ARCTIC
VOL. 49, NO. 1 (MARCH 1996) P. 23–28

Effects of Petroleum Development on Terrain Preferences of Calving Caribou

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(Received 21 May 1995; accepted in revised form 30 August 1995)

ABSTRACT. We investigated terrain preferences of caribou (*Rangifer tarandus granti*) in an oilfield region near Prudhoe Bay, Alaska. Under disturbance-free conditions, the distribution of calving caribou determined by aerial transect surveys was correlated with indices of terrain ruggedness based on map contours. Caribou preferred quadrats dominated by fine-textured rugged terrain, particularly when present in large clusters, and avoided quadrats with flatter terrain. Displacement of maternal females from a zone within 4 km of roads and production-related facilities reduced use of rugged terrain types in that zone by 52%; the remaining preferred terrain was scattered and less accessible. This reduction was accompanied by a 43% increase in caribou use of rugged terrain 4–10 km from surface development. Given that terrain ruggedness is positively correlated with forage quality and biomass availability, combined underuse and overuse of these important habitats may compromise summer nutrition of lactating female caribou, thereby depressing body condition and, hence, subsequent reproductive success.

Key words: calving, caribou, *Rangifer tarandus*, habitat, terrain, disturbance, oilfield, petroleum development

RÉSUMÉ. On a étudié les préférences de terrain du caribou (*Rangifer tarandus granti*) dans une région pétrolifère près de Prudhoe Bay en Alaska. En l'absence de perturbations, la distribution du caribou gravide déterminée par des relevés aériens de transects était corrélée avec les indices d'inégalité du terrain établi d'après des courbes de niveau. Le caribou préférait des quadrats dominés par un terrain légèrement accidenté, surtout lorsque les quadrats formaient de grands groupes, et il évitait ceux où le terrain était plus plat. Le déplacement des femelles gravides hors de la zone située à moins de 4 km de routes et d'installations reliées à la production du pétrole a réduit de 52 p. cent l'utilisation de types de terrain accidenté dans cette zone; le reste du terrain privilégié était éparpillé et moins accessible. Cette réduction s'accompagnait d'une augmentation de 43 p. cent de l'utilisation par le caribou de terrain accidenté situé de 4 à 10 km de l'exploitation en surface. Vu que l'inégalité du terrain est corrélée de façon positive à la qualité de l'herbe et à la biomasse disponible, une sous-utilisation combinée à une sur-utilisation de ces habitats primordiaux peut compromettre la nutrition estivale de la femelle caribou en train d'allaiter, affectant ainsi de façon négative son état de santé et par conséquent ses chances de reproduction.

Mots clés: mise bas, caribou, *Rangifer tarandus*, habitat, terrain, perturbation, champ pétrolifère, exploitation pétrolière

Traduit pour la revue *Arctic* par Nésida Loyer.

INTRODUCTION

Arctic caribou (*Rangifer tarandus granti*) often calve where snow is patchy (Lent, 1980; Eastland et al., 1989) and show a preference for well-drained tundra (Bishop and Cameron, 1990) which, during melt-off, yields nutritious *Eriophorum* flowers (Kuropat and Bryant, 1980; White and Trudell, 1980). Fine-textured, rugged terrain (i.e., relief < 20 m) is characterized by a higher proportion of graminoids in early phenological stages, higher total biomass, and more *Eriophorum* flowers than other terrain, even within similar vegetation communities (Nellemann and Thomsen, 1994). These areas should therefore offer superior forage during the calving period.

The Central Arctic Herd (CAH) calves on the Arctic Coastal Plain near Prudhoe Bay, Alaska, in early June (Cameron and Whitten, 1979). Discontinuous snow cover and variations in micro-relief ostensibly provide many of the above benefits. During the past two decades, however, considerable petroleum extraction has taken place within a portion of the CAH calving grounds, and the resultant redistribution of females and calves suggests constraints on foraging (Dau and Cameron, 1986; Cameron et al., 1992).

In this paper, we examine relationships between density of calving CAH caribou and the occurrence of rugged terrain. In particular, we show how avoidance of roads and production-related facilities affects access to and use of preferred habitats.

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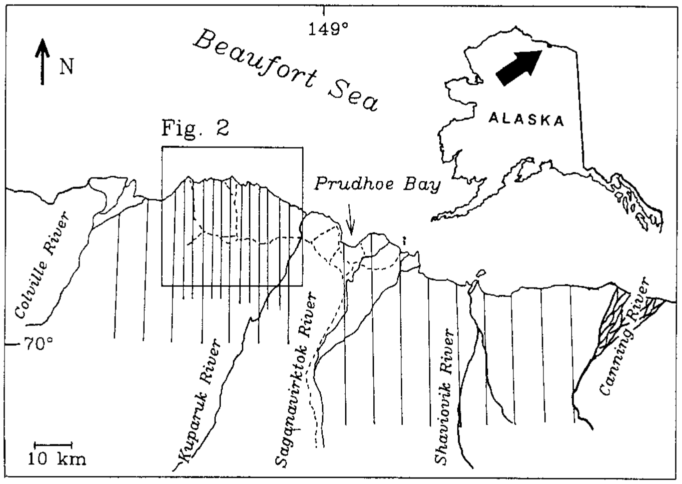

FIG. 1. The study area on the Arctic Coastal Plain of Alaska with strip-transects surveyed by helicopters.

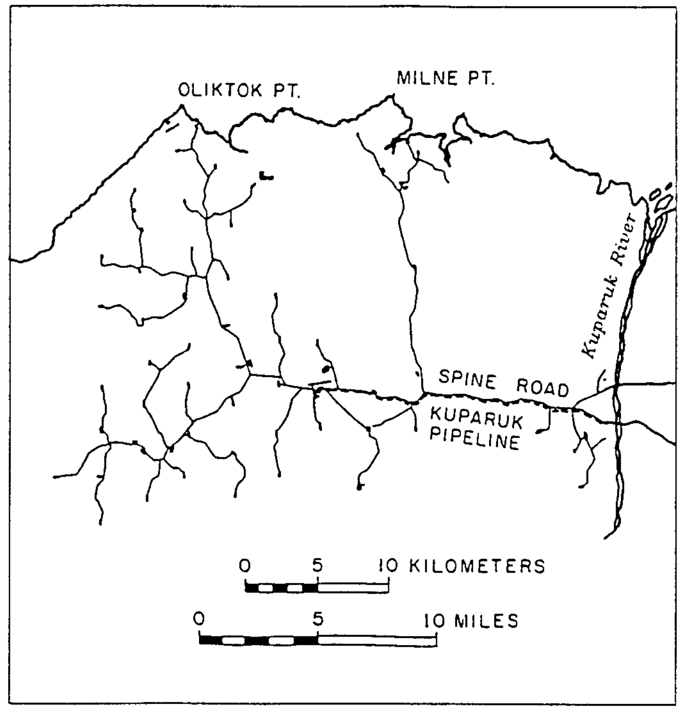

FIG. 2. The Kuparuk Development Area, ca. 1990.

STUDY AREA

The study area lies within 60 km of the Beaufort Sea, between the Colville and the Canning Rivers, encompassing the greater calving grounds of the CAH (Whitten and Cameron, 1985; Cameron, unpubl. data) (Fig. 1). It is a typical thermokarst landscape dominated by thaw lakes (Walker, 1985; Walker and Acevedo, 1987). Topographic relief, mainly the result of various frost phenomena, occurs in the form of pingos, as well as low- and high-centered polygons. Localized relief promotes variations in snow cover and soil moisture, resulting in diverse plant communities (Walker et al., 1980; Miller, 1982; Shaver et al., 1990).

In 1978, following completion of the Trans-Alaska pipeline, surface development expanded westward from the Prudhoe Bay oilfield complex across the Kuparuk River. By 1990, an extensive network of roads, pipelines, and other facilities was in place. This region has become known as the Kuparuk Development Area (KDA) (Cameron et al., 1992) (Fig. 2).

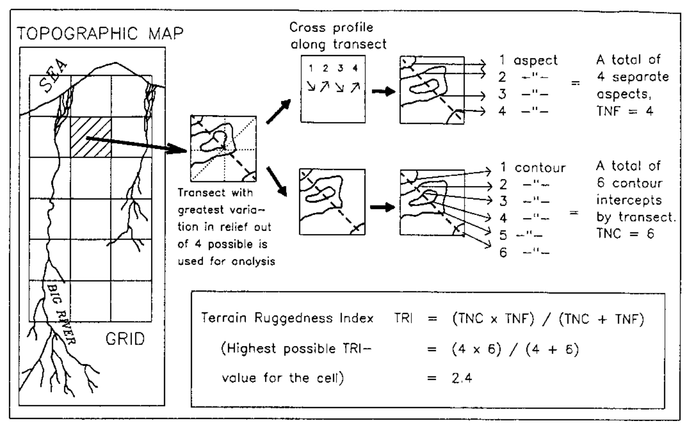

FIG. 3. The calculation of terrain ruggedness indices (TRI) from a topographic map (from Nellemann and Fry, 1995:173. Reprinted with permission from the Arctic Institute of North America).

METHODS

Low-level aerial surveys of the study area (Cameron et al., 1985; Whitten and Cameron, 1985; Dau and Cameron, 1986) were conducted from 10 June to 14 June in the years 1987–1992 (except 1991), that is, one or two weeks after the peak of calving. A pilot and three observers in a Bell 206B helicopter searched for caribou within 16 north-south strip-transects, each 3.2 km wide and 40–60 km long (Fig. 1). Transect centerlines were spaced at 9.6 km intervals, except in the KDA where eight intermediate transects were added. For each group of caribou observed, we recorded location, total number, and sex and age composition. Locations were marked on a United States Geological Survey (USGS) topographic map and later converted to UTM coordinates using a digitizing table, or coordinates were recorded directly from an airborne LORAN or GPS receiver.

For the terrain analysis, we used a simple index of terrain ruggedness (TRI) calculated from topographical maps (USGS 1:63 360) with contour intervals of 15.5 m (Nellemann and Thomsen, 1994; Nellemann and Fry, 1995). The index estimates terrain ruggedness at a meso-scale of 10–20 m, which includes relief such as bluffs, hollows, and small drainages (Chernov, 1985). Strip-transects were subdivided into 3.2 km segments, generating 301 10.25 km^2 (4 mi^2) quadrats. Four reference lines were drawn through the center of each quadrat, and a TRI was calculated based on the number of interceptions with contour lines (TNC) and the number of changes in separate aspects (TNF) (Nellemann and Thomsen, 1994; Nellemann and Fry, 1995) (Fig. 3):

$$\text{Terrain Ruggedness Index} = (\text{TNC} \times \text{TNF}) / (\text{TNC} + \text{TNF})$$

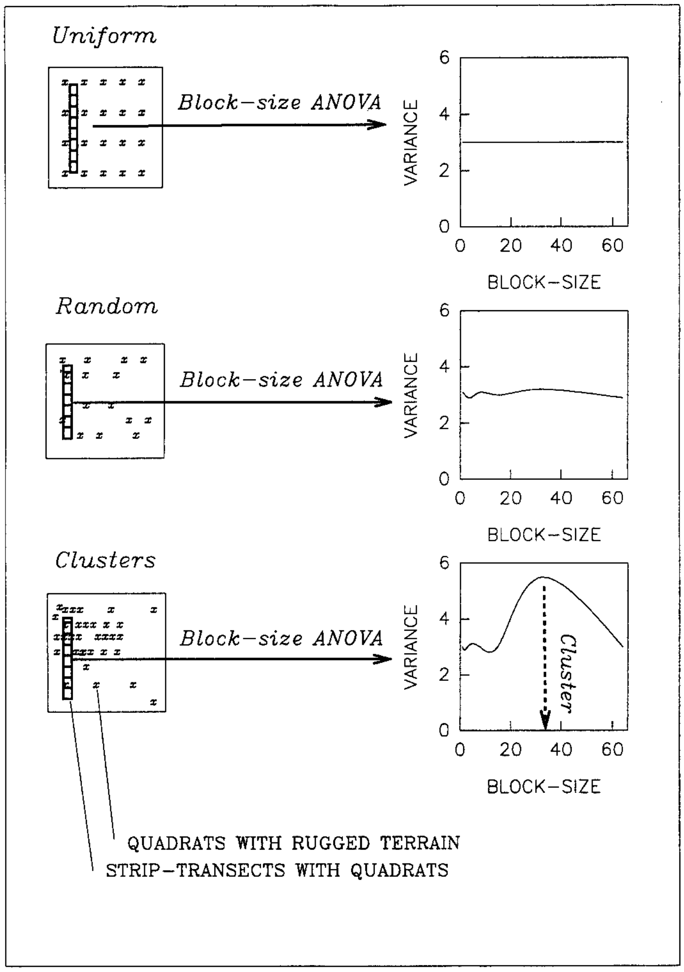

FIG. 4. Technique used to compare distribution patterns of caribou with the occurrence of rugged terrain. Three (hypothetical) spatial patterns of a random variable (uniform, random and clustered) and their resultant graphs from a block-size ANOVA are presented (based on Ludwig and Reynolds, 1988).

Hence, an area with many contour intercepts and changes in slope direction will have a high TRI, while smooth or gently rolling terrain will have a low TRI. The highest of the four TRIs calculated for each quadrat was used. We then categorized quadrats into 10 TRI-classes (i.e., 0.0–0.4, 0.5–0.9, etc.).

To establish unbiased relationships between the occurrence of caribou and terrain ruggedness, we used data from all quadrats >10 km from surface development, an area assumed to be beyond the influence of disturbance. For individual years, correlations between caribou density and TRI were based on uncorrected density. For analyses across years, however, we used the mean percentage of caribou within quadrats as units of abundance. We also calculated caribou densities for 10.25 km^2 quadrats at two TRI ranges (0.0–2.4 and 2.5–5.0) and three zones of distance from structures (<4 km; 4–10 km; and >10 km). Distance classification of quadrats (i.e., more than one-half of a quadrat within a given distance zone) was based on measurements from a schematic map of the KDA road system for 1990–91 (1:63 360) provided by ARCO Alaska, Inc.

To identify clustering of caribou and rugged terrain types, we conducted a block-size analysis of variance (ANOVA) after Ludwig and Reynolds (1988). Briefly, their program groups contiguous quadrats in increasingly larger blocks (e.g., 2 and 2 quadrats, 4 and 4 quadrats, 8 and 8 quadrats, etc.) and calculates a variance for each block-size. Plotting variance against block-size provides information on scale and pattern (Fig. 4): peaks in variance indicate clustering of quadrats with abundant caribou or rugged terrain at that block-size. We compared block-size ANOVAs for caribou density and terrain ruggedness to determine the degree of covariance. We also assessed the relationship between the occurrence of caribou and cluster-size of rugged terrain (TRI > 2.4) by calculating caribou density for various clusters of that terrain along the transects (i.e., for single and contiguous multiple quadrats).

We performed statistical analyses in SIGMASTAT (Jandel, 1992) after testing data for normality using a Kolmogorov-Smirnov test. We evaluated relationships between caribou density and terrain ruggedness by Spearman's rank correlation, and compared caribou densities for different terrain types and distance zones using Kruskal-Wallis tests (ranked one-way ANOVA) and multiple pairwise comparisons with Dunn's tests. We used separate Bonferroni tests for each year to assess use versus availability of terrain types (Neu et al., 1974). In all cases, we considered *p*-values <0.05 to be statistically significant.

RESULTS

Caribou abundance was significantly related to terrain ruggedness at the meso-scale ($r = 0.82, p < 0.01$) for areas >10 km from surface development (Fig. 5). Among-year differences were noted, however, and there was no correlation in 1990 (Table 1). Numbers of adult females and calves also were correlated with terrain ruggedness ($r = 0.73, p < 0.05$; and $r = 0.80, p < 0.01$, respectively), reflecting a predominance of cow-calf pairs in the groups observed (Cameron et al., 1992). For simplicity, we deal only with total caribou here. During all years (1987–92), caribou used rugged terrain (i.e., TRI = 2.5–5.0) more than expected from availability ($p < 0.01$), and avoided flat terrain (i.e., TRI = 0.0–2.4) ($p < 0.01$).

Densities of caribou within quadrats characterized by rugged terrain were significantly higher than those within quadrats having flat terrain. This was the case for all distance categories (Table 2). Moreover, for both terrain classes, caribou density was lowest within 4 km of roads and facilities. For quadrats of rugged terrain, density was highest 4–10 km from surface development and, thus, higher than expected on the basis of use of rugged areas >10 km from development. For flat terrain, density was not significantly different in the 4–10 km zone.

Both rugged terrain and high caribou density occurred in small and large clusters of quadrats, and their variances between clusters peaked at approximately the same spatial scales (Fig. 6A, B). However, the smallest peak in variance for rugged terrain (Fig. 6A) corresponded to a much smaller peak in variance for caribou density (Fig. 6B). This indicates that caribou density increased with availability of rugged terrain principally when such terrain was present in large clusters. Indeed, density of caribou increased directly with cluster-size of rugged terrain (Fig. 7).

Quadrats characterized by rugged terrain comprised 27% of the entire area sampled and 45% of the KDA (Table 3). Surface developments tended to be located on or near rugged terrain. For example, 55 of the 94 quadrats (59%) within 4 km of surface developments were classed as rugged. Within the KDA, 55 of the 65 rugged quadrats (85%) were located within 4 km from surface developments. In contrast, in areas > 4 km from surface structures, only 10 of the 50 quadrats (20%) within the KDA were classified as rugged.

Despite the relative abundance of rugged terrain near surface developments, caribou use of areas within 4 km of these structures declined 52% (1.19 vs. 2.49 caribou/km^2). Correspondingly, in quadrats 4–10 km from man-made facilities, caribou density increased by 43% (3.57 vs. 2.49 caribou/km^2) in spite of the relative paucity of rugged terrain.

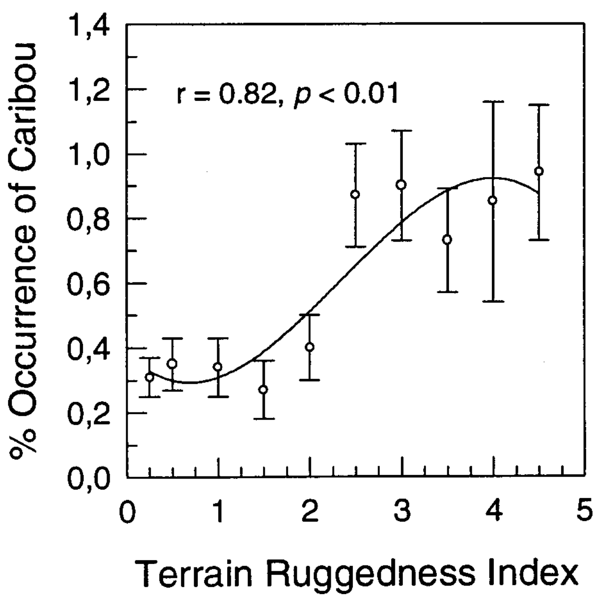

FIG. 5. Relationship between mean (± S.E.) percentage occurrence of caribou during calving and terrain ruggedness index (TRI) for quadrats >10 km from surface development, Colville-Canning region, Alaska, 1987–92.

TABLE 1. Relationships between caribou density (no./km^2) and terrain ruggedness index (TRI) at the mesoscale (10–20 m) for areas >10 km from surface development, Colville-Canning region, Alaska, 1987–92 (n = 174).

Year	Spearman's r	p
1987	r = 0.88	0.003
1988	r = 0.78	0.020
1989	r = 0.74	0.030
1990	r = 0.20	0.680
1991	(no surveys flown)	
1992	r = 0.64	0.050

TABLE 2. Mean (± S.E.) density of caribou (no./km^2) 1987–92 in 10.25 km^2 quadrats with flat terrain (TRI = 0.0–2.4) and rugged terrain (TRI = 2.5–5.0) for three zones of distance from surface development for all quadrats in the Colville-Canning region, Alaska (n = 301).

	Terrain type	
Distance category	Flat	Rugged
0– 4 km	0.42 ± 0.06 a (a)	1.19 ± 0.21 b (a)
4–10 km	0.68 ± 0.11 a (ab)	3.57 ± 0.72 b (b)
> 10 km	1.06 ± 0.10 a (b)	2.49 ± 0.34 b (c)

Different letters (within a row only) indicate significant difference ($p < 0.05$) using Kruskal-Wallis ANOVA with Dunn's test. Different letters in parentheses (within a column only) indicate significant differences with same test.

DISCUSSION

The strong affinity for relatively rugged terrain by calving CAH caribou ostensibly reflects superior foraging conditions (Nellemann and Thomsen, 1994). Local variation in the timing and progress of snow ablation in rugged terrain increases the diversity of vegetation through continuous and prolonged emergence of plants in early phenological stages. These areas generally also have higher biomass available during early summer (Nellemann and Thomsen, 1994). Thus, caribou can maximize the intake of high-quality forage within short distances (White et al., 1975), even if plant phenology differs greatly between vegetation types (Skogland, 1980; Thing, 1984; Klein, 1990).

Graminoid flowers, in particular, provide an important nutrient source for female caribou at parturition and during early lactation (White and Trudell, 1980; Eastland et al., 1989). Because biomass is low (White and Trudell, 1980), caribou need extensive intact areas for foraging, which is consistent with our observation that caribou selected large clusters of rugged terrain (Fig. 7). Surface development, in addition to depressing local use (Table 2), has effectively scattered preferred areas elsewhere into smaller, more isolated patches. The probable net effects are reduced use of these plant communities, implying a reduced intake of nutrients, and an increased degree of utilization of rugged areas away from man-made structures.

Displacement of caribou from the zone within 4 km of surface development was accompanied by higher density of animals in rugged terrain 4–10 km from development, suggesting overuse of the latter habitats. Again, because biomass of graminoid flowers tends to be low, the density of grazing caribou becomes crucial to the forage intake of individuals (White and Trudell, 1980).

The high metabolic cost of early lactation (Oftedal, 1985; Chan-McLeod et al., 1994) emphasizes the importance of access to high-quality forage. During the early post-calving period, grazing takes place largely undisturbed by insects, in sharp contrast to midsummer, when mosquitoes and oestrid flies often disrupt activity patterns (Dau, 1986; Russell et al.,

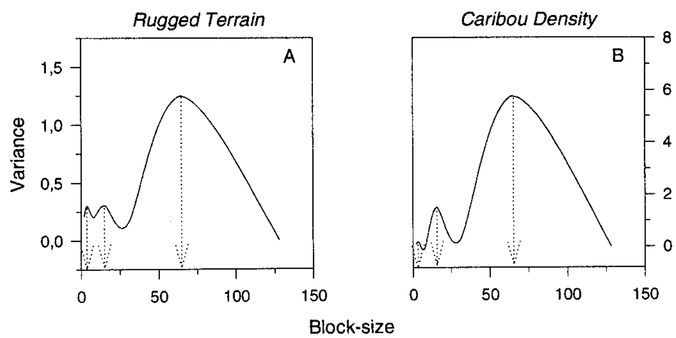

FIG. 6. Changes in variance with block-size (i.e., multiple 10.25 km^2 quadrats) for rugged terrain (A) and for caribou (B). Peaks in variance show clusters of caribou or terrain.

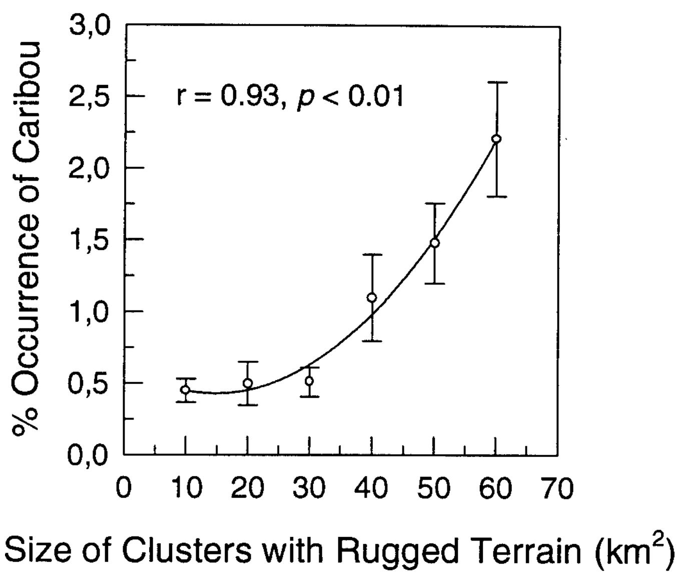

FIG. 7. Relationship between mean (± S.E.) percentage occurrence of caribou and size of clusters of quadrats with rugged terrain (TRI = 2.5–5.0), Colville-Canning region, Alaska.

TABLE 3. Numbers (%) of 10.25 km^2 quadrats predominated by flat terrain (TRI = 0.0–2.4) and by rugged terrain (TRI = 2.5–5.0) < 4 km and > 4 km from surface development, Kuparuk Development Area, Alaska (Fig. 2).

Distance category	Terrain types		
	Flat	Rugged	All
< 4 km	39 (41)	55 (59)	94 (100)
> 4 km	40 (80)	10 (20)	50 (100)
Total	79 (55)	65 (45)	144 (100)

1993). Partial loss of preferred habitats, together with increased travelling distances between those that remain, may depress nutritional status. Even though most weight gain occurs in late summer and autumn (Petersson and Danell, 1993), survival and recovery from winter malnutrition should be enhanced by early access to high-quality forage. If that feeding opportunity is repeatedly compromised and subsequent compensation is insufficient, autumn body weights will decrease (Reimers et al., 1983), inducing more frequent reproductive pauses (Cameron, 1994; Cameron and Ver Hoef, 1994).

Our results show that the amount of rugged terrain rendered less accessible to caribou as a result of local avoidance exceeded that expected from the overall occurrence of rugged terrain within the KDA. Disproportionate losses of preferred habitats are largely attributable to the siting of roads and production-related facilities in higher terrain, specifically avoiding lakes and poorly drained areas; indeed, the practice is encouraged by the regulatory agencies responsible for issuing development permits (P. Martin and R. Post, pers. comm. 1995). Hence, protection of wetlands and nesting waterfowl may exacerbate conflicts on habitats important to caribou, illustrating the tradeoffs associated with mitigating the multi-species impacts of petroleum development.

ACKNOWLEDGEMENTS

We thank D.R. Klein, H. Staaland and the Fulbright Commission for financial and logistic support. Funding for aerial surveys was provided by Federal Aid in Wildlife Restoration through the Division of Wildlife Conservation, Alaska Department of Fish and Game and by the Alaska Fish and Wildlife Research Center, U.S. Fish and Wildlife Service. W.T. Smith, R.T. Shideler, J.M. Ver Hoef, and K.R. Whitten provided valuable technical assistance. G. Fry, D.J. Reed, and R.G. White offered helpful advice on study design and data analyses. Referees J.R. Dau, R. Densmore, and S.G. Fancy made helpful comments on an earlier draft of the manuscript.

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