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Dynamic Responses of Calving Caribou to Oilfields in Northern Alaska

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ABSTRACT. Past research has suggested that during the calving period, caribou (*Rangifer tarandus*) in Arctic Alaska generally avoid areas within 1 km of oilfield roads with traffic. However, avoidance is not absolute, and caribou may habituate to infrastructure (e.g., buildings, roads, well pads) and human activity. We conducted road-based surveys of caribou in oilfields on Alaska's Arctic Coastal Plain during the late calving and post-calving periods of June in 2000–02. We recorded location, composition, and behavior of caribou groups located less than 1 km from active gravel roads and production pads. Caribou groups with calves were on average distributed farther from oilfield infrastructure than were groups without calves, but habituation to oilfield activities, indicated by decreased avoidance, occurred at similar rates for groups with and without calves. During the calving period, sighting rates were greater in areas of low human activity, and calf percentages tended to be greater at night when oilfield activity was reduced. Caribou groups were on average closer to infrastructure during the post-calving periods than during the calving periods in 2000 and 2001, but not in 2002. In 2002, when snow melted early, caribou groups were closer to infrastructure during the calving period than in 2000 and 2001, when snow melted later, emphasizing the importance of examining environmental variables when investigating the dynamic interactions of caribou and oilfields. Overall, caribou appeared to habituate to active oilfield infrastructure after the calving period in 2000, late in the calving period in 2001, and likely before our sampling period in 2002. The timing of annual rehabituation was positively correlated with timing of spring snowmelt. Land and wildlife managers can use information from this study to develop calving period-specific mitigation measures that are more effective and flexible.

Key words: Alaska, avoidance, calving caribou, distribution, habituation, oilfields, *Rangifer tarandus*, road surveys, snowmelt

RÉSUMÉ. Selon des recherches antérieures, pendant sa période de vêlage, le caribou (*Rangifer tarandus*) de l'Alaska arctique évite généralement les régions se trouvant à l'intérieur d'un kilomètre des routes où circulent des véhicules menant aux chantiers pétroliers. Cependant, cet évitement n'est pas absolu, et le caribou peut s'accoutumer aux infrastructures (comme les bâtiments, les routes et les chantiers) et à l'activité humaine. Nous avons effectué le dénombrement des caribous près des routes des champs de pétrole de la plaine côtière arctique de l'Alaska vers la fin de la période de vêlage et après la période de vêlage de juin 2000 à 2002. Nous avons consigné l'emplacement, la composition et le comportement des groupes de caribous se trouvant à moins d'un kilomètre des routes de gravier et des chantiers de production en activité. En moyenne, les caribous qui avaient des petits se tenaient plus loin des infrastructures pétrolières que les groupes de caribous qui n'avaient pas de petits. Cela dit, l'accoutumance aux activités pétrolières, dénotée par un moins grand évitement, survenait à des taux semblables pour les groupes qui avaient des petits et les groupes qui n'en avaient pas. Pendant la période de vêlage, les taux d'observation de caribous étaient plus élevés dans les régions où il y avait peu d'activité humaine, et les pourcentages de petits avaient tendance à être plus élevés la nuit, lorsqu'il y avait peu de va-et-vient aux chantiers. En moyenne, les groupes de caribous s'approchaient plus des infrastructures pendant les périodes suivant le vêlage des années 2000 et 2001, mais pas en 2002. En 2002, quand la neige a fondu plus tôt que d'habitude, les groupes de caribous s'approchaient plus des infrastructures pendant la période de vêlage qu'en 2000 et 2001, lorsque la neige a fondu plus tard. Cela fait ressortir l'importance de tenir compte des variables environnementales lorsque nous faisons des enquêtes sur les interactions dynamiques entre les caribous et les champs de pétrole. Dans l'ensemble, les caribous semblaient s'accoutumer aux infrastructures pétrolières en activité après la période de vêlage en 2000, puis vers la fin de la période de vêlage en 2001, et vraisemblablement avant notre période d'échantillonnage en 2002. Le moment de l'accoutumance annuelle coïncidait positivement avec le moment de la fonte des neiges au printemps. Les gestionnaires des terres et de la faune peuvent se servir de l'information émanant de cette étude pour élaborer des mesures d'atténuation tenant compte de la période de vêlage, mesures qui sont plus efficaces et qui présentent plus de souplesse.

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Mots clés : Alaska, évitement, vêlage, caribou, répartition, accoutumance, champs de pétrole, *Rangifer tarandus*, dénombrements près des routes, fonte des neiges

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INTRODUCTION

The effects of Alaska's North Slope oilfields on caribou of the Central Arctic Herd (CAH) have been the subject of extensive research and monitoring over the last 30 years (Shideler, 1986; Maki, 1992; NRC, 2003). Some authors have suggested that oilfield development has prompted shifts in distribution and displacement of calving caribou from areas within several kilometers of roads (Dau and Cameron, 1986a, b), potentially decreasing nutritional status and reproductive performance (Cameron et al., 1992, 2002, 2005; Cameron, 1995; Nellemann and Cameron, 1996, 1998; NRC, 2003). However, impacts to individuals may or may not translate to population-level impacts. The CAH has increased in numbers since oilfield development began on the North Slope (from ~5000 in 1975 to ~32 000 in 2002; Cameron and Whitten, 1979; Lenart, 2003), and the herd regularly uses habitats in the oilfields (Pollard et al., 1996a; Cronin et al., 1998a; Noel et al., 1998). The variability of the herd's recent high rates of net productivity (Cronin et al., 1998b; Ballard et al., 2000; Lenart, 2003) has been shown to be strongly correlated with environmental factors related to snow cover, and not to presence or absence of oilfields (Haskell, 2003; Haskell and Ballard, 2004). Furthermore, to achieve a suitable body weight for net-productive conceptions (i.e., those resulting in a healthy calf), *Rangifer* females may exhibit a time-minimizing foraging strategy that emphasizes the importance of forage availability during the fall pre-rut period, when CAH caribou are typically located away from the oilfields (Haskell and Ballard, 2004).

Since 1978, systematic aerial surveys have been conducted during the calving and post-calving periods in the Milne Point Unit (MPU), Kuparuk Unit (KRU), and Prudhoe Bay Unit (PBU) of the oilfields and in undeveloped areas (Cameron et al., 1992; Jensen and Noel, 2002; Lawhead and Prichard, 2002). The results of these surveys have been used to describe the number and distribution of caribou within major portions of the CAH's summer range following a northward spring migration from wintering areas (Gavin, 1975). The CAH has two general calving areas: 1) the Kuparuk-Milne Point area, between the Colville and Kuparuk rivers west of Prudhoe Bay, and 2) the Bullen-Staines area, between the Shaviovik and Canning rivers east of Prudhoe Bay (Whitten and Cameron, 1985; Wolfe, 2000). In recent years, the majority of CAH calving west of Prudhoe Bay has occurred approximately 7–27 km south of the coastal KRU, whereas, from 1978 to 1986, the majority of calving typically occurred closer to the coast (Whitten and Cameron, 1985; Murphy and Lawhead, 2000; Wolfe, 2000). After construction of the MPU and KRU in 1982, densities of calving caribou in the new oilfields increased markedly for three years and then dropped in 1986, a year with late spring snowmelt (Cameron et al., 1992; Haskell, 2003). As the herd continued to grow through 2001, the number of caribou using habitats within the oilfields during the calving period did not increase (Noel et al., 2004). It has been suggested that this relative shift in calving density may have been prompted by oilfield development (Nellemann and Cameron, 1998; Cameron et al., 2002, 2005; Griffith et al., 2002). Interactions over time of other biotic factors such as caribou, predator, and parasite densities—for example, herd history as it relates to predator control and social learning among caribou—may also cause changes in calving distributions (Folstad et al., 1991; Barten et al., 2001; Gunn and D'Hont, 2002; Gunn and Irvine, 2003). Also, with plant phenology following the south-to-north snowmelt progression (Lent, 1980; Whitten and Cameron, 1980), higher densities of desirable forage plants in better-drained habitats south of the coastal area (Walker et al., 1980; Walker, 1985; Smith, 1996), and the absence there of significant predation by wolves (*Canis lupus*; Murphy and Lawhead, 2000; Shideler, 2000), the area south of the KRU may provide more suitable habitat during the spring calving period in most years. However, no cause-effect relationship can be determined to explain the relative shift in calving density exhibited by the CAH over the past 20 years (Murphy and Lawhead, 2000).

When considering human disturbance effects on wildlife, it may be useful to examine environmental variables that influence habitat availability and selection, as well as implications of evolutionary theory regarding innate and learned animal behavior (Bergerud, 1974; Frid and Dill, 2002). When selecting an appropriate calving area, parous caribou often face a tradeoff between availability of nutritious spring forage and reduced risk of predation on neonates (Bergerud, 2000; Barten et al., 2001). This may explain why the majority of non-parous CAH caribou lag behind during northward spring migrations: they may prefer the same foraging habitats, but no such tradeoff exists (Cameron et al., 1992). In the MPU oilfield, density of caribou and calves during the calving period has been positively correlated with distance from roads (Dau and Cameron, 1986a; Cameron et al., 1992), but interacting factors that include local habitat selection, snow cover, and intraspecific competition may also affect caribou distributions (Haskell, 2003). Calving distribution relative to oilfield infrastructure is variable; calves are frequently seen within 1–4 km of roads (Lawhead and Prichard, 2002; Noel et al., 2004); displacement effects may wane over the years (Noel et al., 2004); and caribou have recently been documented calving within 500 m of active oilfield roads and production pads (S. Haskell, pers. obs.). Like other deer (Cervidae), caribou may be capable of adapting to human activities (Haskell, 2003).

Caribou surveys from roads in the MPU and KRU oilfields were conducted through the 1980s, during early construction and operation, to assess the effects of the altered habitat and human activities on caribou distribution, group composition, and movement (Dau and Cameron, 1986b; Smith et al., 1994). From sighting rates and percentages of calves within 1 km of roads, Smith et al. (1994) concluded that during calving, occupancy of areas near roads by cow-calf pairs had progressively decreased, and habituation of maternal cows to the road system had not occurred.

We believe that spatial technologies made available to wildlife researchers within the past decade and the greater accuracy and precision of data that new methods produce should increase the scope and reliability of inferences made from such data (Taylor and Knight, 2003). The objectives of our study were to quantify distribution, behavior, numbers, and age and sex composition of caribou within 1 km of active gravel roads and pads in the MPU, KRU, and western PBU oilfields during the late calving and post-calving periods of 2000–02. We were also interested in examining environmental variables that might help to explain patterns of caribou distributions and behavior by inference. We predicted that maternal caribou groups would be distributed farther from active oilfield roads and production pads than non-maternal groups, and that displacement effects would be reduced after the calving period. We refer to results from aerial surveys concurrent to our road surveys to help develop and support our conclusions (Noel et al., 2004). Predicting impacts is part of the environmental review process, and understanding gross processes of habituation by caribou may aid in land management decisions and development of effective mitigation measures for industry and wildlife management agencies.

STUDY AREA

The study area is located on the northern edge of Alaska's Arctic Coastal Plain, between latitudes 70˚10′ N and 70˚30′ N and longitudes 149˚10′ W and 150˚20′ W, within the MPU, KRU, and western PBU oilfields. The PBU and KRU oilfields are the first and second largest producers of oil in North America, respectively (BP Exploration [Alaska] Inc., 2001). Terrain ranges from sea level to 25 m ASL. The area is characterized by low relief, many shallow lakes and drained lake basins, and a variety of habitats dominated by wet and moist graminoid tundra communities (Walker et al., 1980). Large mammals of the area, other than caribou, include grizzly bears (*Ursus arctos*), muskoxen (*Ovibos moschatus*), and occasionally moose (*Alces alces*; Gavin, 1980).

There are three major roads in our study area. The Spine Road, the main road through the oilfields, is oriented east-west approximately 20 km south of the Beaufort Sea coast, while the Milne Point and Oliktok Roads lead from the Spine Road north to the coast (Fig. 1). There are 32 secondary roads leading to production pads or mine sites. All roads and pads are gravel. There are about 222 km of all roads combined within 692.9 km^2 (road density = 0.32 km/km^2), calculated from a minimum convex polygon of external points along the roads surveyed during the 2000–02 road surveys (excluding the Tarn Road, which was surveyed only once during each calving period).

Smith et al. (1994) provided the following sequence of oilfield development. By spring 1978, the Spine Road was extended to about 3 km west of KRU CPF-1. The Kuparuk airstrip and operations center were constructed in winter 1979–80, and the pipeline to Prudhoe Bay was constructed in winter 1980–81. The Milne Point Road was constructed during winter 1981–82, and a corresponding pipeline, in 1984. The road system was extended west in spring 1982 to include the Oliktok Road and Kuparuk River Unit CPFs 2 and 3 (Fig. 1). Most existing facilities have been operational since 1986.

METHODS

Calving of the CAH typically occurs at the end of May, peaks during the first week of June, and is mostly complete by 15 June (Shideler, 1986). Calving has been documented as late as 24 June (S. Haskell, unpubl. data). In previous studies, calving and post-calving periods have been treated separately, and 20 June has been considered the date separating these periods (Dau and Cameron, 1986b; Pollard et al., 1992; Smith et al., 1994). We continue to use this date as the transition from the calving to the post-calving period.

We conducted road-based surveys of caribou from a pickup truck during late calving and post-calving periods in the Milne Point and Kuparuk oilfields and along the Spine Road from the Milne Point Road east to Prudhoe Bay Unit Z-Pad (Fig. 1) during 15–29 June 2000, 12–28 June 2001, and 11–18 and 21–26 June 2002. Depending on weather and caribou numbers, it took three or four 8-hour periods (1.5–2 days with two surveys per day) to complete coverage of the entire study area. We surveyed the study area in a general east-to-west direction, using standardized routes, to minimize potential biases from sampling varying habitats and areas of intensive human activity disproportionately to their relative abundance. Our systematic surveys are easily repeated, and we consistently maximized the time between surveys of an area (and consequently, the temporal independence of observations). Calving caribou from an adjacent herd traveled 2–3 km/day (Prichard et al., 2001).

We used caribou groups, not individuals, as sampling units to minimize dependence of observations of this

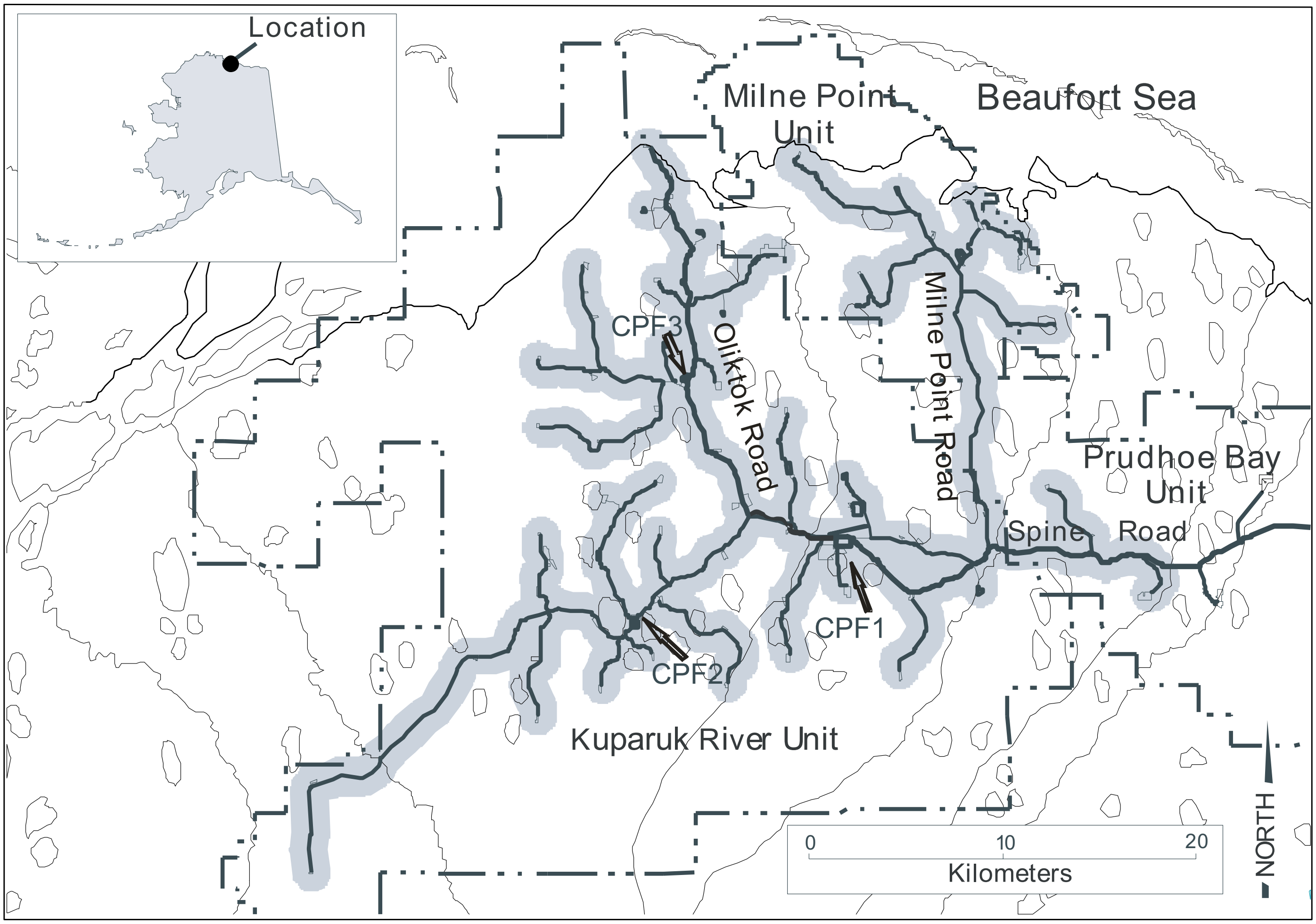

FIG. 1. Area surveyed for caribou within 1 km of gravel roads and pads (shaded) in the Milne Point, Kuparuk, and Prudhoe Bay oilfields, Alaska, June 2000–02. Oilfields are delineated by dashed lines, and black dots on the road system are production pads. CPF indicates major central processing facilities. The map represents the extent of development in June 2000.

gregarious species. Groups with calves were on average larger than groups without calves, but within group type, group size was independent of distance from infrastructure (Haskell, 2003). Groups were generally well dispersed and beyond visible range of one another. Because of the flat topography and the observers' elevated position, sightability of caribou groups was consistent throughout the study area. However, prone calves in particular can become more difficult to locate as distance increases. We used a global positioning system, laser range-finder, and compass to determine caribou group locations. Group center was subjectively based on individual caribou dispersion within a group (i.e., a weighted centroid). We used a geographic information system to measure the distance from the group center to the nearest active oilfield infrastructure (i.e., gravel road or production pad), and this distance served as a response variable in regression analyses. We obtained annual snow cover data collected at the Kuparuk, Alaska weather station from the National Climatic Data Center, National Oceanic and Atmospheric Administration (Asheville, North Carolina, USA). We used net-sweep methods described by Pollard et al. (1996b) to document parasitic insect activity at the beginning and end of each survey in 2001 and 2002, but relied on field notes to determine insect activity in 2000.

For comparisons of observed sighting rates (number of caribou per km surveyed) and calf percentages (calves as percent of total caribou observed), we classified observations for each group according to human activity level at the observation site (high or low) and time of observation (day or night). High-low area designations were based on general traffic rates and adapted from Johnson and Lawhead (1989). Human activity level was greater in the oilfields during the day than at night, so the standard work-shift change times of 0600 h and 1800 h were used as diel separators. Daylight was continuous, but usually dimmer at night.

Data Analyses

To assess factors influencing caribou group distance from infrastructure, we used a regression analysis with the response variable bound between 0 and 1 km. Responses were not normally distributed, having a heavy right-hand

TABLE 1. Spring snowmelt index, sighting rates (no. caribou/km surveyed), calf percentages, and total numbers of caribou individuals and groups observed during road surveys of the Milne Point, Kuparuk, and western Prudhoe Bay oilfields, Alaska, during the calving and post-calving periods of 2000–02.

		Calving				Post-calving			
Year	FDZSD[1]	Sighting Rate	% Calves	No. Caribou	No. Groups	Sighting Rate	% Calves	No. Caribou	No. Groups
2000	15 Jun	0.91	23.5	260	49	13.98	13.5	12844	407
2001	10 Jun	0.53	19.3	605	142	3.06	24.7	2517	264
2002	18 May	3.31	27.2	2547	318	8.14	27.1	5485	214

[1] First day of zero snow depth recorded at the Kuparuk weather station, Alaska. Data from the National Climatic Data Center, National Oceanic and Atmospheric Administration.

tail, so we transformed distances to ensure that error terms in the final model would be approximately normally distributed with near-constant error variances. We used an empirical logit transformation on distance from infrastructure to obtain a new response variable that was more normally distributed. The empirical logit transformation used was:

$$Y_i' = 1\text{n}\left(\frac{Y_i + 0.001}{1 - Y_i - 0.001}\right),$$

where Y_i was the observed distance (km) of caribou group i from infrastructure. We used SAS proc glm (SAS Institute, 2000) to estimate the coefficients and standard errors of the model:

$$E[Y_i'] = \beta_0 + \beta_1 X_{1i} + \ldots + \beta_p X_{pi},$$

where β_j were unknown coefficients, and X_{ji} were values of the *j-th* explanatory variable measured on the *i-th* observation. The model was fit using the method of maximum likelihood (Neter et al., 1996).

The normal theory regression modeling process began with the full model containing all three main effects of *period*, *calf presence*, and *year* and all possible interactions. Type III F tests were employed to test for significant terms in the model ($\alpha = 0.1$), and non-significant terms were removed, one at a time, until a final model was reached. For reporting purposes, Wald T statistics were computed for all parameters in the final model. Reference levels were changed, if necessary, to estimate means and standard errors for all levels of categorical variables in the final model.

To check that neither spatial nor temporal autocorrelation was present in the model residuals and adversely affecting significance levels of terms in the final model, we assessed deviance residuals (McCullagh and Nelder, 1989) from the final model for spatial and temporal autocorrelation, using Moran's I statistic (Moran, 1948; Cressie, 1993). Spatial correlation was assessed between locations less than 5 km apart. We tested for temporal autocorrelation within each of the three years and between observations less than five days apart. If high correlation (temporal or spatial) was found in the residuals, generalized mixed model estimation procedures were employed that specifically allowed for the correlation.

We present data distributions of caribou groups within 200 m distance intervals from 0–1000 m for clarity and support of interpretations (i.e., evidence of no bimodal effect on means) and additional information found beyond the first and second (μ and σ^2) moment statistics. We performed goodness-of-fit analyses using Pearson's chi-square (χ^2) procedures (Zar, 1999), assuming equal areas per interval and an expected uniform distribution of caribou among intervals. Yates' correction for continuity was applied to χ^2 analyses when appropriate. We compared proportions with a normal approximation of the χ^2 test using angular transformations (Zar, 1999).

We used simple linear regressions to determine relationships within years between distance from infrastructure and distribution of maternal groups through the calving period. Maternal caribou during the calving period are the prominent issue regarding oilfield impacts, and this specific relationship could not be addressed in the larger distance analyses without loss of information. Using inferential evidence and linear regression, we suggest a relationship between the timing of spring snowmelt and mean distance from infrastructure of caribou groups during the calving period. Except for tests on the effect of period and calf presence on mean group distance from infrastructure, all analyses were a posteriori.

RESULTS

Calving period surveys covered the entire study area 1.3 times (5 surveys) in 2000, 4.8 times (15 surveys) in 2001, and 3.7 times (14 surveys) in 2002. Post-calving surveys covered the entire area 5.5 times (17 surveys) in 2000, 3.5 times (13 surveys) in 2001, and 3.3 times (11 surveys) in 2002. Although we have no data to confirm this, individual caribou were likely observed more than once within and between years, but not within a survey. Sighting rate calculated during the calving period was greatest in 2002, when the snow melted earliest (Table 1). Sighting rate during the post-calving period was greatest in 2000 (Table 1). Insect harassment caused large aggregations (up to 2000 individuals) of caribou to form and move rapidly

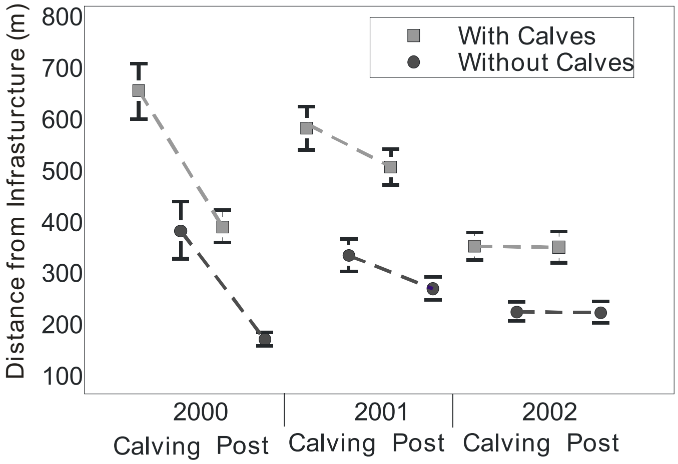

FIG. 2. Estimated mean distance from infrastructure for caribou groups, based on the final regression model. Error bars represent ± 1 SE. Data are from road surveys conducted in North Alaskan oilfields in June 2000–02.

through our study area towards the coast during this period. During the post-calving period, we observed insect harassment of 64 caribou groups in 2000 and 12 groups in 2002. Insect harassment was not evident during the calving periods of any year or the post-calving period of 2001. We therefore assume it had no direct effect on calving period relationships or others specific to 2001.

Distance from Infrastructure

The full model was first reduced to contain only main effects and two-way interaction terms between all three predictor variables (F-statistic on three-way interaction = 0.19; df = 2, 1382; $p = 0.83$). This model was then further reduced by dropping the period • calf presence interaction (F = 0.149; df = 1, 1384; $p = 0.22$). Inspection of model residuals indicated that the residuals were approximately normally distributed and that variance of the residuals was fairly constant across predicted values of the transformed response. Because spatial and temporal correlation detected in residuals from the final model was small ($-0.01 \leq$ Moran's I ≤ 0.01 in all years), we found that the use of mixed model procedures was unnecessary.

During the calving period, caribou groups with and without calves were closer to infrastructure in 2002 than in 2000 or 2001 (Fig. 2, Table 2). There were no significant differences between calving periods of 2000 and 2001 (Table 2). During the post-calving period, groups tended to be closer to infrastructure in 2000 than in other years, except that groups with calves were at similar distances in both 2000 and 2002 ($p = 0.365$, Table 2). In 2000, greater insect harassment may have been responsible for the shorter distances during the post-calving period, when some caribou groups traveled along north-south roads to coastal habitats (including gravel production pads) that provided relief from insects (for prior documentation see Pollard et al., 1996b; Noel et al., 1998).

Groups with calves were distributed farther from infrastructure than groups without calves during all three years ($p < 0.0001$ for all; Fig. 2, Table 3). Caribou groups were farther from infrastructure during the calving period than during the post-calving period in 2000 and 2001 ($p < 0.0001$, $p = 0.06$, respectively), but not in 2002 ($p = 0.960$; Fig. 2, Table 3).

Groups with calves were farther from infrastructure than expected in the calving period of 2000, but closer than expected during both calving and post-calving periods in 2002 (Table 4). Groups without calves were found closer than expected in both periods of all years except the

TABLE 2. Wald T tests comparing distance to infrastructure between years, in calving and post-calving periods, with or without calves in group (n = number of groups). For each comparison in the "Parameter" column, the second year was set as the reference level in the analysis. A positive estimate indicates that observations during the reference year were closer to infrastructure. Data from road surveys conducted in North Alaskan oilfields in June of 2000–02.

Parameter	Coefficient Estimate	Standard Error	Wald T Statistic	p-Value
Calving Period with Calf Present:				
Year 2000 (22) vs. Year 2002 (140)	1.257	0.268	4.69	< 0.0001
Year 2001 (44) vs. Year 2002	0.944	0.210	4.5	< 0.0001
Year 2000 vs. Year 2001	0.313	0.297	1.05	0.293
Calving Period with No Calf Present:				
Year 2000 (27) vs. Year 2002 (178)	0.757	0.259	2.92	0.004
Year 2001 (98) vs. Year 2002	0.549	0.178	3.09	0.002
Year 2000 vs. Year 2001	0.208	0.275	0.76	0.450
Post-Calving Period with Calf Present:				
Year 2000 (132) vs. Year 2002 (90)	0.170	0.188	0.91	0.365
Year 2001 (100) vs. Year 2002	0.645	0.194	3.32	0.001
Year 2000 vs. Year 2001	-0.474	0.193	-2.46	0.014
Post-Calving Period with No Calf Present:				
Year 2000 (275) vs. Year 2002 (124)	-0.330	0.154	-2.14	0.032
Year 2001 (164) vs. Year 2002	0.250	0.168	1.49	0.138
Year 2000 vs. Year 2001	-0.579	0.148	-3.91	< 0.0001

TABLE 3. Wald T tests comparing mean distance from infrastructure of caribou groups, by period and by calf-presence, within each survey year. A positive estimate indicates that groups in the second classification being compared were closer to infrastructure. Data from road surveys conducted in North Alaskan oilfields, June 2000–02.

Year	Parameter	Coefficient Estimate	Standard Error	Wald T Statistic	p-Value
2000	Calving vs. Post-Calving Periods	1.094	0.239	4.57	< 0.0001
	Calf Present vs. No Calf Present	1.127	0.157	7.20	< 0.0001
2001	Calving vs. Post-Calving Periods	0.306	0.164	1.86	0.060
	Calf Present vs. No Calf Present	1.023	0.164	0.16	< 0.0001
2002	Calving vs. Post-Calving Periods	0.007	0.139	0.05	0.960
	Calf Present vs. No Calf Present	0.628	0.138	4.55	< 0.0001

TABLE 4. Pearson's goodness-of-fit analyses, assuming uniform distributions of caribou groups with and without calves within 200 m intervals from infrastructure. Caribou observations are from road surveys in North Alaskan oilfields during the calving and post-calving periods, June 2000–02.

			No. of Groups Observed by Interval[1]						H_o: P1 = P2… = P5	
Year	Period	Group Type	0–199	200–399	400–599	600–799	800–999	Expected Values	χ^2	p
2000	Calving	With Calf	0 -	5	2	5	10 +	4.4	13.00	0.011
		No Calf	6	6	7	4	4	5.4	1.33	0.856
	Post	With Calf	35	33	22	24	18	26.4	8.08	0.089
		No Calf	151 +	66	25 -	22 -	11 -	55	241.13	< 0.001
2001	Calving	With Calf	3	10	10	9	12	8.8	5.32	0.256
		No Calf	29 +	23	19	17	10 -	19.6	10.16	0.038
	Post	With Calf	12	27	29 +	17	15	20	11.40	0.022
		No Calf	63 +	41	38	8 -	14 -	32.8	60.21	< 0.001
2002	Calving	With Calf	43 +	38 +	22	19	18 -	28	19.36	0.001
		No Calf	82 +	51 +	24 -	15 -	6 -	35.6	110.76	< 0.001
	Post	With Calf	29 +	20	25	10 -	6 -	18	21.22	< 0.001
		No Calf	56 +	29	22	13 -	4 -	24.8	63.34	< 0.001

[1] Number of groups observed > ("+") or < ("-") expected ($\alpha = 0.05$).

calving period of 2000 (Table 4). No maternal groups were initially observed within 200 m of infrastructure during the calving period of 2000 (Table 4).

Mean distance from infrastructure during the calving period, for groups with and without calves, was positively correlated with the timing of spring snowmelt (Fig. 3). When complete snowmelt occurred relatively early, caribou groups were on average distributed closer to roads and production pads than they were when snow melted later (Fig. 3). Persisting snow hinders the northward spring migration of the CAH (Gavin, 1975) and probably reduced the exposure time of caribou to oilfields during our sampling period.

For groups with calves, distance from oilfield infrastructure (as plotted along an hourly continuum) did not change measurably during the late calving period in 2000 and 2002 ($p > 0.550$, Fig. 4). In 2001, however, groups with calves were seen closer to infrastructure as the calving period progressed ($p = 0.037$, Fig. 4). These results, along with mean comparisons between periods within and among years and calving-period frequency distributions (Tables 2, 3, and 4; Fig. 2), suggest that maternal groups reduced avoidance, or habituated, after the putative end of the calving period (20 June) in 2000, late during the calving period in 2001, and likely sometime before our sampling began in 2002.

Avoidance of Human Activity

Sighting rates were lower in areas of high human activity in all years during the calving period, but not during the post-calving period (Table 5). Calf percentages (% calves of caribou observed) were significantly greater at night than in the day during the calving periods of 2001 and 2002 and the post-calving periods of 2000 and 2001 (Table 6). During the calving period of 2000 and the post-calving period of 2002, there was no significant difference in calf percentages between day and night (Table 6).

DISCUSSION

Results from studies using aerial survey techniques indicated that displacement effects for caribou and calves

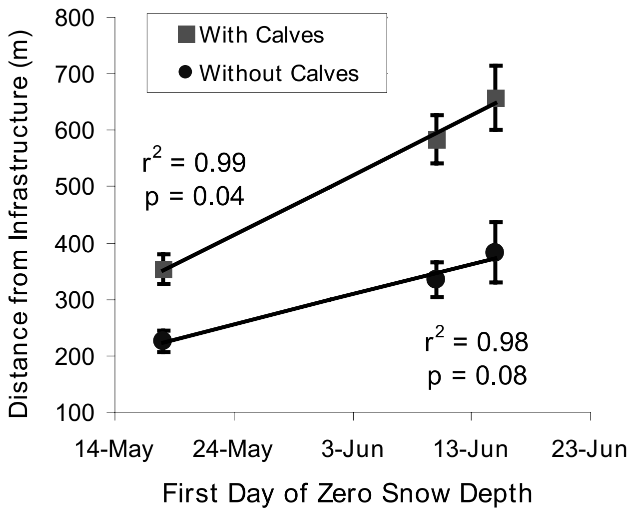

FIG. 3. Mean predicted distance from infrastructure (in meters, ± 1 SE) of caribou groups with and without calves during the calving period, in relation to the first day of zero snow depth recorded by the NOAA weather station at Kuparuk, Alaska, in 2000–02.

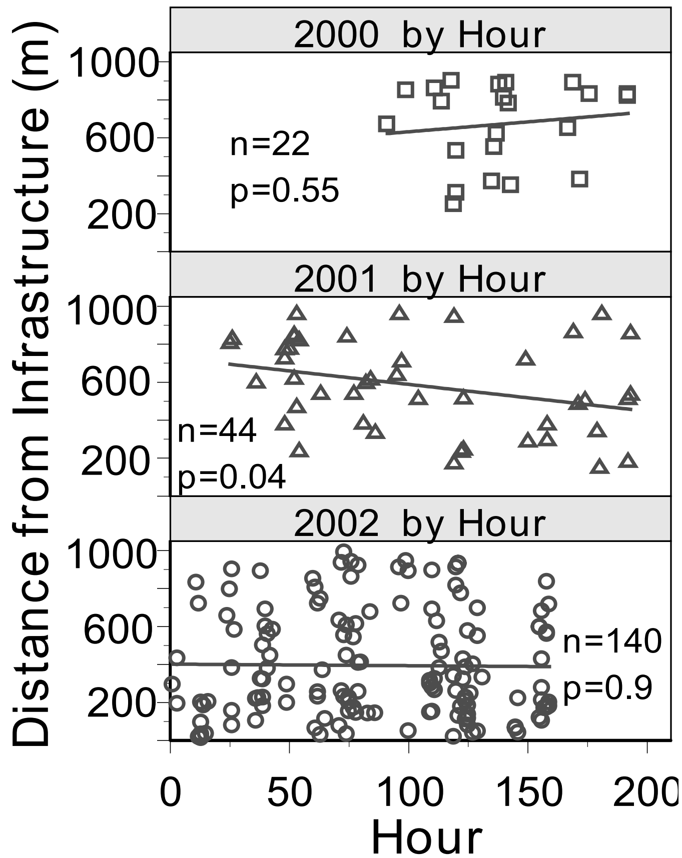

FIG. 4. Distance (m) from active oilfield infrastructure of caribou groups with calves observed during the late calving period in 2000–02 and plotted along an hourly continuum consistent among years (11 June 2200 h to 19 June 2300 h).

during the late calving period were measurable at the 1 km interval nearest the Milne Point Road after construction (Dau and Cameron, 1986a; Cameron et al., 1992). We examined caribou response at a finer scale (< 1 km) and can make inferences beyond our study area only with caution. However, results from more recent aerial surveys centered on the Milne Point Road, some of them concurrent with our own road surveys, indicated no displacement effects at the 1 km spatial resolution (Noel et al., 2004). Thus, the extent of displacement described in this study may be the true extent at present for the latter part of the calving period. It could be argued that our results do not apply to the entire western segment of CAH calving caribou because we have documented displacement effects only for a sample of caribou with a predisposition for oilfield tolerance. We believe this to be possible but unlikely, for reasons given in the introduction and the discussion below.

Our data quantitatively supported previous observations of heightened sensitivity in maternal caribou after parturition (de Vos, 1960; Skoog, 1968; Bergerud, 1974). Maternal caribou groups avoided infrastructure more than non-maternal groups, but exhibited a waning avoidance response, or habituation, at a similar rate between periods (i.e., insignificant calf presence•period interaction in distance regression analysis; see Fig. 2). Although calf age may affect avoidance behavior of maternal cows, particularly during the first few days of neonate development, we conducted our surveys during the latter half of the calving period, when calves were generally highly mobile and capable of evading real or perceived predatory threats (i.e., grizzly bears or human activity; review by Frid and Dill, 2002). The fact that groups with and without calves similarly reduced avoidance behavior from the calving period to the post-calving period indicated that calf presence was not the underlying cause and justified the term “habituation” to describe the waning over time of the avoidance response.

Disturbance that triggers an avoidance response is necessary before habituation to that disturbance can occur. Avoidance of human activity during the calving periods was measurable in both space and time. Displacement effects during the calving period that may have reached beyond our study area were more likely to have occurred in localized areas of high human activity unless caribou were displaced within the study area from areas with high activity to areas with low activity (Table 5). Our diel analyses were useful in that the confounding factor of habitat quality as it relates to animal use was mostly circumvented by ensuring that similar numbers of surveys were conducted during the day and at night in each section of the study area. Parous caribou tended to be more represented in the population of caribou within 1 km of active oilfield infrastructure at night, when human activity levels were lower (Table 6). Reasons why day and night calf percentages were similar during the 2000 calving period may include small sample sizes, or a late spring thaw that may have attracted parous caribou to dust shadows near roads (Walker and Everett, 1987; Smith et al., 1994) or other snow-free habitats, particularly within low-activity areas. The insect-free post-calving data for 2002 indicated

TABLE 5. Comparison of sighting rates (no. caribou/km surveyed) and distance surveyed between areas of low and high human activity in North Alaskan oilfields during the late calving and insect-free post-calving periods of 2000–02. Ratio data are not amenable to significance testing.

Activity Area		2000		2001		2002	
		Calving	Post	Calving	Post	Calving	Post
Low	Sighting rate	1.90	7.93	0.83	4.29	4.85	4.84
	No. km	120	397	544	387	384	308
High	Sighting rate	0.29	7.35	0.39	2.98	2.34	8.41
	No. km	109	448	392	286	293	257

TABLE 6. Calf percentage (% calves of total caribou) and number of caribou observed day and night during the late calving and insect-free post-calving periods 2000–02. Results of two-sample tests for equality of proportions with continuity corrections are shown testing differences in calf % between diel periods.

Diel Period		2000		2001		2002	
		Calving	Post	Calving	Post	Calving	Post
Day	Calf %	27.5	12.9	10.3	17.0	25.6	21.0
	No. caribou	69	1668	243	654	1616	2898
Night	Calf %	22.0	20.2	25.4	27.4	29.9	21.4
	No. caribou	191	4773	362	1863	931	752
Significance between calf %:		$p = 0.444$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p = 0.023$	$p = 0.836$

no diel difference in calf percentages, apparently because habituation of caribou had already occurred. Discrepancies between calf percentages and sighting rates as indicators of an avoidance response may be explained by the absolute difference in avoidance between caribou groups with and without calves, and possibly also a diel response of maternal groups observed in areas of high human activity.

Group distributional trends within 1 km of infrastructure during calving mainly describe an annual pattern of habituation for the portion of CAH caribou that calve in the oilfields. However, a later influx of large maternal groups from the south will mean that these new arrivals also have to habituate, somewhat confounding our overall results. When we began surveys in 2002 on 11 June, relatively large maternal groups, presumably from a calving concentration area to the south (Murphy and Lawhead, 2000), were observed moving into areas of low human activity at the southern periphery of the oilfields. In the previous two years, when snow melted later, this influx did not occur until the very end of the calving period, around 20 June. This occurrence may explain why sighting rates were higher in areas of low human activity and a diel difference in calf percentage was noted during the calving period of 2002 (Tables 5 and 6) while overall, more groups with calves than expected were observed near infrastructure (Table 4). The influx of these groups from the south appeared to have little effect on overall group distance means and frequency distributions. It may be that the innate hypersensitivity of maternal caribou deteriorates after the neonatal period, allowing these animals to experience cultural and social learning and habituate more rapidly to human disturbance stimuli than the "resident" calving-period caribou that reared neonates in the oilfields upon arrival.

Our results indicated that caribou habituation to oilfields, determined by a measured decrease in overall avoidance of roads, reoccurred annually. The timing of this annual rehabituation was positively correlated with the timing of spring snowmelt (Fig. 3), and accordingly, occurred either before or after the putative end of calving (20 June) in each year (Figs. 2 and 4). This was likely a function of the group's exposure time to oilfields, as the northward spring migration was hindered by persisting snow (Gavin, 1975). Although our results are limited to three years of study, yearly differences in data distribution during the calving period (Table 4), differences in mean group distances from calving to post-calving period within a year (Fig. 2, Table 3), and distribution of maternal groups through all three calving periods (Fig. 4) all support the hypothesis of a snowmelt-dependent timing of annual rehabituation. Available road and aerial survey data through the 1980s have been used to further extrapolate, apply, and support the hypothesis of a snowmelt-dependent timing and extent of annual rehabituation (Haskell, 2003).

According to our hypothesis of annual rehabituation, caribou should have been most sensitive to oilfield activities during the calving period in 2000, when snowmelt was later than in other years. Except during the calving period of 2000, groups without calves were observed near infrastructure more often than expected (Table 4). This pattern was also apparent for groups with calves during the calving and post-calving periods of 2002. We believe that the right-tailed distribution of caribou relative to oilfield infrastructure indicated that the spatial threshold between habituation and avoidance responses (review by Whittaker and Knight, 1998) was generally reduced to less than 200 m from active roads and pads (Table 4). Caribou become less sensitive to disturbance as they move and eventually approach roads, but they may hesitate to move across them as freely as they might on open tundra. In itself, this hesitation does not imply negative energetic effects, but it could affect potential exposure to abomasal parasites and alter optimal foraging strategies if local caribou densities were consistently high (Gunn and Irvine, 2003). Similarly, Noel et al. (2004) found during the late calving period that caribou densities within 6 km from the Milne Point Road were highest in the 1 km interval nearest the road, perhaps documenting the same phenomenon at a greater spatial extent.

The distributional differences between groups with and without calves were statistically significant, meaning that they reflect real behavioral differences. It is unknown whether differences at this small spatial extent have nutritional effects, but given the low densities of caribou and short duration of displacement, such effects are probably negligible. Although mean distances from infrastructure differed between the 2001 and 2002 calving periods, group activity behaviors were consistent: in both years, groups with calves fed more than non-maternal groups (Haskell, 2003). Behavioral data were not collected in 2000.

MANAGEMENT IMPLICATIONS

Previous studies have assessed the effectiveness of mitigation measures implemented in the Prudhoe Bay region to reduce negative impacts of oilfields on CAH caribou (reviews by Cronin et al., 1994; Murphy and Lawhead, 2000). Caribou aversion for infrastructure is likely a conditioned response, whereas vehicular movement may evoke an unconditioned response to perceived predation risk (Bergerud, 1974; Frid and Dill, 2002). Minimizing traffic, especially within calving areas during the calving period when snow melts late, would reduce the potential for negative synergistic impacts on caribou. However, data from this study and concurrent aerial surveys (Noel et al., 2004) indicate that displacement was measurable only within the first kilometer from infrastructure and may not be as far-reaching as has often been reported (e.g., Dau and Cameron, 1986a; Cameron et al., 1992, 2002, 2005; NRC, 2003). Immediately after arriving in oilfields, maternal caribou rearing neonates may cross roads in haste, not lingering to forage nearby, and thus experience functional displacement from areas within 200 m of roads (see 2000 in Table 4 and 2001 in Fig. 4). Nutritional effects from displacement remain unknown, but are probably negligible. The necessity of calving period-specific mitigation measures (e.g., convoys and mass transit) should be considered on a case-by-case basis. If such measures are deemed justifiable given costs, they should be revaluated regularly, particularly in areas of new development, considering the potential for caribou learning and tolerance (Haskell, 2003). To maximize efficacy without overregulation, calving period-specific mitigation measures in established oilfields may be terminated prior to or extended beyond 20 June, depending on the timing of spring snowmelt. Our 2001 data (Fig. 4) seemed to approximate well the date of complete snowmelt (10 June) that would translate, in terms of caribou behaviour, into an actual 20 June transition from the calving to post-calving period. More data are needed to fully describe the annual timing of a behavioural transition between discrete calving and post-calving periods, and harassment by parasitic insects as an overriding stimulus may also need to be considered in some years.

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REFERENCES

BALLARD, W.B., CRONIN, M.A., and WHITLAW, H.A. 2000. Caribou and oilfields. In: Truett, J.C., and Johnson, S.R., eds. The natural history of an Arctic oil field: Development and the biota. San Diego: Academic Press. 85–104.

BARTEN, N.L., BOWYER, R.T., and JENKINS, K.J. 2001. Habitat use by female caribou: Tradeoffs associated with parturition. Journal of Wildlife Management 65:77–92.

BERGERUD, A.T. 1974. The role of the environment in the aggregation, movement, and disturbance behaviour of caribou. In: Geist, V., and Walther, F., eds. The behaviour of ungulates and its relation to management. IUCN Publications New Series 24, Vol. 2:552–584.

———. 2000. Caribou. In: Demarais, S., and Krausman, P.R., eds. Ecology and management of large mammals in North America. Upper Saddle River, New Jersey: Prentice-Hall, Inc. 658–693.

BP EXPLORATION (ALASKA) INC. 2001. BP environmental performance report 2001, Part 1: Background. Anchorage: BP Exploration (Alaska) Inc. http://alaska.bp.com/alaska/environment/2001/Part1.pdf. Accessed September 2004.

CAMERON, R.D. 1995. Can petroleum development depress the productivity of Arctic caribou? Paper presented at the 2nd International Arctic Ungulate Conference, 13–17 August 1995, Fairbanks, Alaska. Abstract.

CAMERON, R.D., and WHITTEN, K.R. 1979. Seasonal movements and sexual segregation of caribou determined by aerial survey. Journal of Wildlife Management 43:626–633.

CAMERON, R.D., REED, D.J., DAU, J.R., and SMITH, W.T. 1992. Redistribution of calving caribou in response to oil field development on the Arctic Slope of Alaska. Arctic 45(4): 338–342.

CAMERON, R.D., SMITH, W.T., WHITE, R.G., and GRIFFITH, B. 2002. The Central Arctic herd. In: Douglas, D.C., Reynolds, P.E., and Rhode, E.B., eds. Arctic Refuge coastal plain terrestrial wildlife research summaries. U.S. Geological Survey, Biological Resources Division, Biological Science Report USGS/BRD/BSR-2002-0001. 38–45.

———. 2005. Central Arctic caribou and petroleum development: Distributional, nutritional, and reproductive implications. Arctic 58(1):1–9.

CRESSIE, N.A.C. 1993. Statistics for spatial data. New York: John Wiley & Sons.

CRONIN, M.A., BALLARD, W.B., TRUETT, J., and POLLARD, R.H. 1994. Mitigation of the effects of oil-field development and transportation corridors on caribou. Unpubl. report sponsored by the Alaska Oil and Gas Association, Anchorage, Alaska. Available from ARLIS, Room 111, Library Building, 3211 Providence Drive, Anchorage, Alaska 99508.

CRONIN, M.A., AMSTRUP, S.C., DURNER, G.M., NOEL, L.E., McDONALD, T.L., and BALLARD, W.B. 1998a. Caribou distribution during the post-calving period in relation to infrastructure in the Prudhoe Bay oilfield, Alaska. Arctic 51(2):85–93.

CRONIN, M.A., BALLARD, W.B., BRYAN, J.D., PEARSON, B.J., and McKENDRICK, J.D. 1998b. Northern Alaska oil fields and caribou: A commentary. Biological Conservation 83:195–208.

DAU, J.R., and CAMERON, R.D. 1986a. Effects of a road system on caribou distribution during calving. Rangifer, Special Issue 1:95–101.

———. 1986b. Responses of barren-ground caribou to petroleum development near Milne Point, Alaska. Unpubl. report by Alaska Department of Fish and Game, Fairbanks, Alaska. Available from LGL Alaska Research Associates Inc., 1101 East 76th Avenue, Suite B, Anchorage, Alaska 99518.

DE VOS, A. 1960. Behavior of barren ground caribou on their calving grounds. Journal of Wildlife Management 24:250–258.

FOLSTAD, I., NILSSEN, A.C., HALVORSEN, O., and ANDERSON, J. 1991. Parasite avoidance: The cause of post-calving migrations in *Rangifer*? Canadian Journal of Zoology 69:2423–2429.

FRID, A., and DILL, L.M. 2002. Human-caused disturbance stimuli as a form of predation risk. Conservation Ecology 6(1):11. [online] URL: http://www.consecol.org/vol6/iss1/art11.

GAVIN, A. 1975. Weather and its effect on caribou behavior patterns and migration. In: Luick, J.R., Lent, P.C., Klein, D.R., and White, R.G., eds. Proceedings of the First International Reindeer and Caribou Symposium. Biological Papers of the University of Alaska, Special Report 1. Fairbanks, Alaska. 414–419.

———. 1980. Wildlife of the North Slope: A ten-year study, 1969–1978. Unpubl. report for Atlantic Richfield Company, Anchorage, Alaska. Available from ARLIS, Room 111, Library Building, 3211 Providence Drive, Anchorage, Alaska 99508.

GRIFFITH, B., DOUGLAS, D.C., WALSH, N.E., YOUNG, D.D., McCABE, T.R., RUSSELL, D.E., WHITE, R.G., CAMERON, R.D., and WHITTEN, K.R. 2002. The Porcupine caribou herd. In: Douglas, D.C., Reynolds, P.E., and Rhode, E.B., eds. Arctic Refuge coastal plain terrestrial wildlife research summaries. U.S. Geological Survey, Biological Resources Division, Biological Science Report USGS/BRD/BSR-2002-0001. 8–37.

GUNN, A., and D'HONT, A. 2002. Extent of calving for the Bathurst and Ahiak caribou herds, June 2002. Draft report by the Department of Resources, Wildlife & Economic Development, Government of the Northwest Territories, Yellowknife, NWT, Canada. Available from LGL Alaska Research Associates Inc., 1101 East 76th Avenue, Suite B, Anchorage, Alaska 99518.

GUNN, A., and IRVINE, R.J. 2003. Sub-clinical parasitism and ruminant foraging strategies: A review. Wildlife Society Bulletin 31:117–126.

HASKELL, S.P. 2003. Calving caribou in the northern oilfields of Alaska. MS Thesis, Texas Tech University, Lubbock, Texas.

HASKELL, S.P., and BALLARD, W.B. 2004. Factors limiting productivity of the Central Arctic caribou herd of Alaska. Rangifer 24(2):71–78.

JENSEN, P.G., and NOEL, L.E. 2002. Caribou distribution in the range of the Central Arctic herd. Part A: Aerial surveys of the Milne Point Unit, Prudhoe Bay Oilfield, Badami, and Bullen Point to Staines River study areas, summer 2001. In: Cronin, M.A., ed. Arctic Coastal Plain caribou distribution, summer 2001. Unpubl. report by LGL Alaska Research Associates, Inc., Anchorage, Alaska. Section 2:1–86. Available from LGL Alaska Research Associates Inc., 1101 East 76th Avenue, Suite B, Anchorage, Alaska 99518.

JOHNSON, C.B., and LAWHEAD, B.E. 1989. Distribution, movements, and behavior of caribou in the Kuparuk oilfield, summer 1988. Unpubl. report by Alaska Biological Research, Inc., Fairbanks, Alaska. Available from ARLIS, Room 111, Library Building, 3211 Providence Drive, Anchorage, Alaska 99508.

LAWHEAD, B.E., and PRICHARD, A.K. 2002. Surveys of caribou and muskoxen in the Kuparuk-Colville Region, Alaska, 2001. Unpubl. report by ABR, Inc. – Environmental Research and Services, Fairbanks, Alaska. Available from ARLIS, Room 111, Library Building, 3211 Providence Drive, Anchorage, Alaska 99508.

LENART, E.A. 2003. Unit 26A and B caribou management report. In: Healy, C., ed. Caribou management report of survey and inventory activities 1 July 2000–30 June 2002. Juneau, Alaska: Alaska Department of Fish and Game. 304–326.

LENT, P.C. 1980. Synoptic snowmelt patterns in Arctic Alaska in relation to caribou habitat use. In: Reimers, E., Gaare, E., and Skjenneberg, S., eds. Proceedings of the Second International Reindeer/Caribou Symposium, Røros, Norway, 17–21

September 1979. Trondheim, Norway: Direktoratet for vilt og ferskvannsfisk. 71–77.

MAKI, A.W. 1992. Of measured risks: The environmental impacts of the Prudhoe Bay, Alaska, oil-field. Environmental Toxicology and Chemistry 11:1691–1707.

McCULLAGH, P., and NELDER, J.A. 1989. Generalized linear models. 2nd ed. London: Chapman and Hall.

MORAN, P.A.P. 1948. The interpretation of statistical maps. Journal of the Royal Statistical Society B 10:243–251.

MURPHY, S.M., and LAWHEAD, B.E. 2000. Caribou. In: Truett, J.C., and Johnson, S.R., eds. The natural history of an Arctic oil field: Development and the biota. San Diego: Academic Press. 59–84.

NRC (NATIONAL RESEARCH COUNCIL). 2003. Cumulative environmental effects of oil and gas activities on Alaska's North Slope. Washington, D.C.: The National Academies Press.

NELLEMAN, C., and CAMERON, R.D. 1996. Effects of petroleum development on terrain preferences of calving caribou. Arctic 49(1):23–28.

———. 1998. Cumulative impacts of an evolving oil-field complex on the distribution of calving caribou. Canadian Journal of Zoology 76:1425–1430.

NETER, J., KUTNER, M.H., NACHTSHEIM, C.J., and WASSERMAN, W. 1996. Applied linear statistical models. 4th ed. Boston: McGraw-Hill.

NOEL, L.E., POLLARD, R.H., BALLARD, W.B., and CRONIN, M.A. 1998. Activity and use of active gravel pads and tundra by caribou, *Rangifer tarandus granti*, within the Prudhoe Bay oil field, Alaska. Canadian Field-Naturalist 112:400–409.

NOEL, L.E., PARKER, K.R., and CRONIN, M.A. 2004. Caribou distribution near an oilfield road on Alaska's North Slope, 1978–2001. Wildlife Society Bulletin 31:757–771.

POLLARD, R.H., MILLER, M.E., and WILKINSON, R.C. 1992. Caribou distribution in the Prudhoe Bay oil field, summer 1990. Unpubl. report by LGL Alaska Research Associates, Inc., Anchorage, Alaska. Available from ARLIS, Room 111, Library Building, 3211 Providence Drive, Anchorage, Alaska 99508.

POLLARD, R.H., BALLARD, W.B., NOEL, L.E., and CRONIN, M.A. 1996a. Summer distribution of caribou, *Rangifer tarandus granti*, in the Prudhoe Bay oil field, Alaska, 1990–1994. Canadian Field-Naturalist 110:659–674.

———. 1996b. Parasitic insect abundance and microclimate of gravel pads and tundra within the Prudhoe Bay oilfield, Alaska, in relation to use by caribou, *Rangifer tarandus granti.* Canadian Field-Naturalist 110:649–658.

PRICHARD, A.K., MURPHY, S.M., and SMITH, M.D. 2001. Analysis and mapping of satellite telemetry data for the Teshekpuk caribou herd 1990–1999 with a note on five Western Arctic caribou. Unpubl. report by ABR, Inc., Fairbanks, Alaska. Available from LGL Alaska Research Associates Inc., 1101 East 76th Avenue, Suite B, Anchorage, Alaska 99518.

SAS INSTITUTE, INC. 2000. SAS/STAT users' guide. Cary, North Carolina: SAS Institute, Inc.

SHIDELER, R.T. 1986. Impacts of human developments and land use on caribou: A literature review. Vol. 2. Impacts of oil and gas development on the Central Arctic herd. Technical Report No. 86–3. Juneau, Alaska: Alaska Department of Fish and Game, Habitat Division.

———. 2000. Pipelines and caribou crossings: Agency perspective. In: Established oil and gas practices and technologies on Alaska's North Slope, Alaska Conference Proceedings. U.S. Department of Energy, National Energy Technology Laboratory and National Petroleum Technology Office and the State of Alaska. 47–50.

SKOOG, R.O. 1968. Ecology of the caribou (*Rangifer tarandus granti*) in Alaska. PhD thesis, University of California, Berkeley.

SMITH, M.D. 1996. Distribution, abundance, and quality of forage within the summer range of the Central Arctic caribou herd. MS Thesis, University of Alaska Fairbanks.

SMITH, W.T., CAMERON, R.D., and REED, D.J. 1994. Distribution and movements of caribou in relation to roads and pipelines, Kuparuk Development Area, 1978–90. Wildlife Technical Bulletin 12. Juneau: Alaska Department of Fish and Game.

TAYLOR, A.R., and KNIGHT, R.L. 2003. Behavioral responses of wildlife to human activity: Terminology and methods. Wildlife Society Bulletin 31:1263–1271.

WALKER, D.A. 1985. Vegetation and environmental gradients of the Prudhoe Bay region, Alaska. Cold Regions Research and Engineering Laboratory Report 85-14. Hanover, New Hampshire: U.S. Army Corps of Engineers.

WALKER, D.A., and EVERETT, K.R. 1987. Road dust and its environmental impact on Alaskan taiga and tundra. Arctic and Alpine Research 19:479–489.

WALKER, D.A., EVERETT, K.R., WEBBER, P.J., and BROWN, J. 1980. Geobotanical atlas of the Prudhoe Bay Region, Alaska. Cold Regions Research and Engineering Laboratory Report 80-14. Hanover, New Hampshire: U.S. Army Corps of Engineers.

WHITTAKER, D., and KNIGHT, R.L. 1998. Understanding wildlife responses to humans. Wildlife Society Bulletin 26:312–317.

WHITTEN, K.R., and CAMERON, R.D. 1980. Nutrient dynamics of caribou forage on Alaska's Arctic slope. In: Reimers, E., Gaare, E., and Skjenneberg, S., eds. Proceedings of the Second International Reindeer/Caribou Symposium, Røros, Norway, 17–21 September 1979. Trondheim, Norway: Direktoratet for vilt og ferskvannsfisk. 159–166.

———. 1985. Distribution of calving caribou in relation to the Prudhoe Bay oilfield. In: Martell, A.M., and Russell, D.E., eds. Caribou and human activity: Proceedings of the First North American Caribou Workshop, Whitehorse, Yukon, 1983. Ottawa: Canadian Wildlife Service. 35–39.

WOLFE, S.A. 2000. Habitat selection by calving caribou of the Central Arctic herd, 1980–95. MS Thesis, University of Alaska, Fairbanks, Alaska. 83 p.

ZAR, J.H. 1999. Biostatistical analyses. 4th ed. Upper Saddle River, New Jersey: Prentice-Hall.