a narrow corridor (<10 km) around Star Lake to move between their calving and summer range in the north and their winter range in the south. The winter range was composed primarily of expansive dwarf shrub heaths, fens and bogs, and was characterized by low snow depths and frequent thaws that provided caribou with accessible winter forage (Daaman, 1983). The calving and summer range was also primarily open land, a broad expanse of shallow patterned peatland which offered excellent visibility and predator avoidance terrain. Annual snow accumulation averaged approximately 280 cm and persisted until late May. The summer and calving range versus winter range were separated by the Red Indian Lake watershed (Lloyd's Line; Fig. 1) which ran perpendicular to the herd's migration route and served as a boundary for animals migrating between ranges.

The BPCH increased from less than 2000 animals in the early 1960s to 7300–7800 animals, 1994–2000, estimated from three independent surveys (Mahoney, 2000). The population was hunted annually after 1965; from 1966-1997, a total of approximately 5800 animals was harvested by residents and non-residents. Population inventories from 1960–1997 included 24 aerial censuses, and 28 fall and winter/spring composition surveys (Mahoney, 2000). Wolves (*Canis lupus beothicus*) were absent from Newfoundland since about 1922, but lynx (*Lynx canadensis subsolanus*) and black bears (*Ursus americanus hamiltoni)* occurred throughout the study area and preyed regularly on caribou calves (Mahoney et al., 1990). In addition, coyotes (*Canis latrans*), which reached the island of Newfoundland in 1985, occurred in the study area and were known to kill both calves and adults (S. P. Mahoney, personal observations). Moose (*Alces alces americana)* were widespread in forests.

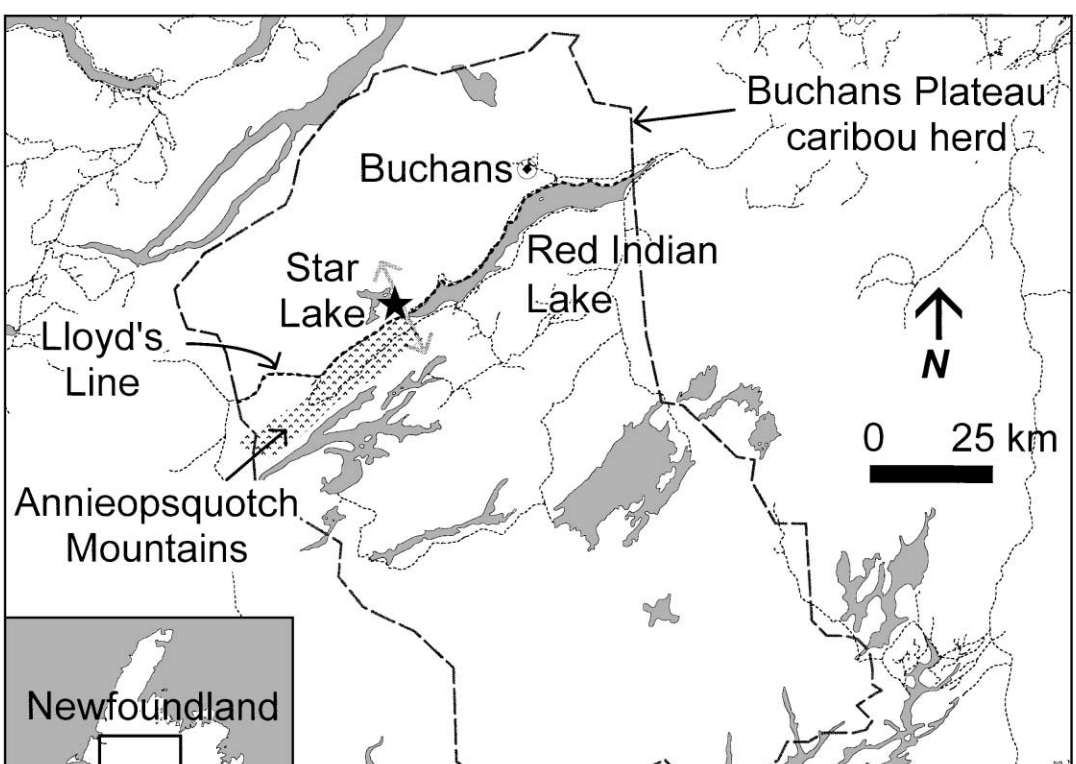

Fig. 1. Range of the Buchans Plateau caribou herd, its major migration route (double arrow), roads (dotted lines), and the hydroelectric development at Star Lake (⋆) in Newfoundland, Canada.

Human access of the study area was confined largely to a few scattered logging roads (Fig. 1).

The north–south migration of this herd was one of the great traditional movements on the island of Newfoundland and the last of those which focused migrating animals through a predictable, narrow corridor. The migration was well-studied in the 1950–1960s by Bergerud (1974) and in the 1980s by provincial Wildlife Division personnel (Newfoundland and Labrador Wildlife Division, unpublished files). The biannual movement took the majority of animals across Lloyd's Line and the Annieopsquotch Mountains whose steep northern escarpments offer only a few approaches to migrating caribou. A minority of the herd moved around the mountains by traveling westward a distance of approximately 50 km.

2.2. Hydroelectric development

Star Lake (Fig. 1) originally had a surface area of 14 km^2, 284 m above sea level on the Buchans Plateau. Its 35-km shoreline was primarily boulder and cobble, but in the western arm, deltas and extensive sand beaches and bars were present. The Star Lake hydroelectric development raised lake water levels by 8 m, flooded 15.4 km^2 of land, and was located in the major artery of the BPCH migration. Facilities consisted of a 15 MW powerhouse and a 250 m long, 18 m high dam near the outflow of Star Brook into Red Indian Lake, a buried penstock (1500 m) and tunnel (1000 m), a diversion dam and dike for diverting adjacent waters from the west into the Star Lake reservoir, a saddle dyke to prevent outflow at full supply levels, a 1.5-km access road and worker accommodations. Construction took place May 1997–September 1998, and flooding January–April 1998; operation commenced October 1998.

Environmental precautions were enacted during the development. Regulations on the disposal of garbage and a ban on wildlife harvesting within 1000 m of the infrastructure were implemented. During the study, there were no reports of killing or translocation of problem black bears, no apparent changes in predation on caribou, no modification in the numbers of caribou hunters or quotas, and no instances of caribou concentrating with greater exposure to hunters (Newfoundland and Labrador Wildlife Division, unpublished files).

2.3. Data collection

Adult ($\geqslant$2-year-old) caribou were immobilized from helicopter with 300 mg/ml xylazine hydrochloride during October 1993, September 1994, and October 1996. Animals were outfitted with mortality-sensing VHF radio transmitters (Lotek Engineering, Newmarket, Ontario, Canada) having a battery life expectancy of 48 months. Caribou were ear-tagged, weighed and measured, and most had an incisor extracted for cementum age analysis (Matson's Laboratory, Milltown, Montana, USA).

Each year, 34–51 radiocollared caribou were monitored with a STOHL-equipped Cessna 185 aircraft with an onboard Global Positioning System. Flights occurred on average four times per month. The total number of relocations between 23 September 1994 and 14 June 2000 was 7019; the median interval between consecutive relocations of individuals was 6 days. Relocations had a minimum accuracy of 500 m based upon repeated blind test positioning of "dummy" transmitters (S. P. Mahoney, personal observations).

2.4. Data analyses

For the analyses, we retained individuals (14 ♂, 40 ♀), each tracked for at least 360 days and 30 locations. Because males and females did not differ in the timing of migration (see Section 3), propensity to migrate, or speed of movement (S. P. Mahoney, personal observations), we pooled the data across sexes. Because of the staggered animal entry and intermittent mortalities, repeated-measures analyses were generally not possible. Therefore, for most analyses, we conducted separate year-to-year comparisons. Data preparation and analyses were carried out with MapInfo version 5.0 (MapInfo Corp., Troy, NY, USA) and STATISTICA 1999 edition (StatSoft, Tulsa, OK, USA). We set $\alpha = 0.10$.

To test for changes in the distribution of animals surrounding the development, we computed the proportion of all radio-tracked individuals in each year with at least one location at 0–3, 3–6, 6–9, and 9–12 km from the site. We tested for differences in these proportions, before and after initiation of construction, with *t*-tests at each distance class. We gauged whether individuals were disturbed by the development by classifying each animal, found in the 0–3 km distance class, as "returning" or "not returning" to that area the following year, before and after start of construction.

To document temporal variation in migration, we established "Lloyd's Line" along the north shore of Red Indian Lake and associated valley (Fig. 1). The line bordered the southern extent of the herd's calving and summer range on the Buchans Plateau, and represented the study site for previous observations of migration behaviour of the herd (Newfoundland and Labrador Wildlife Division, unpublished files). For each animal and year, we estimated the dates of arrival and departure on the Plateau as the midpoint in time between the two successive radio-locations when the line was crossed. To ensure reasonable precision, we discarded observations of any individual in a year where these two successive observations were >14 days apart. Although arbitrary, we considered this approach preferable to inclusion of observations from highly infrequent relocations.

To test for consistency in the order of migration among individuals in consecutive years, we carried out Kendall tao (τ) tests, which represent the difference between the probability that two variables are in the same order versus that they are in different orders, on the dates of arrival and departure on the Buchans Plateau in successive years. We supplemented these tests with Friedman two-way ANOVAs on the set of individuals where observations were available in all years of study ($n=10$ in spring; $n=11$ in fall) and Kendall τ on the average ranks in spring versus fall ($n=10$ animals). We tested for differences between males and females in timing of each migration during each year with Mann–Whitney U tests.

We assessed variation in site fidelity, the tendency of an individual to return to a particular place. We denoted fidelity as the distance between locations of an individual, 1 year apart (Schaefer et al., 2000). We carried out the analyses during times when the philopatry of caribou is most pronounced (Schaefer et al., 2000), i.e. calving (24 May–6 June), post-calving (7 June–1 September), and breeding (9–19 October). In cases of >1 observation per animal per year during the period, we computed the average easting and northing Universal Trans-Mercator grid coordinates of each animal before computing the distance. We performed ANOVA on the log-transformed distances among years. Observations of $\geqslant 20$ individuals were available from each yearly period.

To analyse the potentially confounding influence of snowcover (Bergerud, 1974; Eastland et al., 1989), we analysed consecutive-year variation in site fidelity and timing of migration in relation to snowfall. We used year-to-year changes in cumulative snowfall during April and May, and during October and November, recorded at the meteorological station at Buchans (Fig. 1; Environment Canada, unpublished).

3. Results

Individuals were less likely to be located in vicinity of the project site after the initiation of construction. On average, more than half of the radio-collared individuals were found within 3 km of the site each year before 1997, but this proportion declined to less than one-quarter after construction began ($t_3=5.025$, $P=0.0075$, one-tailed). Coincident with the project initiation, a gradient became apparent, with declining occupancy by the population with increasing proximity to the site (Fig. 2). We did not detect any significant variation among marked individuals, nonetheless, in the tendency to return to within 3 km of the project site in the following year. These frequencies before (seven returning in 15 instances) and after (eight returning in

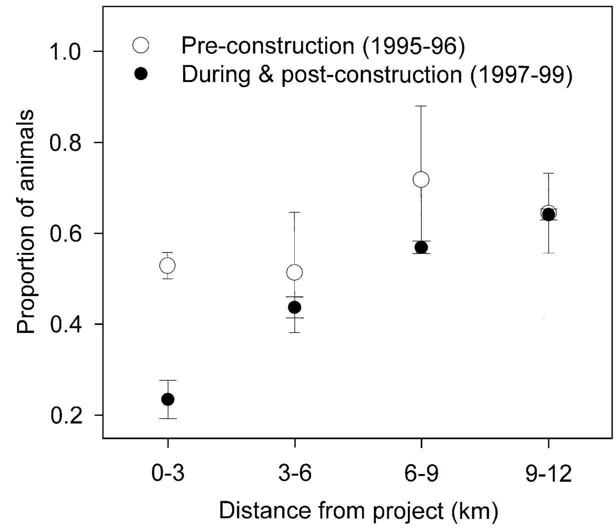

Fig. 2. Changes in the proportion of radio-collared Buchans caribou (±1 SE) before (1995–1996), during and after (1997–1999) the start of construction of the Star Lake hydroelectric project, at various distances from the development.

27 instances) the initiation of construction were not significantly different (Fisher exact test, $P=0.220$, one-tailed). Our sample size, however, was small.

There was substantial variation in the timing of migration among years. The median dates of crossing Lloyd's Line, both spring and fall, differed by more than 1 month during the study, i.e. from 17 April to 25 May in spring, and from 8 October to 7 November in fall (Table 1). Despite this wide variation in the absolute timing, we found predictability across years in the rank order of migration by individuals. In our analysis of animals with 5 years of observations, there was individual-specific consistency in spring arrival (Friedman tests; $\chi^2=15.0$; df=9, $P=0.091$) and fall departure from the Buchans Plateau ($\chi^2=28.9$; df=10, $P=0.0013$). There was also a mild tendency for early-arriving individuals to depart early: across all 5 years, average individual ranks in spring migration tended to be positively correlated to those in fall, although this pattern was not significant (Kendall $\tau=0.289$, $n=10$, $P=0.245$).

When examined year-to-year, the timing of spring and fall migrations was independent of sex (Mann–Whitney U tests; $P>0.22$, all tests) and age ($r^2<0.15$, $P>0.10$, all tests). In most years, the rank order of migration among individuals were generally consistent (Table 2). This predictability was disrupted during construction. The between-year order of individuals was not significantly related in 1996–1997 and 1997–1998 for both spring and fall migrations, but was re-established after 1998 (Table 2).

Similar to the pattern across all years, we found little evidence that rank order of migration was related between spring and fall in each successive season. Only

Table 1
Median dates of spring and fall migration by Buchans caribou, Newfoundland, Canada

Year	Spring migration	Fall migration
1995	14 May	13 October
1996	17 April	8 October
1997	25 May	28 October
1998	7 May	7 November
1999	3 May	23 October
2000	23 May	–

one instance, spring and fall 1995, was significant and, in this case, positively correlated ($\tau = 0.380$, $n = 23$, $P = 0.011$); all others showed no relationship ($P > 0.10$).

From 1995–1996 to 1998–1999, site fidelity was not substantially different among years during post-calving ($F_{3,127} = 1.08$, $P = 0.360$) nor breeding ($F_{3,123} = 1.23$, $P = 0.194$), but was substantially different during calving ($F_{3,128} = 7.84$, $P = 0.0059$). This year-to-year variation in inter-annual distances during calving was significantly correlated with snowfall during April and May ($r_s = 0.900$, $n = 5$, $P = 0.037$).

4. Discussion

How are we to disentangle natural from human-caused variations in the responses of mobile species? Here, we concur with Bergerud et al. (1984): there is weakness in the approach of relying on coincidence between change in animal response and an event hypothesized to be detrimental. Indeed, inferences based on temporal patterns alone are weaker than comparisons across both space and time (Fig. 2; Green, 1979; Schaefer et al., 2001). Nevertheless, we suggest that an established pattern, its disappearance coincident with project initiation, and subsequent reappearance constitutes more compelling evidence, at least in the case of temporary effects. On the other hand, a population growing coincident with development, in itself, does not constitute evidence of no impact (cf. Bergerud et al., 1984; Cronin et al., 1998). Most studies of caribou have failed to uncover negative responses in survival or reproduction due to disturbance (Cronin et al., 1998). Given the obstacles to assessing demographic impacts on *Rangifer*, however, we suggest that this absence of evidence does not constitute evidence of absence. There are compelling reasons in biological conservation for focussing on Type II errors and minimising chances of mistaken exoneration (Caughley and Gunn, 1996; Dayton, 1998).

For *Rangifer*, lower abundance of animals in the vicinity of disturbed areas has been documented repeatedly, often with diminished range use within 1–5 km (Mahoney et al., 1991; Cameron et al., 1992; Smith et al., 2000; Dyer et al., 2001; Nellemann et al., 2001; cf. Cronin et al., 1998). The evidence is now sufficient, in our view, to predict the effective loss of habitat at this scale, in a zone beyond the physical development.

Infrastructures and associated human activities can also disrupt caribou movements, and potentially lead to the fragmentation of range (Wolfe et al., 2000). For Buchans caribou, the absolute timing of migration was highly variable across years. Bergerud (1974) also reported that the modal date of fall migration by the BPCH, 1957–1963, differed by nearly a month, precipitated by the arrival and melt of snowcover. The influence of snowcover on calving site selection (Eastland et al., 1989) was reflected in our study by the annual changes in calving site fidelity. Despite this natural environmental buffeting, Buchans caribou displayed remarkable year-to-year consistency among individuals in the order of arrival on, and departure from, the summer and calving grounds (Table 2). Among migratory species, this form of individual behaviour has rarely been documented, i.e. only for two avian species (Rees, 1989; Hopp et al., 1999). For caribou, age and sex did not appear to influence the relative times of arrival or departure. This lack of relationship to age and sex differs from many other species (reviewed by Potti, 1998; Hopp et al., 1999). Nor did we find a relationship between spring and fall migrational tendencies (Rees, 1989): individuals arriving early in spring showed no strong propensity to leave relatively earlier or later in autumn.

Table 2
Consecutive-year patterns in rank order of migration by Buchans caribou and differences in snowfall[a]

Period	Rank order of spring migration			Change in April–May snowfall (cm)	Rank order of fall migration			Change in October–November snowfall (cm)
	τ	n	P		τ	n	P	
1995–1996	0.353	24	**0.016**	−6	0.390	22	**0.011**	+20
1996–1997	−0.157	20	0.333	+68	0.139	29	0.290	+7
1997–1998	0.060	29	0.648	+6	0.199	26	0.153	−1
1998–1999	0.361	22	**0.019**	−37	0.329	22	**0.032**	−1
1999–2000	0.344	18	**0.046**	−38				

[a] For year-to-year correlations in migrational timing, the values of Kendall tao (τ), sample size (n; the number of animals), and significant values (in bold) are indicated.

Based on its absolute timing, the effects of the Star Lake project on migration would have been masked by high inter-annual variation. Knowledge of individual migratory patterns was thus valuable for inferring effects of the Star Lake hydro development, enabling us to use individuals as controls. Temporary disruption of the orderly arrival and departure, perhaps as some individuals encounter the hydroelectric site during construction, appears to be a measurable effect of the Star Lake project. This underscores the need for multi-annual observations of individuals, both before and after potential disturbance, if we are to be able to gauge effects on mobile, long-lived species.

The re-establishment of migrational behaviour by Buchans caribou after construction is consistent with previous studies: caribou appear to be more sensitive to the human activities associated with construction, traffic, and noise, than to the infrastructure per se (Curatolo and Murphy, 1986; Murphy and Curatolo, 1987; Nellemann and Cameron, 1998; Smith et al., 2000; Dyer et al., 2001). Migrating caribou can be deflected by obstructions (Curatolo and Murphy, 1986). Animals may habituate within a few years (Bergerud et al., 1984; Mercer et al., 1985) provided that the degree of human activity is not too high (Wolfe et al., 2000), although habituation does not always occur (Cameron et al., 1992; Nellemann and Cameron, 1998). We cannot dismiss the possibility, however, that the disruption of movement might be harmful, with respect to demography, where human activities are protracted in either space or time.

Redistribution to undisturbed habitat, if available, seems to be the primary adaptation of caribou to unfavourable range alterations (Schaefer and Pruitt, 1991; Nellemann and Cameron, 1998). A critical, unresolved question concerns cumulative effects, which, in our view express the potential for a non-linear relationship between animal response and the area or degree of disturbance (Nellemann and Cameron, 1998). Given the degree of variation between caribou populations, their ranges, and the form of human developments, we are yet to arrive at a predictive understanding of where and when these thresholds exist.

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