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To:	MVEIRB	From:	**Jean Teillet**
Attention:	Glenda Fratton	Fax No:	867 766-7074
Date:	April 15, 2003	File:	Dogrib 400-DeBeers

Originals to be sent: Yes ☐ No X

Page 1 of ~~20~~ 22

Re: **The Report on the Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope (2003) - Caribou**

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APR 15 2003
MACKENZIE VALLEY ENVIRONMENTAL IMPACT REVIEW BOARD

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April 15, 2003

Ms Glenda Fratton
De Beers Snap Lake Environmental Assessment Coordinator
Mackenzie Valley Environmental Impact Review Board
Box 938, 5102-50th Avenue
Yellowknife, NT, X1A 2N7
By Fax: 867 766-7074

Re: Report on the Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope (2003) with respect to Caribou

Dear Ms Fratton:

Attached please find selected parts of the *Report on the Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope* (2003). This report is soon to be published in hard copy by the National Research Council of the National Academies Press. The version we have included is the prepublication copy available on their website at <www.nap.edu>. We have included only the parts of Chapter 8 that address issues of cumulative effects on Caribou.

Please include this report on the public registry for the DeBeers Snap Lake Environmental Assessment.

Please feel free to contact me should you have any further questions.

Yours truly,

Jean Teillet

* personal law corporation
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PREPUBLICATION COPY

Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope

Committee on the Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope

Board on Environmental Studies and Toxicology

Polar Research Board

Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

March 2003

CARIBOU

Introduction

The effects of North Slope industrial development on barren-ground caribou (*Rangifer tarandus granti*) herds have been contentious. Although much research has been conducted on caribou in the region, researchers have disagreed over the interpretation and relative importance of some data and how serious data gaps are. The disagreements are especially significant because caribou are nutritionally and culturally important to North Slope residents and because caribou are widely recognized as important symbols of the state and well-being of North Slope environments. For these reasons, the committee assembled information on caribou and evaluated conflicting interpretations of the information about how oil and gas development might have affected their population dynamics. The committee's consensus on effects to date, and projections of probable future effects, is the product of this careful analysis and deliberation.

Assessing the effects of oil and gas development on caribou is not straightforward because many factors other than oil and gas activities affect the sizes of North Slope caribou herds—changes in weather vegetation, disease, and predators, for example. Therefore, there is no steady baseline against which to identify and assess disturbance-induced changes. To evaluate the effects of petroleum development on caribou, the committee examined changes in distribution and habitat use, and evaluated the nutritional and reproductive implications of those changes and how they altered population dynamics.

Background

Caribou are ubiquitous on the North Slope. Four separate herds, ranging nearly 20-fold in size, are recognized on the basis of distinctly different calving grounds (Skoog 1968, Figure 8-2). The extent of seasonal migration varies with herd size (Bergerud 1979, Fancy et al. 1989, Skoog 1968). By far the largest is the Western Arctic Herd (WAH), estimated at 460,000 (in 2001). It calves in the Utukok uplands south of Barrow and summers throughout the North Slope and Brooks Range west of the Colville River, including most of the National Petroleum Reserve-Alaska. Wintering areas include both the western North Slope and the southern foothills of the Brooks Range. The annual range of the Teshekpuk Lake Herd (TLH), numbering 27,000 (in 1999), lies within the WAH summer range. Calving and summer ranges are in the coastal zone near Teshekpuk Lake; the winter range typically is confined to the coastal plain and nearby foothills. Estimated at 123,000 (in 2001), the Porcupine Caribou Herd (PCH) calves on the coastal plain and lower uplands in northeastern Alaska within the Arctic National Wildlife Refuge and adjacent Yukon Territory. During the summer, the PCH ranges throughout much of the eastern North Slope and Brooks Range; its wintering areas include the Ogilvie and Richardson mountains in western Canada and the southern Brooks Range in eastern Alaska. At 27,000 (in 2000), the Central Arctic Herd (CAH) is distributed primarily within state lands between the Colville and Canning rivers. CAH calving and summer ranges are on the coastal plain, and the winter range typically extends southward into the northern foothills of the Brooks Range. During the past 27 years, the size of the PCH has been nearly constant; the other three herds have increased substantially (Figure 8-3).

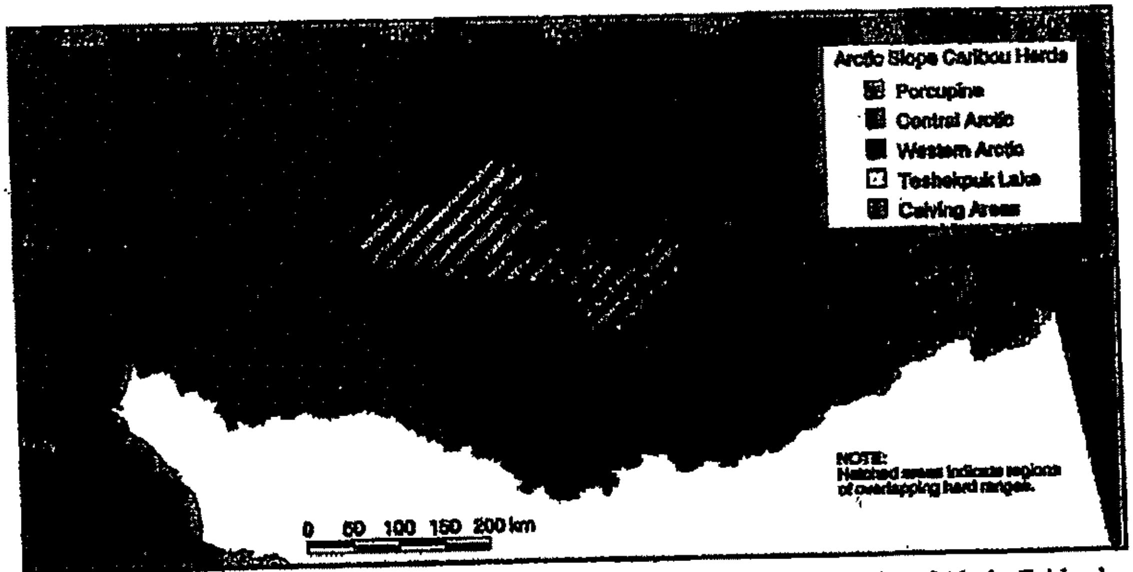

FIGURE 8-2. Arctic Caribou Herds. Source: Alaska Geobotany Center, University of Alaska Fairbanks 2002.

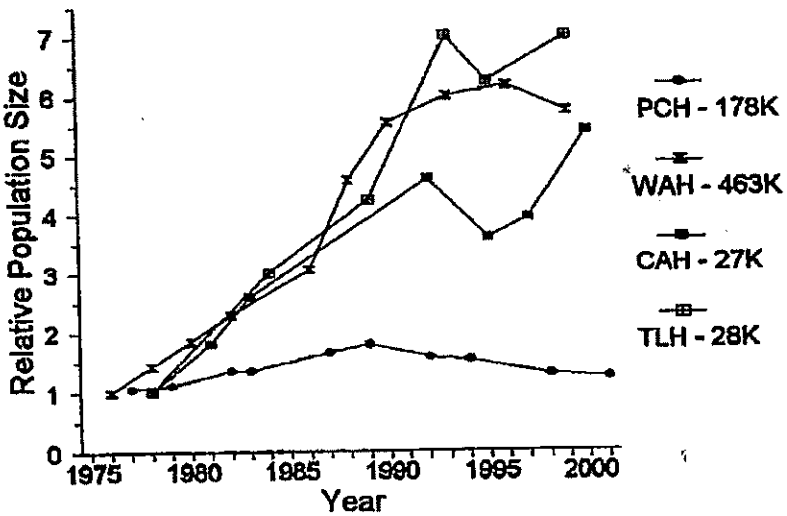

FIGURE 8-3. Relative post-calving herd sizes (minimum observed = 1.0) of the 4 Alaska barren-ground caribou herds (PCH = Porcupine caribou herd; WAH = Western Arctic herd, CAH = Central Arctic herd; TLH = Teshekpuk Lake herd), 1976-2001. Maximum observed population size for each herd is noted in the legend. Source: Griffith et al. 2002.

Central Arctic Herd

For the past 50 or 60 years, all four herds (Figure 8-2) have been exposed to oil and gas exploration activity, but only the CAH has been in regular and direct contact with surface development related to oil production and transport. Its calving ground and summer range lie within the oil-field region near Prudhoe Bay; its autumn, winter, and spring ranges encompass the Dalton Highway (also called the Haul Road) and the area around the Trans-Alaska Pipeline (Cameron and Whitten 1979b). The CAH has increased from around 5,000 animals in the late 1970s to its current (2000) size of 27,000 (Figure 8-3).

Parturient females, along with most nonparturient females and yearlings, arrive on the coastal calving ground in mid-May (Gavin 1978, Smith et al. 1994). The exact timing depends on patterns of snowfall and snowmelt (Cameron et al. 1992, Gavin 1978). Most calving occurs within 50 km (31 mi) of the Beaufort Sea (Whitten and Cameron 1985, Wolfe 2000). Virtually all calves are born between late May and early June (Cameron et al. 1993) within two or three calving concentration areas (Whitten and Cameron 1985, Wolfe 2000). At the landscape level, selection and repeated use of a calving ground is probably related to both the distribution of predators, which are less abundant on the coastal plain (Rausch 1953; Reynolds 1979; Shideler and Hechtel 2000; Stephenson 1979; Young et al. 1992, 2002), and the likelihood of favorable foraging conditions (Griffith et al. 2002). Annual shifts in concentrated calving within the overall calving ground are driven by spatial changes in the quality and quantity of new forage, principally sedges (Bishop and Cameron 1990, Wolfe 2000). An additional advantage of coastal calving is proximity to "insect-relief habitat," which eliminates the need for extensive travel with a young calf.

Bulls and the remaining noncalving females and subadults, which stay inland during the calving period, follow the northward progression of plant growth (Whitten and Cameron 1980), arriving on the coastal plain in late June (Cameron and Whitten 1979, Gavin 1978). The midsummer diet includes a variety of deciduous plants (Roby 1978; Trudell and White 1981; White and Trudell 1979, 1980; White et al. 1975, 1981).

Insects substantially affect nutrient balance by reducing food intake and by increasing energy expenditure. Mosquitoes are present from late June through late July (White et al. 1975, Russell 1976, Dau 1986). On warm, calm days, when mosquitoes are active, caribou move rapidly to cooler, windier areas on or near the coast, returning inland to preferred feeding areas when harassment abates (Cameron and Whitten 1979, Cameron et al. 1995, Child 1973, Dau 1986, Roby 1978, White et al. 1975). These movements appear to optimize foraging opportunity relative to energy expenditure (Russell 1976, Russell et al. 1993, Walsh et al. 1992, White et al. 1975). Oestrid flies (warbles and nose bots) emerge in mid-July and persist through early August (Dau 1986). When oestrids are active, caribou stand head-down or run erratically (Dau 1986, Nixon 1990, Roby 1978). This behavior probably reduces larval infestation, but it increases activity and reduces feeding time at the expense of nutrient balance (Helle and Tarvainen 1984, Murphy and Curatolo 1987, Russell et al. 1993).

By autumn, caribou move inland (Cameron and Whitten 1979a), and breeding occurs from late September through mid-October, while enroute to the winter range. Most of the CAH winters in the foothills and mountainous terrain of the northern Brooks Range, although a few caribou typically remain on the coastal plain year round (Cameron and Whitten 1979b, Cameron et al. 1979, White et al. 1975). Lichens, which are low in protein, predominate in the winter and spring diets (Roby 1978).

Ecological Strategies

During June and July, caribou body energy and nutrient reserves are low (Chan-McLeod et al. 1999, Gerhart et al. 1996), and parturient and maternal females attempt to maximize their intake of high-quality forage (Klein 1970, Kuropat 1984, Kuropat and Bryant 1979, Russell et al. 1993, White et al. 1975). They replenish body protein reserves mobilized during late gestation (Gerhart et al. 1996) and attempt to meet or exceed the metabolic demands of lactation (White et al. 1975, 1981), which are highest during the first 3 weeks postpartum (Chan-McLeod et al. 1999, White and Luick 1984). The benefits of good nutrition include increased growth rates (Allaye-Chan 1991, White 1992) and survival of calves (Haukioja and Salovaara 1978). Good nutrition is enhances summer weight gain of a female and increases the probability that she will conceive in autumn (Adams and Dale 1998; Cameron and Ver Hoef 1994; Cameron et al. 1993, 2000; Dauphiné 1976; Eloranta and Nieminen 1986; Gerhart et al. 1997b; Lenvik et al. 1988; Reimers 1983; Thomas 1982; Thomas and Kiliaan 1998; White 1983).

The intake of high quality forage often is reduced by adverse weather. A late spring snowfall or late snowmelt decreases forage quality and availability, resulting in lower birth weight (Adamczewski et al. 1987, Bergerud 1975, Eloranta and Nieminen 1986, Espmark 1979, Reimers 2002, Rognmo et al. 1983, Skogland 1984, Varo and Varo 1971) and delayed parturition (Cameron et al. 1993; Skogland 1983, 1984), both of which reduce survival of offspring (Adamczewski et al. 1987, Eloranta and Nieminen 1986, Haukioja and Salovaara 1978, Rognmo et al. 1983, Skogland 1984). From late June through early August, repeated and often severe insect harassment reduces the frequency and duration of both suckling (Thomson 1977) and foraging bouts (Helle et al. 1992, Mórschel and Klein 1997, Russell et al. 1993, Toupin et al. 1996). The result is less nursing opportunity, and—because fewer maternal nutrients are allocated to milk—lower rates of milk intake. Factors that individually or collectively reduce a female's ability to raise a calf also reduce her ability to restore her body reserves, to fatten, and to breed (Crête and Huot 1993).

Tradeoffs therefore are inevitable: If maternal protein or fat reserves are not replenished fast enough, calves are weaned prematurely (Russell and White 2000). Calf survival is reduced by early weaning, but parturition and conception rates increase (Davis et al. 1991, Russell and White 2000). Delayed weaning enhances calf survival, but extended lactation precludes breeding that year (Gerhart et al. 1997a,b; Russell and White 2000). By comparison, well-fed cows initiated weaning during the rut, and both calf survival and fecundity are high.

During August and September, when insects are absent, growth of calves and fattening of adults continue relatively unimpeded. Milk production is low (White and Luick 1984), and offspring graze actively (Russell et al 1993) as they approach nutritional independence. Although most forage species have senesced, with a decline in quality, their high biomass permits high rates of food intake (White et al. 1975) and, therefore, body-fat synthesis. Fattening is enhanced in some years by the inclusion of mushrooms in the diet (Allaye-Chan et al. 1990). An unseasonably early, heavy snowfall, however, can disrupt the fattening process, and movement into more mountainous terrain increases exposure to predators. Hunting by humans tends to intensify in early autumn as well.

Females that wean their calves early, together with most that are in good enough condition to wean at normal times, conceive in October (Russell and White 2000). Cows in superior condition are less likely to lose their embryos early (Crête and Huot 1993, Russell et al. 1998), and, hence, are more likely to produce a calf the next spring.

A dietary shift from deciduous vegetation to lichens, begun in autumn, is virtually complete by midwinter. Males and nonpregnant females typically maintain body weight (Steen 1968) even when weather and foraging conditions are unfavorable. In contrast, pregnant females, faced with the increasing metabolic demands of a growing fetus, have difficulty maintaining nitrogen balance. They metabolize muscle tissue and conserve body fat during the last trimester to support early lactation (Chan-McLeod et al. 1994, Tyler 1987). Adequate winter nutrition increases the chances of timely parturition and early postnatal survival (Cameron et al. 1993, Eloranta and Nieminen 1986, Rognmo et al. 1983).

When snow is deep or encrusted, foraging requires more energy because caribou must dig through the snow (Fancy and White 1985a,b; Miller 1976). Far more serious is ground-fast ice. During frequent freeze-thaw cycles, typically in coastal areas during late winter or early spring, vegetation under the snow becomes encased in ice and thus inaccessible (Miller and Gunn 1979, Miller et al. 1982). As during autumn, mortality from predation and hunting can be appreciable.

Effects on Distribution, Movements, and Activity Patterns

Seismic Surveys

Until recently, the location and timing of seismic testing resulted in few conflicts with caribou in arctic Alaska. Surveys on state lands through the 1990s were conducted principally within the area of the CAH summer range, but during winter, when caribou were largely absent. Similarly, long-term programs within the National Petroleum Reserve-Alaska during the 1970s and 1980s occurred mostly within the summer ranges of the TLH and WAH, but again during winter. Seismic exploration crews on the coastal plain of the Arctic National Wildlife Refuge in the 1980s had no contact with caribou of the PCH, which winters south and east of the Brooks Range.

Even when seismic testing was conducted on winter range, the direct effects on caribou were probably temporary and minor. Early two-dimensional (2-D) surveys were of low intensity and, because wintering bands of caribou tend to be small and often widely dispersed, few caribou would have been in simultaneous contact with seismic activities. Moreover, caribou appear least sensitive to human-induced disturbance during winter (Roby 1978).

Recently, however, both the extent and intensity of seismic activities have increased. Active exploration now extends southward into the upper foothills of the central Brooks Range and westward to new lease tracts in the northeastern portion of the National Petroleum Reserve-Alaska. With a seismic line density 10-20 times greater than that for 2-D procedures, expanded application of the new three-dimensional (3-D) technology in those areas will increase the potential for conflicts with the CAH and TLH. Avoidance of seismic lines and the attendant human activity could reduce the animals' ability to avoid areas of deep snow (Dyer et al. 2001). The energy costs of multiple encounters with seismic disturbance could increase winter weight loss and reduce calf production and survival (Bradshaw et al. 1998).

Exploration and Drilling

Most exploration drilling—a site-specific, high-intensity event—is not connected to a permanent road system. As novel features on the landscape, drilling sites that are active in late spring almost certainly would be avoided by calving caribou. During midsummer, effects include localized changes in habitat use, longer approach distances, and altered activity patterns (Roby 1978, Wright and Fancy 1980). Caribou did not approach a drilling site closer than 1,200 m (0.7 mi) and were seen less frequently within 2 km (1.2 mi) of a drilling site than in a control area. Those entering the drilling area spent less time feeding and lying and more time moving than did caribou in a control area (Wright and Fancy 1980). In studies involving a simulated gas compressor station, caribou usually avoided the source of sound by at least 0.2 km (0.12 mi) (McCourt et al. 1974). Sensitivity appears to decline during other seasons, when calves are older.

Isolated Roads and Pipelines

Perhaps as an anti-predator strategy (Bergerud and Page 1987), parturient females and postpartum females with newborn calves distance themselves from potentially threatening stimuli. Aerial survey observations before and after placement of a road system (and later, an aboveground pipeline) through a calving concentration area near Milne Point (Whitten and Cameron 1985), in the Kuparuk Development Area (KDA), illustrate that sensitivity. After construction, the density of maternal females increased with distance from roads; no relationship was apparent before construction (Dau and Cameron 1986). Mean caribou abundance declined by more than two-thirds within 2 km (1.2 mi) of roads and was less than expected, overall, within 4 km (2.5 mi); but abundance nearly doubled at 4-6 km (2.5-3.7 mi) (Cameron et al. 1992), resulting in two separate concentrations (Dau and Cameron 1986, Lawhead 1988, Smith and Cameron 1992). Road traffic was light during the study (Dau and Cameron 1986; Dau and Smith, unpublished data; Lawhead 1988), suggesting that the presence of a road or pipeline alone, without vehicular or human activity, can elicit avoidance.

Concurrent ground observations within the KDA corroborate those findings. Few females and calves were seen from the road system during early June, and correspondingly few were observed crossing roads or pipelines (Smith et al. 1994). This is consistent with a tendency for parturient females to be relatively sedentary during the calving period (Fancy and Whitten 1991, Fancy et al. 1989).

A similar pattern of avoidance of a tourist resort and separate power-line corridor has been reported for semi-domesticated reindeer (*Rangifer tarandus tarandus*) during the calving period. Mean reindeer densities within preferred habitat were 73% and 78% lower in areas less than 4 km (2.5 mi) from the resort and power-line corridor, respectively, than in areas beyond 4 km (2.5 mi). Traffic and human activity were low, again implying a dominant influence of the structures themselves (Vistnes and Nellemann 2001).

From late June through July, sensitivity to disturbance appears to decline as calves mature and are less vulnerable to predation and other sources of mortality. Maternal females are less protective and therefore less reactive to novel stimuli than during the calving period. Also, when insect harassment is high, caribou are less likely to avoid anthropogenic disturbances (Murphy and Lawhead 2000).

Even so, avoidance of transportation corridors can persist through summer. During construction of the Trans-Alaska Pipeline, 1975-1978, calves were increasingly underrepresented among caribou observed from the Dalton Highway; calf percentages, on average, were 69% lower than regional estimates determined by aerial survey. Caribou sightings within, and crossings of, the pipeline corridor in 1976-1978 averaged 30% and 80% less, respectively, than did those in 1975 (Cameron and Whitten 1980, Cameron et al. 1979). Collared males crossed the corridor more frequently than did collared females (Whitten and Cameron 1983). Jakimchuk and colleagues (1987) attributed those observations to sex differences in habitat use, arguing that maternal females avoid riparian habitats to reduce the risk of predation by grizzly bears along the Sagavanirktok River, which is adjacent to the pipeline corridor. A reexamination of the data, however, revealed that bull numbers were high and calf numbers were low only within riparian areas associated with the corridor (Whitten and Cameron 1986). Young and McCabe (1998) reported neither avoidance of riparian habitats by PCH females nor selection of those habitats by bears; they also rejected the antipredator explanation.

Similar avoidance was observed within the KDA, during placement of the smaller Kuparuk pipeline along the Spine Road and during construction of the first processing facility. Calves were underrepresented in groups observed in areas of heavy construction and traffic (Smith et al. 1994).

Within the CAH summer range, crossing success[2] varies with design and juxtaposition of roads and pipelines, as well as with the amount of vehicular traffic. Most early pipelines in the Prudhoe Bay oil-field complex (PBOC) were constructed 1 m or less above ground, posing physical barriers to movement (Shideler 1986). Gravel ramps were placed over some low pipelines to encourage crossings, but anecdotal observations indicated that caribou made limited use of those structures. In the adjacent KDA, however, all pipelines were elevated at least 1.5 m (5 ft), and ramps were built at road intersections. Curatolo and Murphy (1986) reported no selection for particular surface-to-pipe clearances within the range of 1.5-4.3 m (5-14.1 ft), indicating that, under most conditions, the regulatory standard of 1.5 m (5 ft) is sufficient for caribou crossings (Cronin et al. 1994, Curatolo and Murphy 1986). However, crossing success at elevated pipelines close to roads with traffic was lower than for pipelines without associated roads and traffic (Curatolo and Murphy 1986). Large mosquito-harassed groups had particular difficulty negotiating road-pipeline corridors (Child 1974; Curatolo and Murphy 1986; Fancy 1983; Smith and Cameron 1985a,b). Crossing success appears to increase during the oestrid fly season, but it is unclear whether that is attributable to the presence of smaller groups or to different reactions to the two insect pests (Smith and Cameron 1985a). Under some circumstances, ramps enhance pipeline crossings (Child 1973, Cronin et al. 1994, Curatolo and Murphy 1986, Shideler 1986, Smith and Cameron 1985b).

Effects on caribou activity near road-pipeline corridors are most pronounced when there is no insect harassment. During insect-free periods, maternal and nonmaternal groups within 600 m (2,000 ft) of a corridor with traffic spent less time lying and more time moving than did controls. Maternal groups and groups of more than 10 individuals were most reactive to disturbance (Murphy 1988, Murphy and Curatolo 1987).

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[2] Curatolo and Murphy (1986) considered a crossing successful when more than half of an observed group crossed a road and/or pipeline (or a hypothetical pipeline in a control site). Success was then expressed as a percentage which was evaluated statistically by comparison with the corresponding "expected" percentage obtained from the control site.

From autumn through early spring, the CAH has considerably less contact with industrial development. By the autumn rut, most of the herd has moved well inland (Cameron and Whitten 1979a). Only those few caribou that winter on the coastal plain are likely to interact with oil fields, and the effects appear to be minor. However, females with calves avoided inland portions of the Trans-Alaska Pipeline corridor during its construction. Calf percentage for caribou near the Dalton Highway was approximately representative of regional percentages in 1975, but diverged during 1976-1978, averaging 32% less than regional estimates. Sighting frequency declined about 60%, relative to the 1975 estimate, but crossing rates were inconsistent (Cameron and Whitten 1980, Cameron et al. 1979). Overall, avoidance of the pipeline corridor by females with calves decreased measurably between summer and autumn, correlated with the advanced age of the calves and distractions of the rut. Habituation to construction activity is also a possibility.

Oil-Field Complexes

Given that calving caribou avoid roads and pipelines (Cameron et al. 1992, Dau and Cameron 1986), their densities should be reduced in areas with corridors closer together than some minimum distance. In fact, the proportion of calving caribou in the densely developed western portion of the KDA declined significantly from 1979 through 1987 (Cameron et al. 1992). Concentrated calving activity shifted inland from the Milne Point area beginning about 1987 (Lawhead et al. 1993, 2002; Murphy and Lawhead 2000; Wolfe 2000), associated with the increasing density of oil-field infrastructure. Caribou did not abandon the area near Milne Point (Lawhead et al. 2002, Nellemann and Cameron 1996), but continued to occupy the KDA in numbers consistent with the amount of undisturbed habitat. Other explanations advanced for the inland shift west of the Sagavanirktok River include expansion of the calving ground with increasing herd size, changing vegetation characteristics, and parasite avoidance (Lawhead et al. 2002). One or more of these factors could have accelerated that process. However, none explains the absence of a similar shift by the undisturbed part of the caribou herd east of the Sagavanirktok River (Wolfe 2000).

During the summer insect season, dense surface development within the PBOC also altered the distribution of caribou, especially females with calves. As early as 1978, mean calf percentage in the core area of the industrial complex was less than half the minimum regional estimate (Smith and Cameron 1983). With continued growth of the complex, changes in caribou distribution became even more pronounced. An analysis of more than 1,200 point locations of 141 radio-collared females (Cameron et al. 1995) suggests that caribou use of the area has declined substantially from that noted by Child (1973), White and colleagues (1975), and Gavin (1978). From 1980 through 1993, abundance within and east-west movements through the area were lower than for other areas along the arctic coast. Conservative calculations yielded an estimated 78% decrease in use and a 90% decrease in lateral movements.

Other researchers (Cronin et al. 1998, Pollard et al. 1996a) concluded that the PBOC infrastructure has had little effect on the midsummer distribution of caribou. However, the studies lack important data needed to support that conclusion. Without spatial controls—undeveloped areas—they lacked the ability to compare the distribution of cows with calves in the field as a whole with that in either the denser central area or in the less-developed areas to the northwest. Many caribou, including some females and calves, do periodically use the

PBOC, particularly the less-developed northwestern areas (Murphy and Lawhead 2000, Ballard et al. 2000). Moreover, data reported by Pollard and colleagues (1996a) indicate that caribou were numerous in the PBOC only during periods of moderate or high insect harassment and that females with calves generally were underrepresented. These latter data and evidence for reduced abundance and movements of females with the complex (Smith and Cameron 1983, Cameron et al. 1995) indicate that patterns of caribou use have been appreciably altered.

Changes in Habitat Use

Ecological theory and data support the premise that animals generally select the best available areas for reproductive activity. For calving CAH caribou, the probable consequence of disturbance-induced changes in distribution is selection of lower-quality habitats. The number of caribou affected is directly related to the area and intensity of disturbance, which could range from the localized avoidance of an isolated road to a regional shift of large calving concentrations away from areas occupied by multiple oil field complexes. With the gradual loss of access to preferred foraging habitats, increasingly more females seek "next best" available areas. As those areas become insufficient to accommodate the population, use declines at a rate proportional to the increase in density of structures (Nellemann and Cameron 1998, UNEP 2001).

The shift in calving activity west of the Sagavanirktok River might have increased predation risk, particularly in recent years. Since at least 1995, the inland calving concentration west of the river has overlapped extensively with relatively high densities of brown bears (R. Shideler, unpublished data). However, estimates of calf survival during 1988-2001 were similar west and east of the river (84% and 88%, respectively; $P = 0.426$) (Table 8-1), implying that any increase in mortality attributable to predation was compensatory (that is, predation on calves predisposed to die from other causes).

Oil-field infrastructure also can delay or prevent access to insect-relief areas and foraging habitats. In the KDA, the lower success of or delays in crossing road-pipeline corridors by large insect-harassed groups of caribou (Curatolo and Murphy 1986, Murphy 1988, Murphy and Curatolo 1987, Smith and Cameron 1985b) apparently encouraged a general shift to peripheral areas of the complex with less surface development and human activity. Routes of movement within and through the KDA are now primarily in the Oliktok Point/CPF-3 area and along the Kuparuk floodplain (Smith et al. 1994). This shift suggests that caribou were impeded in their efforts to move between coastal and inland habitats.

Much of the PBOC poses a behavioral, if not a physical, barrier to movement of adult females at times (Cameron et al. 1995, Whitten and Cameron 1983). Radio-collared females were scarce in the most densely built (and oldest) part of the complex (Figures 8-4 and 8-5), especially when insects were relatively inactive. During periods of moderate to high insect activity, caribou south of the complex often divert eastward, into the prevailing northeasterly winds, to the Sagavanirktok River and move downstream to the coast (Lawhead et al. 1993). Alternatively, caribou might occupy gravel pads for insect relief (Noel et al. 1998, Pollard et al. 1996b, Truett et al. 1994) when other habitats are unavailable (Wolfe 2000).

Table 8-1 Parturition rates of radiocollared female caribou[a] and summer survival of their calves, west and east of the Sagavanirktok River[b], during 1988-1994[c] and 1998-2001[d]. Central Arctic Herd, Alaska.

	Parturition rate, %[e] (*n*)			Calf survival, %[f] (*n*)		
Years(s)	West	East	P[g]	West	East	P[g]
1988	72.7 (11)	100.0 (8)		66.7 (6)	100.0 (6)	
1989	53.8 (13)	77.8 (9)		83.3 (6)	60.0 (5)	
1990	83.3 (12)	100.0 (7)		85.7 (7)	60.0 (5)	
1991	45.5 (11)	75.0 (12)				
1992	72.7 (11)	75.0 (12)		87.5 (8)	100.0 (9)	
1993	55.6 (9)	62.5 (8)		100.0 (5)	100.0 (5)	
1994	66.7 (6)	87.5 (8)		75.0 (4)	85.7 (7)	
1988-1994	64.3 ± 5.0	82.5 ± 5.3	0.003	83.0 ± 4.6	84.3 ± 8.0	0.898
1998	92.3 (13)	100.0 (6)		90.9 (11)	100.0 (6)	
1999	100.0 (13)	100.0 (8)		88.8 (9)	100.0 (8)	
2000	83.3 (12)	90.0 (10)		77.8 (9)	77.8 (9)	
2001	90.9 (11)	100.0 (7)		80.0 (10)	100.0 (5)	
1998-2001	91.6 ± 3.4	97.5 ± 2.5	0.062	84.4 ± 3.2	94.4 ± 5.5	0.091
All years	74.3 ± 5.3	88.0 ± 4.1	0.001	83.6 ± 2.9	88.4 ± 5.3	0.426

[a] All sexually-mature.
[b] Individual locations consistently west (oil field development present) or east (no surface development, except for the Badami pipeline and oil field beginning in 1996) during the calving period.
[c] Forty-three females observed for 2-7 years (Cameron 1995; Cameron et al. 2002).
[d] Twenty-nine females observed for 2-4 years (Lenart, ADF&G, unpublished data, 2002).
[e] Based on parturition status determined by fixed-wing aircraft (Cameron et al. 1993).
[f] Percentage of parturient females with calf at heel 2-6 weeks postpartum.
[g] *t*-test, paired comparisons. Mean and standard errors shown.

Changes in distribution and movements during calving and when insects are present reduce the capacity of the range to support CAH caribou. This is due to loss of preferred habitats (Cameron et al. 1995, Wolfe 2000) and through correspondingly greater use of lower-quality habitats (Klein 1973, Nellemann and Cameron 1996, Wolfe 2000).

Nutrition and Reproductive Implications

The reproductive success of arctic female caribou is highly correlated with their nutritional status. Parturition rate varies directly with body weight or fat content during the previous autumn (Cameron and Ver Hoef 1994; Cameron et al. 1993, 2000; Gerhart et al. 1997a), whereas calving date and survival within about 48 h after birth are more closely related to maternal weight at the time of parturition (Cameron et al. 1993).

Those relationships form the link between the disturbance-induced changes in distribution described above and potential changes in reproductive success. Wolfe (2000) studied 96 radiocollared females at 183 calving sites from 1980-1995. Concentrated calving areas west of the Sagavanirktok River (closer to areas of petroleum activity) shifted inland away

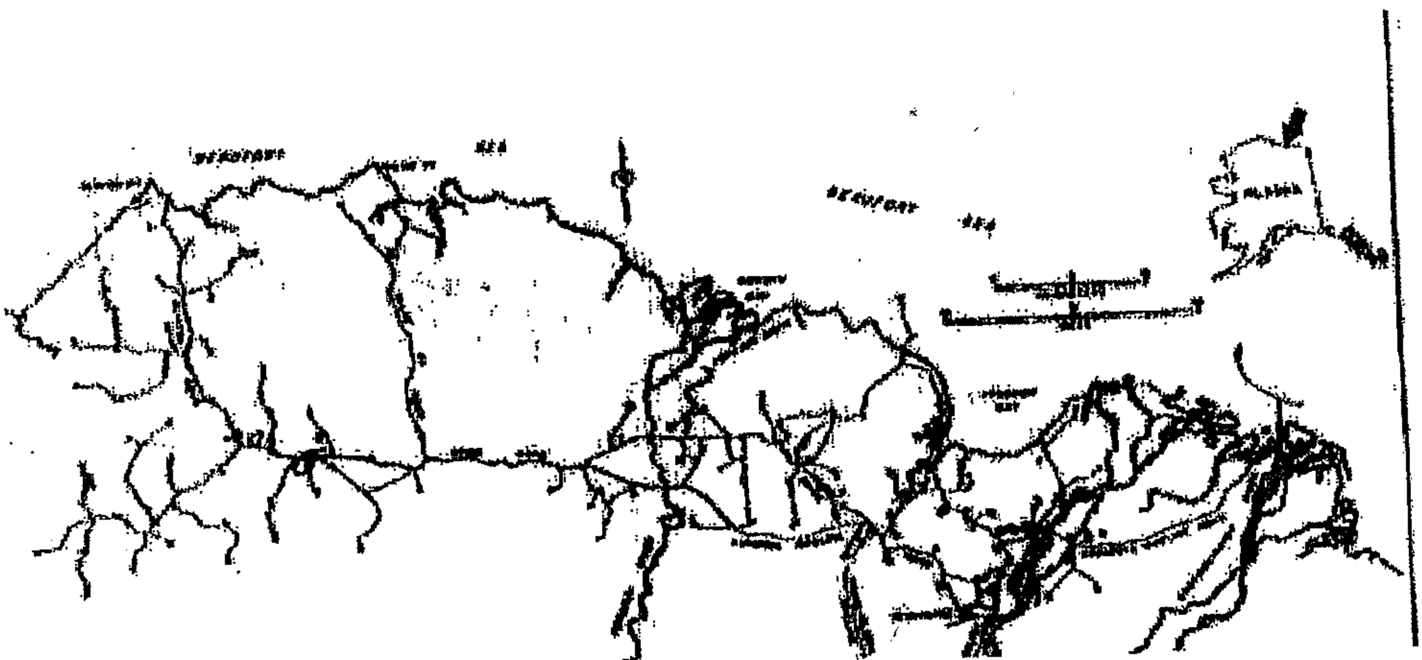

FIGURE 8-4. Roads and pipelines in the Prudhoe Bay region, Alaska, ca. 1990. Note: One or more pipelines (stippled) are adjacent to most roads. Source: Cameron et al. 1995.

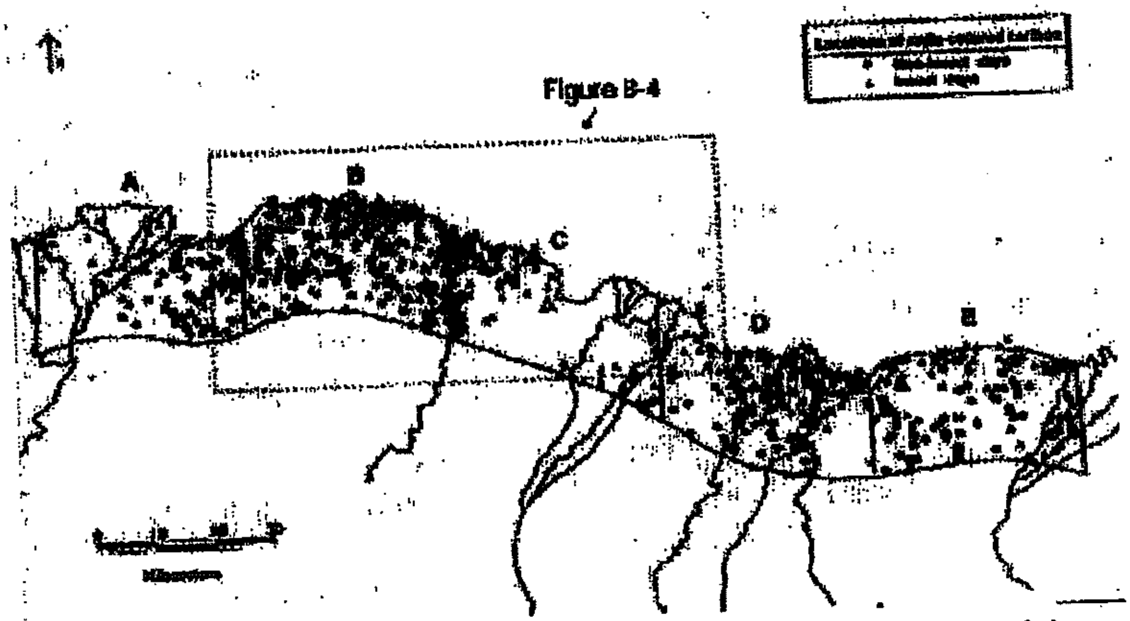

FIGURE 8-5. Locations of radiocollared female caribou within 850-km² coastal quadrants in relation to insect activity. Central Arctic Herd, Alaska, summer 1980-1993. Note: Some points represent >1 female in a single group. Source: Cameron et al. 1995.

from development into habitats with lower green-plant biomass.[3] On the east side of the river, an area without development, no such shift in calving was observed: Females selected habitats with above-average green-plant biomass (Wolfe 2000). For the PCH, calf survival through their first few weeks is primarily a function of the relative amount of forage available on the annual calving ground during the peak lactation period (Griffith et al. 2000a, 2002). However, survival estimates (Table 8-1) and Wolfe's (2000) NDVI data do not suggest such a relationship for the CAH, but sample sizes are small.

Impaired movements during the insect season also could decrease energy balance (Murphy and Lawhead 2000, Russell 1976, Russell et al. 1993, Smith 1996, Weladji et al. 2002, White et al. 1975) and hence reduce rates of summer weight gain. However, changed activity patterns of caribou near transportation corridors (Murphy 1988, Murphy and Curatolo 1987) might not reduce weight gain enough to depress parturition rates (Murphy et al. 2000). Nevertheless, individual or collective conflicts that result in nutrient insufficiency can decrease fecundity.

In fact, from 1988-1994, the mean parturition rate for radio-collared females west of the Sagavanirktok River was 64%, compared with 83% for those east of the river ($P = 0.003$). Parturition rates were similar from 1998 through 2001 (92% and 98%, respectively; $P = 0.062$), but differed for the eleven years overall (74% and 88%, respectively; $P = 0.001$) (Table 8-1). Estimated frequencies of reproductive pauses (periodic failure to produce a calf because of poor condition at breeding) (Cameron 1994, Cameron and Ver Hoef 1994) for the combined data were 26% and 12%, or approximately one pause every 4 and 8 years, respectively.

This longitudinal analysis provides a reliable assessment of difference in reproductive success. Because radio-collared females were used, interannual shifts of individual females between areas west and east of the Sagavanirktok River (Cronin et al. 2000; Lawhead and Curatolo 1984, cited in Murphy and Lawhead 2000; Whitten and Cameron 1984) could be detected and samples adjusted accordingly, yielding multiyear histories of females that had consistent use of the two areas.

Lower fecundity of females west of the river could be due to inadequate compensation for milk production (Cameron and White 1992). By reducing rates of forage intake or increasing rates of energy expenditure, conflicts during the calving and insect periods might diminish chances of achieving the weight gain required to support annual reproduction (Cameron and White 1992, Russell et al. 2000). In general agreement are anecdotal reports from Nuiqsut residents that caribou taken recently have been leaner than in years past (Miller 2001, Pedersen et al. in press).

Population Dynamics

Observed changes in the size of the CAH (Figure 8-6) are correlated with estimates of net calf production—the product of parturition rate and calf survival. From 1978 through 1983, when the herd increased, on average, 16% annually, net calf production exceeded 90%. The next census was not done until 1992, so the trajectory in herd size during the intervening period is not known; but the steady decrease in net calf production implies a deceleration of growth though the early 1990s. Between 1992 and 1995, years with consistently low productivity, the

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[3] The actual measurement was a Normalized Difference Vegetation Index (NDVI), which measures the amount of land-cover greenness. The NDVI value can vary with species composition and other factors (Jia et al. 2002).

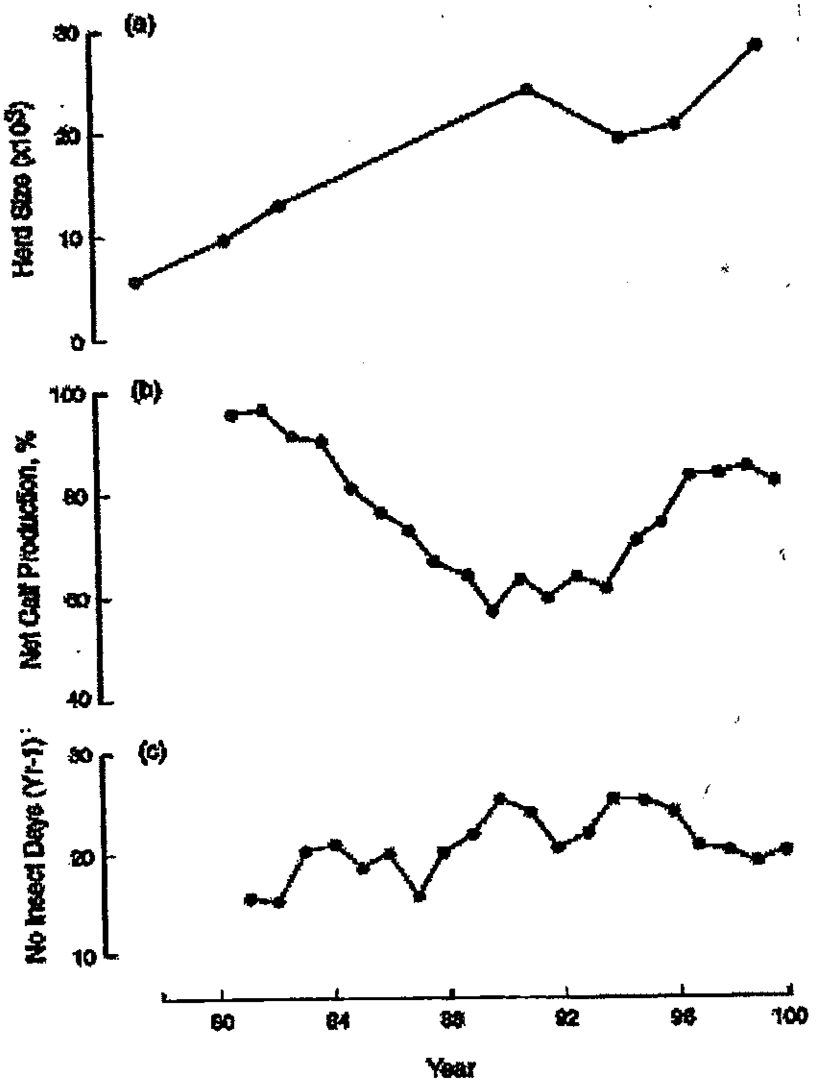

FIGURE 8-6. Central Arctic Herd in Alaska. (a) Herd size, 1978-2000. Point estimates determined by photo-census. (b) Net calf production. Three-year moving averages of radio-collared female caribou, 1981-2000, Lenart 2001, ADF&G files. Percentage of parturient females with a calf at heel ca. 2-8 weeks postpartum; approximate equivalent of the product of parturition rate and over-summer calf survival (see Table 8-1). (c) Number of insect days in July. Three-year moving averages, 1980-1999. Weather data for Deadhorse Airport, Alaska State Climate Center, UAA applied to the predictive models of Russell et al. 1993; criteria for insect days from Cameron et al. 1995.

CAH actually declined by about 8% per year. From 1995 until the census in 2000, the herd increased 14-15% annually, correlated with a sustained increase in net calf production.

Net calf production is affected by factors that influence acquisition and retention of nutrients. An important factor is insect activity. From 1981 through 2000, net calf production was inversely correlated with the number of days of high insect activity in July of the previous year (Figure 8-7) (Spearman's rank, $P = 0.012$). A lower frequency of insect-induced movements and insect avoidance behavior enable caribou to spend more time in high-quality habitats, thereby increasing chances that they will eat enough to produce milk. Maternal females would then experience greater weight gain, superior condition at breeding, and a higher probability of producing a calf the following spring.

Because parturition rate accounts for most of the variability in net calf production (Table 8-1), the committee focused on differences in parturition rate that might be related to level of insect activity. Dividing the 11 paired estimates of parturition rate west and east of the Sagavanirktok River into (previous) years of low and high insect activity yielded significant differences within each category ($P = 0.043$ and $P = 0.004$, respectively; Figure 8-7). When insects were relatively inactive, mean parturition rate of females west of the River was only about 10% lower than for those to the east. Following years of relatively high insect activity, however, the reduction was more than 25%.

Thus, oil-field development, by delaying or deflecting movements of caribou within and between habitats (Murphy and Lawhead 2000, Smith and Cameron 1985, Smith 1994), probably exacerbates the adverse effects of insect harassment. If the ability to forage or escape insects is sufficiently reduced, nutrition and fecundity will decline, with direct consequences for herd growth. Indeed, decreasing herd size in 1992 to 1995 (Figure 8-6) was associated with relatively high insect activity (2 of 3 years, 1992-1994). The subsequent trend of increasing size from 1996 through 2000 occurred during a period of generally low insect activity (3 of 5 years, 1995-1999).

Net growth of the CAH over the past 25 years is not, by itself, sufficient evidence for the absence of any adverse effect of petroleum development on caribou (WMI 1991). We cannot know what the growth trajectory of the herd would have been in the absence of oil-field development. However, multiyear data on the reproductive performance of collared CAH females exposed to oil-field development, relative to an undisturbed control group, indicate that productivity did decline when the attendant disturbance and habitat losses were superimposed on other conditions that adversely affected nutrient balance. Interestingly, these changes occurred during a period in which the growth rate of the CAH decreased relative to that of the similar TLH (Figure 8-3).

Future Effects

The results of the committee's analysis of the consequences of petroleum-related disturbance to CAH caribou provide a basis for assessing the probable future effects on the CAH and other arctic herds of the likely expansion of oil and gas development over the next 25 years eastward on state lands from the Badami unit, southward into the foothills of the central Brooks Range, and westward into the National Petroleum Reserve-Alaska from the Alpine unit. Unless the density of new access roads and new production and support facilities can be substantially reduced relative to infrastructure now in place, conflicts with CAH caribou east of the

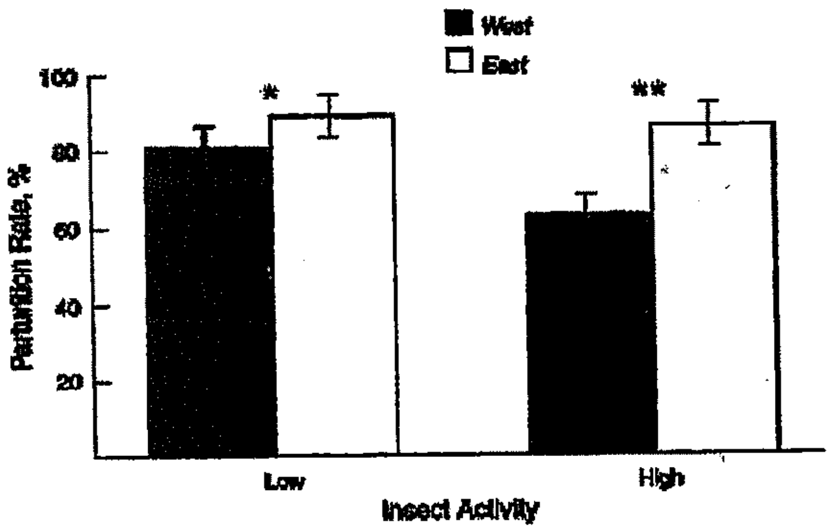

FIGURE 8-7. Parturition rates of 72 radio-collared female caribou of the Central Arctic Herd in Alaska west and east of the Sagavanirktok River, 1988-2001, following years of low and high insect activity. Determined, respectively, as the number of insect days below and above the median of 20.5 days (range, 15-27) for 1987-2000 (see Fig. 8-5 legend). *$P = 0.043$, paired t-test. **$P = 0.004$, paired t-test.

Sagavanirktok River will increase during the calving and insect-harassment periods. Higher insect activity associated with climate warming could counteract benefits of reduced surface development by increasing the frequency with which caribou encounter infrastructure (Klein 1999). With inland expansion, more of the CAH will come into contact with development on this winter range, with unknown consequences. If the calving ground of the TLH continues to be protected, direct conflicts with parturient females of that herd are unlikely, provided that their movements are not impeded. However if inland lease tracts in the northeastern portion of the National Petroleum Reserve-Alaska are developed, effects on midsummer distribution, habitat use, and productivity of TLH caribou are possible. The exact outcome and the degree to which these effects would accumulate depend on a host of unknowns, including characteristics of the oil and gas reservoir and advances in extraction technology. Within the next 25 years, major expansion of industrial activity into the WAH calving ground is unlikely, and inroads to its primary summer range are expected to be modest. If so, effects should be minor and not accumulate significantly.

If a proposed road north of the Red Dog mine to a North Slope site of a coal-fired power plant were constructed, it would cross a major east-west zone of travel, possibly interfering with insect-induced movements. A road would also open the region to further development.

To date, oil and gas activities have had little influence on the Porcupine Herd, but petroleum exploration and subsequent development on the coastal plain (1002 Area) of the Arctic National Wildlife Refuge could lead to development on the calving ground of that herd. To assess the potential effects of such developments on the PCH, Griffith and colleagues (2002) combined pertinent information on the CAH with the extensive data on the PCH. They simulated the effects of progressive development of the 1002 Area by displacing 17 annual calving grounds, between 1985 and 2001, using five scenarios (Clough et al. 1987). The concentrated calving area within each annual calving ground was repositioned 4 km (2.5 mi) from the periphery of industrial infrastructure. June calf survival was then calculated for each annual calving ground observed and for those hypothetically displaced, using a predictive model based on forage biomass during peak lactation and predation risk. A significant ($P < 0.0001$) inverse relationship was obtained between change in calf survival and displacement distance, even though calving still remained primarily on the coastal plain where habitat was good for foraging and predator avoidance. The results of these simulations suggest that an average displacement of approximately 27 km (17 mi) would be sufficient to halt growth of the PCH.

Consequences similar to those reported for the CAH are possible on PCH summer range, depending upon the extent and intensity of surface development. Impaired movements during years of high insect activity could reduce weight gain of lactating females, with comparable effects on fecundity (Figure 8-7). If superimposed on reduced calf survival (Griffith et al. 2002), the additive effects on PCH productivity could be substantial.

The PCH has the lowest growth capacity of the four arctic herds and, consequently, the least capacity to resist natural and anthropogenic stresses (Griffith et al. 2002). That vulnerability is, in part, attributable to the critical importance during calving of free access to the highest quality foraging and predator-avoidance habitats and to a lack of suitable alternative habitats (Griffith et al. 2002).

It is impossible to characterize future development infrastructure and activity in areas that have not been fully explored. Until exploration has occurred, the amount, distribution, and exact nature of any extractable hydrocarbon deposits remain unknown. But the amount, distribution, and type of hydrocarbon deposits profoundly influence the nature and extent of development infrastructure, thus how many roads and pipelines will be needed, and how much activity will occur and when it will occur. Current technology will probably continue to evolve, as discussed elsewhere in this report, but adverse effects on caribou are likely to increase with both the density of infrastructure development and the area over which it is spread.

Findings

- The intensively developed part of the PBOC has altered the distribution of female caribou during the summer insect season. Elsewhere, a network of roads, pipelines, and facilities has interfered with their movements between coastal insect-relief and inland feeding areas. Possible consequences of these disturbances include reduced nutrient acquisition and retention throughout the calving and midsummer periods, poorer condition in autumn, and a lowered probability of producing a calf in the following spring.
- Pregnancy rates and survival of young caribou during their first summer is positively correlated with the availability of food. Insect harassment reduced nutrient-intake rates by females of the CAH as the animals moved to habitats where they could avoid insects but where they foraged less efficiently. Radio-collared female caribou west of the Sagavanirktok River shifted their main calving area from developed areas nearer the coast to undeveloped areas inland. No such shift has occurred for caribou calving east of the Sagavanirktok River where there is no development. The shift by caribou west of the Sagavanirktok River was into an area with lower green-plant biomass than the area previously used. From 1988 to 1994, parturition rates of radio-collared females in regular contact with oil-field infrastructure west of the Sagavanirktok River were lower than those of undisturbed females to the east. Reduction in parturition rates—the variable part of net calf production—for those caribou was exacerbated by intense insect harassment during the period. Thus, it appears that the effects of oil-field development accumulate with effects of insect harassment by impairing movements between coastal and inland habitats.
- As a result of conflicts with industrial activity during calving and an interaction of disturbance with the stress of summer insect harassment, reproductive success of Central Arctic Herd female caribou in contact with oil development from 1988 through 2001 was lower than for undisturbed females, contributing to an overall reduction in herd productivity. The decrease in herd size between 1992 and 1995 may reflect the additive effects of surface development and relatively high insect activity, in contrast to an increase in the herd's size from 1995 through 2000, when insect activity was generally low.
- For the females of the CAH west of the Sagavanirktok River, avoidance of expanding infrastructure in the region triggered changes in distribution, progressing from localized adjustments to major shifts in the use of calving and summer habitats. Expanded loss of preferred habitats, which could accompany the spread of industrial activity across the National Petroleum Reserve-Alaska and into the foothills of the Brooks Range, and climate change that increases insect harassment, are likely to depress nutrient status and, therefore, summer weight gain of lactating females.
- Unless future requirements for infrastructure can be greatly reduced, exploitation of oil and gas reserves within the calving and summer ranges of the CAH, TLH, and PCH will likely have similar consequences.

Recommendations

- Determine the responses of caribou to seismic testing under different snow conditions and estimate the probable consequences in terms of energy intake and nutrient balance and reproductive success.
- Determine the minimum distance between road-pipeline corridors that is compatible with continued use of an area by calving caribou and how design of corridors influences those effective distances.
- Studies are needed to characterize the nutrient-energy tradeoffs associated with insect-induced movements; quantify the conditions of nutrient intake and body condition associated with each of the various weaning decisions (tradeoffs) made by maternal females; and within known levels of exposure to disturbance, determine the over-summer nutritional performance of females and their calves.
- Determine whether winter calf mortality is additive or compensatory, relative to early postnatal mortality; that is, do those that survive unfavorable foraging conditions in spring or summer die during the winter anyhow?

MUSKOXEN

Muskoxen (*Ovibos moschatus*), which were exterminated from Alaska, have been reintroduced and are now found at low densities on the North Slope, mostly in riparian areas. Populations are expanding into other habitats. Helicopters and low-flying aircraft sometimes cause muskoxen to stampede and abandon their calves (Winters and Shideler 1990). Seismic exploration is of concern because muskoxen are present year-round on the North Slope. The response to the noise of seismic exploration appears to differ from herd to herd, perhaps because of each herd's previous experience. Some seem unaffected by seismic activities as close as 300 m (980 ft); others appear disturbed by activity 10 times more distant (Winters and Shideler 1990). Therefore, although no adverse effects have been recorded to date, the expansion of 3-D seismic exploration to primarily unsurveyed areas, particularly in riparian areas, could result in increased disturbance to this species.

Finding

No effects of seismic exploration on muskoxen have been detected to date. However, the expansion of 3-D seismic exploration to new areas, particularly in riparian areas, might increase disturbance to this species.

ARCTIC FOXES

Past and current industrial activities on the North Slope have probably increased the availability of shelter and food for the arctic fox (*Alopex lagopus*). Developed sites within the Prudhoe Bay oil field are used by foxes for foraging on garbage and handouts, and for resting.