Energetic implications of disturbance caused by petroleum exploration to woodland caribou

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Abstract: Woodland caribou (*Rangifer tarandus caribou*) in Alberta are classified as endangered and apparently have declined. Disturbance from petroleum exploration has been implicated as a possible cause, so we constructed a simple model to estimate the energy costs of multiple encounters with disturbance (i.e., loud noise). Our objective was to estimate if woodland caribou in northeastern Alberta have been exposed to enough disturbance from 1988 to 1993 to cause winter mass loss to exceed either (*i*) 15% autumn mass or (*ii*) 20% autumn mass. A single disturbance event costs caribou 3.46–5.81 MJ. Caribou would have to encounter (*i*) 20–34 (mean = 27) disturbance events to lose >15% mass over winter and (*ii*) 41–137 (mean = 89) events to lose >20% mass. There were five occasions from 1988 to 1993 (i.e., in a particular caribou distribution zone and winter) when the encounter rate (number of potential encounters per square kilometre) exceeded a level expected to result in caribou losing more than the estimated mean 15% autumn mass. There were four occasions when the encounter rate exceeded the lower limit expected to cause >20% mass loss and one occasion when it approached the mean rate expected to cause >20% mass loss. Modelling the cumulative influence of disturbances demonstrates an effect on individual energy loss during winter at certain exploration intensities. It is the first attempt at estimating the consequences of petroleum exploration for wildlife in northeastern Alberta and provides important information for future research and land-use management.

Résumé : En Alberta, la population du Caribou des bois (*Rangifer tarandus caribou*) est réputée en voie de disparition et elle est effectivement en déclin; les perturbations occasionnées par les opérations pétrolières y contribuent probablement. Nous avons construit un modèle mathématique simple qui permet d'estimer les coûts énergetiques associés aux instances multiples de telles perturbations (notamment le bruit intense). Nous avions pour objéctif d'estimer si la population a subi suffisamment de perturbations entre 1988 et 1993 pour occasionner une perte de masse en hiver supérieure (*i*) à 15% de la masse à l'automne ou (*ii*) à 20% de la masse à l'automne. Une seule perturbation coûte à un caribou de 3,46 à 5,81 MJ. Un caribou doit donc être soumis à (*i*) entre 20 et 34 (moyenne = 27) perturbations pour perdre plus de 15% de sa masse en hiver et (*ii*) à entre 41 et 137 (moyenne = 89) perturbations pour en perdre plus de 20%. Entre 1988 et 1993, il y a eu cinq circonstances (i.e., dans une zone de répartition particulière et au cours d'une saison précise) où le taux des perturbations (nombre de perturbations potentielles par kilomètre carré) a été plus élevé que le nombre théorique susceptible d'engendrer une perte moyenne de masse de plus de 15% en hiver. Il y a eu quatre circonstances où ce taux a dépassé le seuil inférieur susceptible de provoquer une perte de masse de plus de 20% et une seule circonstance où il s'est approché du taux moyen relié à une perte de masse de plus de 20%. Ce modèle mathématique démontre que les effets peuvent être cumulatifs et entraîner une perte d'énergie chez certains individus soumis à des perturbations particulièrement intenses au cours de l'hiver. Il s'agit là d'une recherche inédite sur les conséquences de l'exploration de pétrole et notre modèle fournit des informations fort utiles pour la recherche et la gestion des terres dans le nord-est de l'Alberta.

Introduction

Woodland caribou (*Rangifer tarandus caribou*) in Alberta are considered endangered (Edmonds 1991; General Wildlife Regulation 1994) because they exist at low densities (Bradshaw and Hebert 1996; Stuart-Smith et al. 1997) and are thought to have declined since early this century (Stelfox 1966; Bloomfield 1980; Edmonds 1986, 1988). Despite limited evidence of a decline (Bradshaw and Hebert 1996), petroleum exploration and development have been implicated as possible causes (Fuller and Keith 1981; Edmonds 1988, 1991; Bradshaw et al. 1997).

Bradshaw et al. (1997) determined experimentally the behavioural responses of woodland caribou to a single disturbance of simulated petroleum exploration. Since a single encounter with disturbance (i.e., loud noise) is unlikely to cause deleterious energy consumption, the significance of exposure to disturbance should be proportional to the number of times an animal encounters disturbance events (Geist 1978; Gilliam and Lent 1982). Predicting the frequency with which woodland caribou encounter disturbance events during winter permits a calculation of the potential increase in mass loss resulting from multiple exposures.

Our objective was to construct a simple model to estimate (*i*) the energy cost of a single encounter with disturbance

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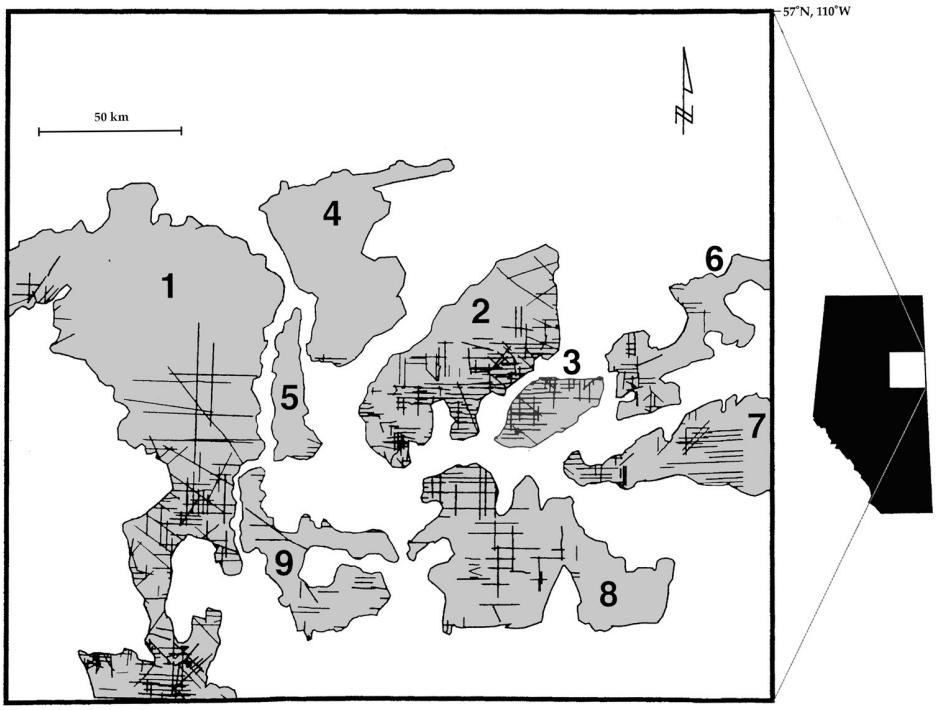
Fig. 1. Study area with woodland caribou distribution zones (CARB) and petroleum exploration programs explored within them from 1988 to 1993. Numbers refer to zone attributes described in Table 1.



caused by petroleum exploration and (*ii*) the annual and regional effects of multiple disturbances on caribou mass loss during winter in northeastern Alberta from 1988 to 1993.

Study area

The study area was in northeastern Alberta, Canada (centre: 56°N, 112°W), and encompassed about 20 000 km^2 of boreal mixed woods and peatlands (Fig. 1). See Bradshaw et al. (1995, 1997) and Stuart-Smith et al. (1997) for a detailed description of the vegetation and landscape configuration of the study area.

Methods and results

This simple model uses a combination of energy values from the literature and a detailed description of woodland caribou distribution and past petroleum exploration in northeastern Alberta. We only modelled mass loss in females, using 132 kg as the average mass of an adult female woodland caribou (Banfield 1961) for all energy calculations.

COST: cost of a single disturbance event

The energetic cost of a single disturbance event (COST) is a combination of the cost of movement, the cost of the initial flight response, and the cost of excitement. Barren-ground caribou require 0.00264 MJ·kg^{-1}·km^{-1} for walking in moderate snow conditions (Boertje 1985). Bradshaw (1994) found that disturbed caribou travelled, on average, 2.11 km farther than control animals during, and immediately following, a single disturbance event. An average female caribou therefore expends an additional (0.00264 MJ·kg^{-1}·km^{-1})(132 kg)(2.11 km) = 0.7353 MJ/day due to movement when disturbed.

Bradshaw (1994) observed that disturbed caribou move rapidly away from the source of disturbance for about 15 min following the initial exposure. Since caribou expend 0.0350 MJ·kg^{-1}·h^{-1} trotting and galloping (Boertje 1985), we estimate that disturbed caribou will expend (0.0350 MJ·kg^{-1}·h^{-1})(132 kg)(0.25 h) = 1.155 MJ during the initial flight response to disturbance.

Prolonged excitement can increase metabolic costs (Blaxter 1962; Webster and Blaxter 1966; MacArthur et al. 1979; Chabot 1991) from 10 to 25% more than required for maintenance (Geist 1978). Since the fasting metabolic rate (FMR) for barren-ground caribou is 0.403 MJ/kg$^{0.75}$ (McEwan 1970; Fancy 1986), we assume an additional 0.10(132 kg)$^{0.75}$ (0.403 MJ/kg$^{0.75}$) = 1.57 MJ to 0.25(132 kg)$^{0.75}$ (0.403 MJ/kg$^{0.75}$) = 3.92 MJ as the cost of excitement due to disturbance. The total COST is therefore 3.46–5.81 MJ.

LOSS: winter mass loss

We assume that woodland caribou normally lose 10–15% (mean = 12.5%) of their autumn mass during winter (Steen 1968), which is an average range when other reported values are considered (Bergerud 1974; Jacobsen and Skjenneberg 1975; Dauphiné 1976). Therefore, a female caribou loses between 0.10(132 kg) = 13.2 kg and 0.15(132 kg) = 19.8 kg during winter (mean = 16.5 kg).

To exceed the 15% normal mass loss maximum, at least an additional 2.5% must be lost, on average (15–12.5%). This is equivalent to 0.025(132 kg) = 3.3 kg additional mass lost during winter.

For this model, we assume that winter mass loss >20% of autumn mass results in reduced calf production because relatively small shifts in mass result in relatively large changes in parturition rate (Cameron and Ver Hoef 1994). To exceed

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Table 1. Mean disturbance potential and encounter rates in caribou zones from 1988 to 1993. Zone names refer to identifying caudastral features (rivers, lakes, etc.) within the study area. Zone numbers are shown in Fig. 1.

Zone	Area (km^2)	Linear exploration (km)	Operating days (encounters)	Mean encounter rate (encounters/km^2 per winter)
1 (Wabasca)	6775	340.2 (±109.2)	131.0 (±31.1)	0.0193 (±0.0046)
1 (south)*	2700	340.2 (±109.2)	131.0 (±31.1)	0.0485 (±0.0115)
2 (Egg)	2286	215.8 (±67.3)	88.4 (±26.8)	0.0387 (±0.0117)
3 (Pony)	507	66.2 (±10.3)	37.0 (±12.1)	0.0731 (±0.0239)
4 (Algar)	1876	3.1 (±3.0)	1.3 (±1.3)	0.0007 (±0.0007)
5 (Agnes)	451	3.8 (±3.8)	1.0 (±1.0)	0.0023 (±0.0023)
6 (Bohn)	1019	33.5 (±15.2)	14.3 (±3.9)	0.0140 (±0.0038)
7 (Christina)	1228	69.9 (±32.0)	22.9 (±7.2)	0.0186 (±0.0059)
8 (Wiau)	2641	95.3 (±30.9)	43.7 (±11.0)	0.0165 (±0.0041)
9 (Wandering)	1114	33.3 (±10.8)	15.5 (±5.0)	0.0140 (±0.0045)

Note: Values in parentheses show the standard error.

*Since most exploration programs occurred in the southern portion of the Wabasca zone (1), the mean encounter rate is also calculated for this area.

20% mass loss during winter, an individual caribou must lose an additional 5–10% of its autumn mass. This is equivalent to an additional 6.6–13.2 kg lost over winter.

ELOS: energy equivalent of winter mass loss

Winter mass loss of endogenous reserves can be divided into two categories: loss by fat catabolism (90% of reserves) and loss by protein catabolism (10% of reserves) (Boertje 1985). Fat produces 39.3 MJ/kg and lean tissue produces 5.0 MJ/kg (Boertje 1985; Hudson and White 1985).

Therefore, >15% mass loss is equivalent to 0.90 (3.3 kg) (39.3 MJ/kg) + 0.10(3.3 kg) (5.0 MJ/kg) = 118.37 MJ. To exceed 20% mass loss, a caribou loses the equivalent of 0.90(6.6 kg) (39.3 MJ/kg) + 0.10(6.6 kg) (5.0 MJ/kg) = 236.74 MJ to 0.90(13.2 kg) (39.3 MJ/kg) + 0.10(13.2 kg) (5.0 MJ/kg) = 473.48 MJ.

EVNT: disturbance events required to cause increased mass loss

The number of disturbance events (EVNT) required to cause >15 and >20% mass loss is the total energy lost during winter (ELOS) divided by the COST. Assuming that a caribou uses all of its home range equally, we divided EVNT by the mean home range of woodland caribou (613.8 km^2) in northeastern Alberta (Bradshaw et al. 1995) to compare disturbance potential among years and regions.

To exceed 15% mass loss, 20–34 (mean = 27) disturbance events are required, or 0.0326–0.0554 event/km^2 (mean = 0.0440). To exceed 20% mass loss, 41–137 (mean = 89) disturbance events are required, or 0.0668–0.2232 event/km^2 (mean = 0.1450).

CARB: distribution of woodland caribou in northeastern Alberta

To define areas used by woodland caribou, we used the results of habitat-selection models (Bradshaw et al. 1995) to identify patches of selected habitat in northeastern Alberta. Many of these habitat patches were discontinuous within the study area, so we constructed agglomerations of neighbouring selected habitat patches within the mean multiyear home-range area (613.8 km^2) of radio-collared woodland caribou (Bradshaw et al. 1995). We attempted to maintain continuity in the habitat agglomerations while maximizing coverage of selected habitat patches. Each separate habitat agglomeration is henceforth referred to as a "caribou zone" (Table 1, Fig. 1).

PETR: petroleum exploration in northeastern Alberta

To determine the amount of petroleum exploration (PETR) in northeastern Alberta, we obtained copies of 290 final plans (maps and details of petroleum exploration programs) submitted by individual petroleum companies between November 1988 and April 1993. A petroleum exploration program consists of separate surveying, tree-clearing, drilling, and blasting phases, and all phases advance in a fixed direction along a "seismic exploration line" (Bradshaw 1994; Bradshaw et al. 1997).

PDEN: petroleum exploration density

Petroleum exploration density (PDEN) is the PETR occurring within CARB. The amount of PETR within CARB varies considerably among years (Table 2). The mean rate of progression (i.e., the rate of movement of all exploration phases along the seismic exploration line) of a petroleum exploration program from 1988 to 1993 was 2.617 km/day.

DISP: disturbance potential

We assumed that on an any day of exploration, a caribou which is disturbed will only be disturbed once that day because it will move away from the source of disturbance (Bradshaw 1994). We also assumed that an animal is equally likely to be disturbed on each operating day of exploration. Thus, a caribou within exposure distance of an exploration program can be disturbed as many times as the number of days it takes to complete the program.

The DISP of any one area depends on the rate of exploration which occurs in that area; therefore, the total number of operating days of all exploration programs within a specific caribou zone represents the number of potential disturbance encounters for that zone. The total linear distance of exploration within a specific caribou zone during one winter season (November to April) divided by the mean rate of progression gives the total number of operating days (i.e., potential disturbance encounters) (Table 1).

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Table 2. Annual attributes of petroleum exploration programs (PETR) completed within caribou zones (CARB) from 1988 to 1993.

Winter season	No. of programs completed	Total distance explored (km)	Mean rate of progression (km/day)	Mean program duration (days)
1988–1989	27	772	4.598	9.79
1989–1990	44	1454	3.713	9.97
1990–1991	46	1337	2.282	14.42
1991–1992	17	373	1.237	19.17
1992–1993	31	470	1.257	12.97

ENCR: disturbance encounter rate

The number of operating days (DISP) divided by the surface area of a caribou zone (CARB) gives the potential disturbance encounter rate (ENCR) for that zone (Table 1). The ENCR for each caribou zone can be compared with the number of disturbance events (EVNT) required to cause >15 and >20% mass loss. When ENCR exceeds EVNT, caribou within a particular caribou zone exceed the predicted level of mass loss.

EVNT compared with ENCR

There were 5 of a total of 45 occasions (11.1%) when ENCR exceeded the mean 15% mass loss EVNT of 0.0440 encounter/km^2 per winter (27 encounters). An occasion is defined as a particular caribou zone (n = 9) in a particular year (n = 5) (Tables 1 and 2). There were four occasions (8.9%) when ENCR exceeded the lower 20% mass loss EVNT threshold of 0.0668 encounter/km^2 per winter (41 encounters). There was also one occasion (2.2%; zone 3 in 1992–1993) when ENCR approached the mean 20% mass loss EVNT of 0.1450 encounter/km^2 per winter (89 encounters), which was the highest potential encounter rate during the 5 years studied. This is largely due to the slow progression rate for that year and the small surface area of that particular caribou zone.

Schematic representation of petroleum exploration in each year studied (Fig. 1) shows the clumping of industrial activity in the southern portion of the Wabasca caribou zone (zone 1). For most winters, almost all programs occurred within the southern section of this zone; hence, it is likely that the encounter rate was higher there. For this reason, we also expressed the encounter rate in south Wabasca for each year using 2700 km^2 as the denominator; these encounter rates were included in the five occasions described above (Table 1).

Discussion

Because we limited our calculations to average snow depth and temperature conditions, years of particularly adverse winter conditions may alter the results of the model. During winters of high snow accumulation and incidences of surface crusting, the cost of displacement due to disturbance may triple (Fancy and White 1987). High snow accumulation can also induce considerable mass loss through lowered foraging opportunities (Swift et al. 1980; Fancy 1986; Hobbs 1989). It is possible that when high snow accumulation impedes locomotion and feeding, winter mass loss may exceed the normal range. During such winters the energetic effects of multiple disturbances are likely to rise. Weather effects on physical condition may persist into subsequent years, even when those years are relatively mild (Hobbs 1989). Therefore, there should be an ability to impose greater restrictions on petroleum exploration within caribou range during harsh winter conditions.

Caribou populations can be affected by winter mass loss in adult females through reduced calf survival. Winter undernutrition can delay parturition (Bergerud 1975; Espmark 1980; Skogland 1983; Cameron et al. 1993), thus reducing the opportunity for growth before winter (Bergerud 1975; Skogland 1983) and increasing the likelihood of calf mortality due to predation and undernutrition (Dauphiné and McClure 1974; Bergerud 1975; Couturier et al. 1990; Whitten et al. 1992; Cameron et al. 1993). Winter undernutrition can also reduce birth mass of the calf (Varo and Varo 1971; Bergerud 1975; Espmark 1980; Rognmo et al. 1983; Skogland 1984; Eloranta and Nieminen 1986; Adamczewski et al. 1987), and small calves experience higher mortality than larger ones (Haukioja and Salovaara 1978; Rognmo et al. 1983).

Limitations of the model

An important assumption in the calculation of additional winter mass loss due to disturbance is that woodland caribou cannot compensate for this loss by increasing forage intake. If after a certain number of encounters with disturbance the net energy lost was replaced by an increase in forage intake (Robbins et al. 1981), we may have overestimated the net cost of disturbance.

Another assumption was that woodland caribou do not habituate to the disturbance resulting from petroleum exploration. When exposed to a predictable, frequent event, animals can habituate to the most conspicuous noises and activities (Bergerud 1978). However, animals may not be able to habituate to the stress caused by disturbance when disturbance is irregular and unpredictable (Harlow et al. 1987). Future research should attempt to address whether caribou can habituate to disturbance from petroleum exploration.

Another concern is evaluating a caribou's response to a far-off disturbance (i.e., several kilometres away). When this occurs, only the animals in the immediate vicinity of an exploration program may be affected by the disturbance, and only these animals would lose mass because of disturbance. However, Bradshaw et al. (1997) found no relationship between the distance of an exposed caribou from the source of disturbance and the animal's subsequent response. It is therefore impossible at this time to estimate the proportion

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of the caribou population experiencing additional mass loss due to disturbance.

Conclusions

Disturbance can have significant energetic consequences for northern ungulates when the delicate balance that exists between energy expenditure and forage availability in variable winter conditions is considered (Skogland and Grøvan 1988; Hobbs 1989; Cuyler and Øritsland 1993). Simulated petroleum exploration does affect woodland caribou behaviour, even though it is difficult to infer long-term population effects from the experimental manipulation of individuals (Bradshaw et al. 1997). Our model is a useful addition to the understanding of population effects from petroleum exploration. Cumulative disturbance can potentially affect female mass loss over winter, and possibly calf production and survival. The model is a first attempt at estimating some of the biological consequences of petroleum exploration in northeastern Alberta and provides important information for future research and land-use management (Starfield 1997).

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