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EFFECTS OF PETROLEUM EXPLORATION ON WOODLAND CARIBOU IN NORTHEASTERN ALBERTA

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Abstract: Woodland caribou (*Rangifer tarandus caribou*) in northeastern Alberta apparently have declined and are classified as endangered. Petroleum exploration has been implicated as a possible cause. We examined the effects of simulated petroleum exploration (i.e., loud noise) on caribou movement and behavior. We monitored 5 (1993) and 20 (1994) radiocollared caribou during 3 periods (pretest, test, and post-test) over 2 treatments (exposed and control). Exposed caribou moved significantly faster than control caribou (2.3 ± 0.2 SE vs. 1.6 km/hr ± 0.1), but not significantly farther. Exposed caribou crossed habitat boundaries significantly more than did controls (0.53 ± 0.16 vs. 0.27 changes/period ± 0.14). Disturbance did not affect significantly the proportion of time allocated to feeding. Treatment caribou demonstrated higher overall movement rates in 1993 than 1994 (2.7 ± 0.2 vs. 1.7 km/hr ± 0.1), displacement (3.5 ± 1.3 vs. 2.3 km ± 0.6), and more time allocated to feeding (27.5 ± 2.9 vs. 9.0% ± 1.7). Habitat boundaries crossed did not differ significantly between years. We suggest that increased movement may result in higher energy expenditure during winter, and that disturbed caribou may switch habitat type for cover or escape terrain. We believe that differences in movement between years resulted from higher snow depths in 1994. We also suggest that land-use managers should limit total disturbance during winter rather than mitigate industrial activity with timing restrictions.

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Key words: Alberta, behavior, disturbance, feeding, habitat change, movement, petroleum exploration, *Rangifer tarandus,* woodland caribou.

Woodland caribou have declined since early this century (Stelfox 1966, Lynch and Pall unpubl. data, Bloomfield 1980; Edmonds 1986, 1988) and now are distributed sparsely in Alberta where they are classified as endangered (Edmonds 1991, Gen. Wildl. Regul. 1994). Despite limited evidence (Bradshaw and Hebert 1996), petroleum exploration and development have been implicated as possible causes for the decline (Fuller and Keith 1981; Edmonds 1988, 1991).

The initial phase of petroleum exploration, geophysical survey, is perhaps the most disturbing to woodland caribou because it involves an unpredictable series of events. Although geophysical surveys usually create a regular series of noises continuing in a fixed direction, many explorations may occur simultaneously in a spatially unpredictable pattern. Describing changes in individual behavior and energy use is an empirical approach to evaluating the effect of disturbance on woodland caribou.

Our objective was to design an experiment to determine behavioral responses of woodland caribou to simulated petroleum exploration in northeastern Alberta (Bradshaw 1994). Upon exposure to a loud noise disturbance, we measured an individual's response for changes in movement rate, linear displacement, habitat use, and feeding behavior.

We hypothesized that exposure to loud noise would increase a caribou's rate of movement, linear displacement away from the source of disturbance, and, subsequently, the number of habitat patch boundaries crossed. We also hypothesized that caribou exposed to such disturbance would decrease the time spent feeding because of increased movement and vigilance behavior.

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STUDY AREA

The study area was in northeastern Alberta, Canada (center: 56°N, 112°W) and encompassed about 20,000 km^2 of boreal mixed-woods and peatlands; see Bradshaw et al. (1995) for a detailed description of vegetation in the study area. We used peatland habitat types (Bradshaw et al. 1995) to describe landscape configuration. Mean habitat patch size within the study area (all peatland habitats combined) was 33.6 km^2 (SD = 223.7 km^2; n = 647 patches). See Stuart-Smith et al. (1997) for a detailed analysis of landscape configuration.

METHODS

We examined the effects of simulated seismic exploration for petroleum (i.e., loud noise) on the behavior of woodland caribou using a before-after-control-impact design (Underwood 1994). We fitted adult woodland caribou with VHF radiotransmitting collars between January 1991 and February 1994 as described in Bradshaw et al. (1995). All animal treatment procedures were approved by the Canadian Council on Animal Care (CCAC) Animal Welfare Protocol, University of Alberta Biosciences Animal Care Committee (No. 587301).

We used a Zon Gun®, a type of propane cannon, as the source of disturbance. The noise produced from the cannon varied from 90 to 110 decibels (measured about 2 m from the cannon mouth with a noise intensity meter) and was most similar to the mean noise intensity and frequency (about 1-sec blast/min) of the blasting phase of exploration. Typical petroleum exploration consists of separate surveying, tree-clearing, drilling, and blasting phases, and all phases advance in a fixed direction. We measured the noise intensity and frequency of all exploration phases (4 separate exploration programs) with a noise intensity meter. We also determined that when remaining still one could detect noise generated from each exploration phase for about 1 hour; thus we used a 1-hour disturbance exposure period.

We monitored the behavior and movement of individual caribou during 3 separate periods: (1) one hour before disturbance (pretest), (2) one hour during disturbance (test), and (3) one hour after disturbance (post-test). For each caribou monitored, a Bell 206B Jet Ranger helicopter transported one person 975 m ± 75 (mean ± SE) from the caribou to be exposed. We made all efforts to land downwind of each animal. Once on the ground, the cannon operator carried the cannon and propane tank on foot to a distance of 331 m ± 52 from the test animal. We visually monitored the position of the operator from the air and used 2-way radios for directions to the caribou. Thus, we were able to calculate the distance from the caribou to the operator when the cannon was first started. The pretest period started as the cannon operator approached the animal to insure a full hour would elapse before the test period began. We fired the cannon at regular intervals every 1–2 minutes for one hour after the pretest and monitored the animal for an additional hour after the last cannon blast.

In winter 1993 (17–21 Mar) we examined the responses of 5 collared caribou (4 F and 1 M) exposed to disturbance using the experimental design described. In 1994 (18 Jan–14 Mar) we exposed 10 animals to disturbance (all F) and added 10 control animals (9 F and 1 M) to the experiment. All caribou had been collared at least 2 months before the experiment began and we exposed each caribou to only one experimental disturbance bout. We randomly assigned individuals as either exposed or control, and we tested only one animal per day. We treated control animals in exactly the same manner as exposed animals, with the exception that control animals were not exposed to the noise of the propane cannon during the test period. Control caribou experienced all other aspects of the experimental design, including the approach by helicopter and cannon operator. Of the 15 planned experimental disturbance bouts (1993 and 1994 combined), 2 were terminated because the caribou moved before the cannon was in place. We continued to follow these an-

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imals, however, during the rest of the experiment and classified them as controls. We also strove to reproduce the regular, pretest approach employed by the cannon operator for these 2 animals.

We used radiotelemetry to monitor caribou movements indirectly. We relocated caribou fitted with VHF transmitters from a Cessna 185 aircraft flying at 450–550 m aboveground level (high enough to avoid eliciting an excitatory response—Calef et al. 1976, Miller and Gunn 1979, Harrington and Veitch 1992). We used a global positioning system (GPS) onboard the aircraft to fix caribou locations visually or by VHF signal strength. We also tested pilot accuracy by comparing GPS fixes taken at transmitters placed in known locations (on ground) and GPS fixes taken of these transmitters from the air.

We first determined the daily movement rate based on locating 7 caribou twice a day for 8 days to ensure that they remained in a small enough area to expose them experimentally to noise. For each experimental bout we determined a caribou's location about every 10 minutes during each of the 3 hour-long experimental test periods. We calculated the distance moved between 2 successive positions and divided this value by the time elapsed between positions (10.46 min ± 0.10) to obtain movement rate values for each animal. We also calculated total linear displacement from the first position to the last position recorded for each test period to determine if there was net movement away from the disturbance source. Before each experimental bout we searched the area near the treatment animal to avoid inadvertently exposing other collared caribou to the disturbance.

When an individual increases its movement through an area comprising a mosaic of different habitat types, that individual is likely to cross habitat boundaries more frequently. To test this hypothesis, we recorded the habitat type of each caribou position as one of 7 peatland habitats (Vitt et al. 1992, Bradshaw et al. 1995). We then tallied the number of habitat borders crossed per test period and compared these occurrences between exposed and control caribou.

We also monitored broad behavioral categories from the aircraft using mercury tip-switch activity sensors embedded in the radiocollars. All 5 caribou monitored in 1993 and 12 (6 treatment and 6 control) of the 20 caribou monitored in 1994 wore collars equipped with the sensors. The activity sensors about doubled their pulse rate when the caribou lowered its head. We calibrated the signals from captive caribou and could distinguish head-down (feeding) and head-up (resting, walking, or vigilance) behaviors. We did not analyze head-up signals because we could not distinguish among behaviors. We expressed head-down (feeding) signals as a percentage of total observation time when activity signals were recorded.

We analysed animal movements with the aid of a GIS using ARC/INFO® software (Environ. Syst. Res. Inst. Inc. 1990). We juxtaposed all animal positions with 1:250,000 digital peatland habitat maps (Vitt et al. 1992) to determine habitat patch changes (Bradshaw et al. 1995).

We analysed movement rates, displacement, habitat-patch changes, and feeding proportions using analyses of variance (ANOVA). We log-transformed displacement data and used the angular transformation (arcsin $\sqrt{x}$) for feeding proportions to reduce the model coefficient of variation. We used the variance stabilizing transformation ($\sqrt{x + 1}$) for habitat change data to render error variances homogeneous (Snedecor and Cochran 1980).

Combining all caribou monitored, we used SAS® (SAS Inst. Inc. 1988) to test a general linear model (GLM) including treatment (exposed or control), animal, period (pretest, test, post-test), and the treatment × period interaction. Each test period included 6 measures (each 10-min interval). We used the interaction term to test the working hypothesis that disturbance altered movement rate, displacement, changes of habitat patch, and feeding. We did not include exposed animals from 1993 in these analyses because of the absence of a 1993 control group. We did, however, do a second univariate GLM ANOVA using both 1993 and 1994 exposed groups to test for overall differences between years (substituting 'year' for 'treatment' in the above model). We also analysed the distance exposed caribou were from the cannon when it was first fired and the mean movement rate during the test period using least-squares linear regression. This allowed us to test the null hypothesis that the differences in distance we placed the cannon from the exposed caribou had no effect on the animal's subsequent movement rate. We rejected null hypotheses when $P \leq 0.05$.

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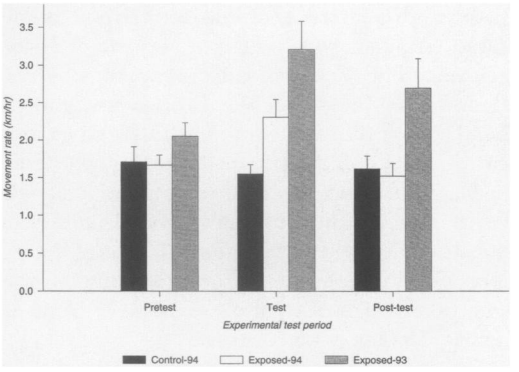

Fig. 1. Mean movement rates per experimental test period (+SE) for exposed (1993–94) and control caribou (1993).

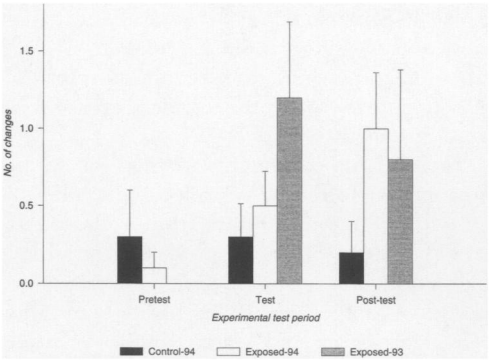

Fig. 2. Mean number of habitat patch changes per experimental test period (+SE).

RESULTS

In general exposed animals were stationary, feeding, or moving slowly in an apparently random manner during the pretest period. When we started firing the cannon, animals typically moved away from the source of disturbance for the duration of the test period. During the post-test period, response varied from no measurable effect to continued movement away from the disturbance.

Pre-experiment Procedures

The GPS precision based on 7 different recordings of the same location (on ground) was 142.8 m ± 15.1. The mean disagreement between 10 GPS ground and air fixes was 151.3 m ± 11.5. For winter 1993 the mean movement rate of undisturbed caribou was 0.065 km/hour ± 0.015 (c. 24-hr measurement intervals), thus demonstrating that individual caribou could be followed within the timeframe of the disturbance experiment.

Movement Rate

Exposed animals demonstrated higher mean movement rates (2.3 km/hr ± 0.2) than did control animals (1.6 km/hr ± 0.1) during the test period (Fig. 1), and the GLM interaction term of treatment × period was significant ($F = 4.29$; 2, 336 df; $P = 0.02$). We therefore rejected the null hypothesis that there was no effect of disturbance on movement rate.

Movement rate of exposed animals in 1993 (2.7 km/hr ± 0.2) was higher than for exposed animals in 1994 (1.7 km/hr ± 0.1; Fig. 1) for all test periods combined (F = 19.31; 1, 251 df; $P = 0.0001$). There was no significant relation between the distance an exposed animal was from the cannon when it was activated and the animal's subsequent mean test period movement rate ($r^2 = 0.08$; $F = 6.0 \times 10^{-5}$; 1, 13 df; $P = 0.99$).

Displacement

Although mean linear displacement per test period was greater for treatment animals (0.90 km ± 0.20) than control animals (0.49 km ± 0.09), the GLM interaction term was not significant ($F = 2.68$; 2, 36 df; $P = 0.08$). However, displacement was significantly greater in 1993 (3.5 km ± 1.3) than in 1994 (2.3 km ± 0.6) from the beginning of the pretest period to the end of the post-test period (F = 7.44; 1, 26 df; $P = 0.01$).

Habitat Patch Changes

The interaction term of treatment × period was significant ($F = 5.36$; 2, 36 df; $P = 0.009$), demonstrating that exposed caribou made more habitat patch changes (Fig. 2) during the test period (0.53 ± 0.16) than did controls (0.27 ± 0.14). The effect due to year was not significant (F = 0.33; 1, 26 df; $P = 0.57$).

Proportion of Time Feeding

The interaction term describing the effect of disturbance on feeding was not significant ($F = 0.06$; 2, 200 df; $P = 0.94$). We therefore failed to reject the null hypothesis that disturbance did not alter time spent feeding during the experiment. Exposed animals in 1993 fed significantly more overall (27.5% ± 2.9) than exposed animals in 1994 (9.0% ± 1.7; $F = 66.56$; 1, 183 df; $P = 0.0001$).

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DISCUSSION

We found that loud noise disturbance significantly increased a caribou's rate of movement, and that the overall movement rate was higher in 1993 than in 1994. This difference between years may have been due to the considerable difference in mean snow depths between winters. We tested caribou in 1993 when snow was almost absent in the study area, whereas caribou in 1994 faced maximum snow depths exceeding 1 m (Bradshaw et al. 1995). Although caribou are adapted to movement in deep snow (Telfer and Kelsall 1984), depths of 1 m or greater appeared to impede movement during this experiment. Deep snow impedes movement, consequently, a caribou's energetically optimal walking speed declines with snow depth (Fancy and White 1985). A significant difference in movement rate between years suggests that caribou compensated for the increased cost of locomotion in deep snow in 1994.

Noise disturbance did not cause linear displacement to increase significantly, which suggests that animals were not displaced significantly from their original positions even though they were moving faster during the disturbance. However, displacement in 1993 was greater than in 1994, thereby corroborating the hypothesis that deep snow in 1994 impeded movement.

Potentially the most hazardous and long-term effects of disturbance are the avoidance or abandonment of optimal habitats and the reduction in a population's range (Klein 1971, Geist 1978). The effects of disturbance are, however, difficult to evaluate for caribou because range shifts tend to occur over decades (Geist 1978). In apparent contradiction to the lack of significant effect observed for displacement, we found that disturbance caused caribou to increase habitat patch changes despite large mean patch size (33.6 km^2) relative to distances moved during the experiment. This finding suggests that movement away from the source of disturbance still occurred by means of changing habitat type. Habitat patch size and interspersion in the landscape affect the frequency of crossing patch boundaries; therefore, our results suggest that (1) habitat patches were well-interspersed, or (2) caribou were near patch boundaries when initially disturbed. Movement through different habitat types may be simply random, but it is possible that adjacent habitat patches provided better escape or cover for animals responding to disturbance.

Caribou behavior, like that of other ruminants, is characterized by an approximately regular alternation between periods of activity and rest. After a few hours of foraging and slow movement, animals usually lie down to ruminate and rest for a similar period (Gaare et al. 1975). In winter caribou typically forage for 2 to 3 hours in the morning and then again in the afternoon, with a regular 2 to 2.5-hour lying period at mid-day (Gaare et al. 1975). Foraging takes up from 35 to 50% of a reindeer's time, more in winter than in summer (Gaare et al. 1975). This pattern poses certain problems in the remote detection of modifications to feeding behavior in response to disturbance. If exposed animals encountered disturbance during a morning feeding bout, the feeding likely was interrupted. Indeed, on the 2 occasions that the cannon operator directly observed the exposed animal before the test period, feeding behavior appeared normal. On both occasions the first cannon blast interrupted this feeding as the animal fled from the cannon's position, and we later verified these observations with the activity sensor data. Possibly, many of the animals showing little or no reduction of feeding in response to disturbance were ruminating at the time of disturbance.

Having insufficient time available for foraging may prevent a wild ruminant from meeting its daily energy requirement (Renecker and Hudson 1993). Although we relied exclusively on the activity sensor data from each collar to assess feeding behavior, sample size possibly was too small to detect a significant difference ($n_{93} = 5$; $n_{94} = 6$). However, the lack of significant effect on feeding suggests that caribou still will be able to meet their nutrient requirements.

Exposed caribou in 1993 spent more time feeding than did both control and exposed 1994 animals, and we believe this to be the result of the difference in mean snow depth between winters 1993 and 1994 (Bradshaw et al. 1995). Animals must spend more time digging to feed as snow depths increase (Vandal and Barrette 1985), but when snow is virtually absent, as in 1993, animals can feed continuously without lifting their heads.

The experimental design we used to determine the degree to which woodland caribou respond to petroleum exploration was practical in detecting some of the more subtle effects of

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disturbance. However, the difficulty in tracking individual caribou for experimental purposes, and other confounding environmental factors (wind speed and direction, temperature, etc.) likely reduced our statistical power to detect an effect of disturbance. Furthermore, it is difficult to infer long-term population effects of repeated disturbances from the experimental manipulation of individuals.

Using a helicopter to approach animals made the experiment logistically possible, and although we controlled for this confounding disturbance experimentally, we would have preferred approaching the animals entirely on foot. A propane cannon, although practical, may not have been the ideal method to simulate the noise generated from petroleum exploration. In retrospect, we should have included in the experimental design other noise intensities and frequencies to represent better the spectrum of disturbances woodland caribou may experience in northeastern Alberta.

Our results support the hypothesis of higher energetic costs associated with disturbance, and other studies either have modelled or attempted to calculate the effects of disturbance on ungulate energetics (Skogland and Grøvan 1988, Hobbs 1989, Cuyler and Øritsland 1993). From these studies, it appears that disturbance can have significant energetic consequences for northern ungulates when considering the delicate balance that exists between energy expenditure and forage availability in variable winter conditions.

MANAGEMENT IMPLICATIONS

Disturbance resulting from petroleum exploration in northeastern Alberta affects the behavior of woodland caribou and possibly their energetic balance during winter. Wildlife and land-use managers should focus on obtaining precise estimates of woodland caribou density and relate these to the intensity and distribution of normal petroleum exploration activities. The cumulative effect of repeated encounters with noise disturbance may alter significantly use of traditional range.

Alberta land-use guidelines for industrial activity in woodland caribou habitat generally focus on timing and access restrictions to mitigate the effects of potential disturbance. We suggest instead that wildlife managers focus on the cumulative effects of disturbance on caribou population trends and dynamics, examining also the degree of habituation to disturbance demonstrated by caribou. We believe both wildlife and industrial land-use needs would be better achieved by reducing total disturbance. We also suggest that wildlife researchers and managers need to explore how disturbance affects the predator-prey relations existing between wolves (*Canis lupus*) and both caribou and moose (*Alces alces*) in this region, and how the removal of trees during exploration changes the landscape configuration of the boreal forest.

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