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A Literature Review and Synthesis on the Effect of Pipeline Height on Caribou Crossing Success

Brian E. Lawhead, Julie P. Parrett, Alexander K. Prichard, and David A. Yokel

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Cover Photo

Caribou graze near elevated pipelines in the Kuparuk Oilfield, northern Alaska, after reaching coastal mosquito-relief habitat on 10 July 2002. Photo by Brian Lawhead, ABR, Inc.

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ABSTRACT

The effects of elevated pipelines on the movements of caribou (*Rangifer tarandus*) in Alaska have been studied since the late 1960s. The recent expansion of oil development west of the Kuparuk Oilfield raised the issue of pipeline height to prominence for local residents of Nuiqsut and other North Slope villages and prompted this review of the literature. Linear infrastructure such as pipeline/road corridors can act as obstructions that impede caribou movements but do not act as complete barriers unless they are physically impassable, such as large-diameter pipelines on or near the ground. Most of the pipelines in the Prudhoe Bay Oilfield were constructed in the 1970s before the minimum height of 1.5 m (5 ft) above ground level was stipulated by the State of Alaska. Older pipelines elevated 0.4–1.1 m above ground level in the Prudhoe Bay field constitute barriers to caribou crossings in the absence of crossing ramps. The available data on pipe-height selection by caribou demonstrate that pipelines elevated to the minimum height of 1.5 m are high enough to accommodate crossings by caribou during snow-free periods. The limited data on pipeline crossings by caribou in winter indicate that pipeline heights in the range of 2.1–2.5 m (7–8 ft) are more likely to be used by caribou than are lower heights. Because of a tendency for more snow to accumulate beneath lower pipe, elevating pipelines higher than 1.5 m will decrease the risk of reduced clearance between the snow surface and the bottom of pipelines, especially in severe winters. Research in northern Alaska oilfields has confirmed that the most important factor affecting caribou crossing success at pipeline/road corridors is traffic on nearby roads. The combination of high-traffic roads (15 or more vehicles/hr) adjacent to pipelines elevated to the minimum height of 1.5 m created a synergistic effect that reduced caribou crossing success. Hence, to be as effective as possible, elevated pipelines should be separated at or beyond the recommended minimum distances of 122–152 m (400–500 ft) from roads. Separating roads from pipelines also achieves the important purpose of eliminating snow drifts under pipelines next to roads. In addition to traffic, other factors that confound evaluation of pipeline-crossing success by caribou include differences in infrastructure and study design, caribou group dynamics, insect harassment, season, habitat, topography, and habituation. Needs for further information regarding the effects of pipeline characteristics on caribou crossing success include the adequacy of 1.5-m-high pipelines in winter (to supplement the scant data available); the effects of habituation; the effects of reflectivity of pipeline sheathing and other potentially confounding factors not yet investigated, such as auditory and chemical stimuli; and the adequacy of the 1.5-m minimum height for crossings by subsistence users on snowmobiles.

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INTRODUCTION

In the North Slope oilfields of arctic Alaska (Figure 1), the oil carried in pipelines must remain hot to flow properly, both in gathering lines within the oilfields and for transport south through the Trans-Alaska Pipeline System (TAPS). From a practical standpoint, it is impossible to bury hot pipelines in ground containing permafrost because thermal erosion of the ground ice (thermokarst) would soon compromise the stability of the ground and thus of the pipelines. Therefore, pipelines in arctic Alaska typically are insulated and elevated above the surface of the ground on structures consisting of horizontal cross members between metal pilings called vertical support members (VSMs). The most comprehensive compilation of North Slope infrastructure to date listed 724 km (450 mi) of pipeline corridors in the North Slope oilfields as of 2001 (NRC 2003: Appendix E), in addition to the 676 km (420 mi, or 53% of the length) of elevated pipeline along the 1,287-km (800 mi) length of TAPS (BLM 2002).

The potential effects of pipelines on the movements of caribou (*Rangifer tarandus*) in Alaska have been debated since planning began for the development of the North Slope oilfields and TAPS in the late 1960s. The effect of pipeline height on the ability of caribou to cross beneath elevated pipelines was addressed in applied research and impact overviews in the 1970s and 1980s (Child 1973; Cameron and Whitten 1976, 1977, 1978; Klein 1980; Banfield et al. 1981; Eide et al. 1986; Curatolo and Murphy 1986; Shideler 1986; Carruthers and Jakimchuk 1987). Most of the information available up to the early 1990s was summarized in a review of mitigation-related research (Cronin et al. 1994) prepared for the Alaska Caribou Steering Committee, a group comprising representatives from the Alaska Oil and Gas Association (AOGA), the Alaska Department of Fish and Game (ADFG), the U.S. Fish and Wildlife Service, and the North Slope Borough.

By the late 1990s, oil development spread farther westward from the Kuparuk Oilfield to the Alpine Project on the Colville River delta and eastward from the Prudhoe Bay Oilfield to the Badami Project (Figure 1). The expansion of oil development into areas west of the Kuparuk field again raised the issue of pipeline height to prominence, this time for the local residents of Nuiqsut, the Iñupiaq village located nearest to the oilfields (PAI 2001). Public involvement during the North Slope Borough permitting process for construction of Kuparuk Drill Sites 2-P (the "Meltwater" project) and 3-S (the "Palm" project) underscored the concern of local residents about the adequacy of minimum pipeline height stipulations, especially for caribou encountering infrastructure during the winter, when snow accumulates on the ground beneath elevated pipelines, and for local residents traveling by snowmobile. This discussion continues today as oil development expands further from the Alpine project to associated "satellite" developments on the Colville delta and into the Northeast Planning Area of the National Petroleum Reserve–Alaska (NPR-A) (BLM 2004).

The stipulations placed on development of oil and gas leases in the Final Integrated Activity Plan/Environmental Impact Statement (IAP/EIS) for the Northeast Planning Area of NPR-A (BLM 1998) specified that all pipelines would be elevated to a minimum height of 152 cm (5 ft; referred to hereafter as 1.5 m) above the ground surface. More recently, the Record of Decision (ROD) for the Alpine Satellites Development Plan (ASDP) and the Final Amended IAP/EIS for the Northeast Planning Area of NPR-A (BLM 2005) mandated that above-ground pipelines be elevated to a minimum height of 213 cm (7 ft; referred to hereafter as 2.1 m) above ground level, similar to the design used for the Kuparuk DS-2P and DS-3S project pipelines in 2001 and 2002 (see Appendix C, Figure C-1).

This review was undertaken to revisit the issue of pipeline height in relation to caribou crossing success and to assess the applicability of existing information to current questions. Specifically, how much clearance is needed to allow caribou to cross beneath elevated pipelines and how does height influence crossing success? Is 1.5 m of clearance adequate to allow caribou passage throughout the year? The answers to these questions can largely be extracted from a variety of studies conducted over the last three decades. This review focuses specifically on the issue of pipeline height in relation to crossing success, rather than on a broader evaluation of the response of caribou to linear developments, which would encompass a much larger body of literature and was beyond the scope of this review. For more information on the latter question, the reader is referred to other reviews and papers (Shank 1979, Jakimchuk 1980, Smith and Cameron 1985a, Curatolo and Murphy 1986, Shideler 1986, Murphy and Curatolo 1987, WMI 1991, Cronin et al. 1994, Jalkotzy et al. 1997, Murphy and Lawhead 2000, Wolfe et al. 2000, NRC 2003), most of which are included in the annotations prepared for this report. Our review focuses primarily on Alaska, where the bulk of the available information has been gathered, but information from other countries is included where pertinent.

METHODS

Previous reviews of mitigation-related research (Shideler 1986, Cronin et al. 1994) were used as primary resources to identify pertinent references, in addition to a search of ABR's database of caribou literature. An electronic search for published journal articles was conducted using ABR's literature database from Current Contents® for Windows/Macintosh (Thomson Scientific, Philadelphia, PA). We included documents that have been published in the open scientific literature, as well as unpublished literature such as research reports by agency biologists and environmental consultants. Although the unpublished literature has not undergone the full peer-review process of journal publication (and hence is annotated with "no" under the peer-review field in the bibliographic database), it remains the only source of information on certain subjects. Most of the unpublished reports we used are known or presumed to have received some level of internal review by editors and some received outside review by agency biologists or other researchers. Most of the references we reviewed were on file in the ABR library in Fairbanks, and other references were obtained from libraries at the University of Alaska Fairbanks, through interlibrary loan, or through direct contact with other researchers.

Selected references judged to be most relevant to the topic were annotated and submitted to BLM as a searchable database using ProCite® bibliographic software (version 5.0.3; Thomson ResearchSoft, Berkeley, CA), and the database contents are appended to this report (Appendix D). The measurement units used in text are metric (with English equivalents at first use), but the literature annotations list units as reported in the original publication; unit conversions are provided, along with acronyms used in text, in Appendix A.

Selected experts in Alaska, Canada, Scandinavia, and Russia were contacted by telephone or e-mail to ask whether they were aware of any data collected since the review by Cronin et al. (1994) or older data that may never have been analyzed or reported. These contacts are listed at the end of the report (Appendix B).

Data from studies conducted by ABR researchers in the Kuparuk Oilfield (summarized in Curatolo and Murphy 1986) and along the Endicott pipeline/road corridor (Lawhead et al. 1993a) were reviewed to assess whether reanalysis was warranted and feasible. Retrieval and reanalysis of the Kuparuk data sets were beyond the scope of this review. We reanalyzed the Endicott pipe-height selection data using the full data set, which was not available to Cronin et al. (1994) when their review was prepared. Pipeline heights crossed by caribou were compared with pipeline heights available in the Endicott study plots using chi-square goodness-of-fit tests; each pipeline interval between adjacent VSMs was assigned to a height category based on field measurements (Lawhead et al. 1993a). We grouped crossings into the same 5 height categories used by Cronin et al. (1994) (<100, 100–149, 150–199, 200–249, and >249 cm, derived by combining several categories from the 7 original 50-cm categories [Lawhead et al. 1993a]) and compared use to availability for all 3 Endicott study plots over all 4 years combined (1987–1990), for each of the study plots for all years combined, and for each year for all study plots combined. Each distance category was tested for significance using Bonferroni multiple-comparison tests (Neu et al. 1974, Byers et al. 1984). Following Cronin et al. (1994), we also compared use to availability for pipeline heights <150 cm and ≥150 cm, as well as between the 150–199 cm and ≥200 cm height categories.

REVIEW AND SYNTHESIS

Analysis of Crossing Success

A note about terminology is useful to bear in mind when reading the literature on caribou passage across linear corridors. The concept of maintaining "free passage" by caribou across pipeline/road corridors was used widely in impact analysis and mitigation discussions in Alaska in the 1970s and 1980s but was not defined in quantitative terms; the concerns were that caribou movements should not be impaired to a degree at which harmful effects would occur and that areas of important habitat should not become unavailable. In discussing caribou crossings, it is useful to distinguish between a "barrier" effect (implying blockage or prevention of crossings) and an impediment, variously referred to as "obstruction" (Banfield et al. 1981) or a "filter" (Jalkotzy et al. 1997). The latter terms connote permeability rather than complete blockage, and thus are more applicable to caribou movements across linear corridors. The only examples of complete barriers are physically impassable structures such as large-diameter pipelines on or near the ground.

The central difficulty in evaluating crossing success is that the investigator is faced with the problem of determining the "intent" of caribou to cross a linear structure. This evaluation has either compared the frequency of border crossings in treatment plots with those in control (reference) plots, or else has assumed that all animals that pass a certain point or approach within a certain distance of a structure "intend" to cross it. The criteria for defining crossing success have differed somewhat among various studies, in terms of three criteria: approach distance for inclusion in the sample, percentage of caribou crossing, and variable duration of observations (Table 1). When caribou groups are deflected and move parallel to pipelines, they typically do so within 50–250 m (Child 1973, Child and Lent 1973, Johnson and Lawhead 1989), but may subsequently move away farther if they are unsuccessful (Smith and Cameron 1985b). These observations indicate that an approach zone of at least 400 or 500 m should be adequate to evaluate caribou crossing success.

Analysis of crossing success must account for the fact that not all caribou cross completely through study plots, even in the absence of infrastructure. The best data on this topic come from studies that included control plots without any infrastructure. Fancy (1983) found that 9.1% of the animals in his control plot reversed direction or "detoured around" hypothetical structures (located along two of the four borders of his grids). Curatolo and Murphy (1986) found that 34% of the groups in their control plots did not cross the northern borders (representing hypothetical structures), and they used that percentage to estimate the expected number of crossings in their treatment plots. Evaluation of crossing success is complicated by the difficulty in anticipating where (or why) movements will occur and thus in obtaining adequate sample sizes for statistical analysis, especially when attempting to partition samples according to group type (sex/age composition), group size, and insect conditions. Hence, multiple years of study usually are required to produce adequate sample sizes.

Analyses of pipeline crossings by caribou tend to be of two types. The most useful studies compared pipeline heights available in study areas with pipe heights actually used for crossings, using either chi-square tests or nonparametric Mann–Whitney tests. These studies were limited by the range of pipeline heights available and the effect of natural topographic features. Most studies compared crossing success of caribou groups under different conditions (e.g., presence of a road, insect presence, group size, direction of travel) but seldom used pipeline height as a variable directly. Those studies provided useful information on the range of pipeline heights caribou crossed, but seldom provided strong evidence of actual selection for specific pipeline heights. All investigators faced the difficulty of deciding what was available to caribou in their study areas, but no universal method was used to address this difficulty.

The literature on caribou crossings of elevated pipelines is predominantly based on observational studies of caribou crossing under existing pipelines; only a few involved experimental studies of simulated pipelines. Because experimental studies were primarily conducted on low-elevation simulated pipelines with caribou or

Table 1. Study design criteria used to evaluate crossing success of caribou groups encountering pipeline/road corridors in the Prudhoe Bay and Kuparuk oilfields, northern Alaska.

Citations	Road Survey or Plot (km²)	Approach Distance (m)[a]	Percentage of Group Crossing[b]	Duration of Observations
Child 1973	Plot (unknown)	Unknown	100%	Unknown
Fancy 1982, 1983	Plot (9.0)	500	>50%	Group exited plot
Curatolo & Murphy 1983, 1986	Plot (1.8–2.8)	800–1,000	>50%	Group exited plot
Reges & Curatolo 1985	Plot (1.6)	200	>50%	Group exited plot
Curatolo & Reges 1986	Plot (0.3–2.7)	Variable[c]	>50%	Group exited plot
Johnson & Lawhead 1989	Road	0[d]	>50%	Focal group could not be followed farther
Lawhead et al. 1993a	Plot (1.3) & road	400	>50%	Group exited plot, or group crossed or retreated from road
Smith and Cameron 1985a; Smith et al. 1994	Road	Unknown	100%	Group crossed or retreated
Coltrane & Lanctot 2000	Plot (0.8)	500	>50%	Group exited plot

[a] Basis for calculating percentage crossing.

[b] Percentage of group crossing to be considered successful; actual percentage of total caribou individuals crossing usually was reported also.

[c] Depended on plot dimensions.

[d] Crossing success was calculated only for groups in which at least 1 caribou crossed.

reindeer, they did not directly address the minimum height needed for caribou to cross consistently under a pipeline. Observational studies of caribou and pipelines have several limitations. The pipeline height is often correlated with topographic features; river beds tend to have high pipeline heights while ridge tops tend to have lower pipeline heights. Therefore, it is difficult to differentiate between the effects of pipeline height and the influence of existing natural movement corridors. In addition, most areas have a limited range of pipeline heights available; most observational studies on the North Slope of Alaska were conducted in areas with a minimum pipeline height of 1.5 m (5 ft).

Study plot sizes differed among studies, ranging from as small as 0.3 km^2 to as large as 9 km^2; most were in the 1–3-km^2 range (Table 1). Fancy (1983), Murphy (1984), and Murphy and Curatolo (1984) used two observers in different locations to cover their plots adequately, whereas the other studies used a single observer for each plot. Larger study plots are more likely to be entered by caribou and crossings are more likely to be recorded in large plots, but the selection of plot size must balance the need to obtain adequate sample sizes with the need to see all parts of the plot well with the personnel available and to coordinate observations and data collection among multiple observers.

An alternative approach to measuring crossing success used road surveys that did not rely on study plots but instead covered specific stretches of road repeatedly, up to several times a day (Smith and Cameron 1985a, Lawhead et al. 1993a, Smith et al. 1994). Lawhead et al. (1993a) collected data using both plot and road methods and found that crossing success calculated from road surveys tended to be higher than from study plots, as would be expected when groups could be followed for longer distances outside plot borders, but the differences were not significant. Biased results could result from road surveys, however, if the observer departed before crossing events ended (Smith and Cameron 1985a, Lawhead et al. 1993a).

Some researchers have disagreed about the use of groups versus individual caribou as sample units for statistical analyses (Whitten and Cameron 1986). Although using groups as a sample unit has the disadvantage of weighting small groups and large groups equally, it is clearly inappropriate to treat the individuals composing a group as independent data points in a chi-square test or other simple statistical test. Lawhead et al. (1993a: Figure 3-7) found strong cohesion among groups; that is, all or nearly all group members either crossed or failed in most crossing attempts. The presentation of percentages based both on groups and on the number of caribou in those groups was more useful in examining crossing success than was using either measure alone. Percentages based on numbers of individual caribou within groups provide useful information when presented as descriptive statistics, but use/availability analysis of crossing locations should be conducted using groups to avoid problems caused by lack of independence among group members.

Pipeline Height

Because the height of elevated pipeline is the central focus of this review, we describe here the major findings concerning caribou responses and crossing success for pipelines below and above the minimum height of 1.5 m stipulated by the State of Alaska for above-ground pipelines in caribou range. It is important to understand that this height stipulation results in average heights that exceed 1.5 m. For instance, the average heights of pipeline in three plots studied by Curatolo and Murphy (1986: Table 3) were 182, 186, and 261 cm, and the overall range among all three plots was 119–432 cm (pipe below 1.5 m occurred in short sections immediately adjacent to crossing ramps, which are short buried sections of pipe).

The reports and studies that address this topic can be divided roughly into three categories: (1) studies that specifically evaluated pipeline height at locations (VSM intervals) crossed by caribou in relation to availability; (2) studies of crossing success that did not evaluate pipeline height but that occurred in areas where the minimum design height of 1.5 m applied; and (3) reviews that discuss pipeline height as a factor affecting crossing success but draw on the information presented in the first two categories above (e.g., Thompson et al. 1978, Shideler 1986, Cronin et al. 1994, Jalkotzy et al. 1997, Wolfe et al. 2000). The first category is not a large body of work, comprising only studies conducted in the Kuparuk and Endicott development areas on the treeless North Slope and along TAPS, mainly in the forested Nelchina Basin of southcentral Alaska. The second category is a larger body of work but the effect of pipeline height is more difficult to ascertain, and the third category provides useful summaries but no new data on the topic of interest here.

The responses of woodland caribou (both the boreal and mountain ecotypes) to linear features (roads, seismic lines, and pipeline corridors) have been evaluated in Alberta since the early 1990s and have produced substantial data, mostly from GPS telemetry and GIS spatial analyses. Woodland caribou in Alberta avoided roads, seismic lines, and streams at distances of up to 250–500 m (Dyer 1999, Oberg 2001), but roads were not a barrier to movement unless traffic was present (Dyer et al. 2002). Caribou were located farther than random from linear corridors but caribou mortalities attributed to wolves were closer to linear corridors, suggesting that the predation risk was higher along linear corridors (James and Stuart-Smith 2000). Because linear features in Alberta are largely cut through boreal forest, however, the results may not apply to barren-ground caribou in tundra landscapes. The findings from Alberta are not directly relevant to address the effects of pipeline height because of the lack of elevated pipelines and specific crossing studies.

Our contacts with selected experts in Alaska, Canada, and Scandinavia (Appendix B) turned up no new (or unpublished older) sources of data on the effects of pipeline height on caribou crossing success. Most oil and gas pipelines in Alberta are buried (K. Smith, pers. comm.; D. Melton, pers. comm.) and few above-ground pipelines are present in the Northwest Territories, except for some short slurry pipelines at diamond mines that have not been studied (A. Gunn, pers. comm.). The recently released EIS for the Mackenzie Gas Project in northwestern Canada describes above-ground pipelines planned for development areas near the Mackenzie River delta, which are designed to be at least 1.5 m high, based on Alaska experience. Most of the pipelines associated with that large project will be buried, however. No new information specific to pipelines in Scandinavia was reported (C. Nellemann, pers. comm.; B. Forbes, pers. comm.). Despite continuing gas and oil development in Siberia (Forbes 1999), information on the effects of above-ground pipelines is scant (B. Forbes, pers. comm.); our search for information from Russia was hampered by the language barrier and lack of response from a Russian expert we attempted to contact.

Pipeline Height Below 1.5 M

Much of the emphasis in early work on the effects of above-ground pipelines focused on the potential barrier posed by low pipelines. A prominently cited example of a serious obstacle to the migration of a herd of wild reindeer from the Taimyr Peninsula in Siberia was the construction of two parallel gas pipelines, each 0.7 m in diameter, ~1–2 km apart, and 250 km long between the cities of Messoyakha and Norilsk, beginning in 1968–1969 (Skrobov 1972; Hemming undated; Klein undated, 1980). Those pipelines were set on wooden supports with a ground clearance of 30–50 cm, and the tops of the pipelines were 1–1.5 m above the ground surface; as a result, they posed a barrier to reindeer except in certain locations. Fall migration and movements in early winter were heavily altered by the pipelines, but some reindeer succeeded in crossing under the pipes in ravines where ground clearance was higher (to ~2 m, which was judged to be a suitable minimum height by Russian biologists). Reindeer were able to cross later in the winter because of snow drifting over the pipelines. After the initial crossing difficulties were noted, short ramps were built over the pipelines and "portals" (stretches of pipe elevated to 3–6 m and 75–100 m wide, spaced at 30–40-km intervals) and lead fences were constructed to aid crossings. Despite these accommodations, only about a quarter of the herd succeeded in crossing the pipelines and lichen ranges near the pipelines were overgrazed and trampled. Ultimately, 54 km of lead fences were built to divert reindeer away from the pipelines into previously unoccupied mountain habitats.

During planning for the TAPS project and Prudhoe Bay oilfield development in Alaska, several pipeline simulations were constructed in 1971–1972 to investigate the responses of caribou and reindeer and to evaluate the effectiveness of crossing structures (Child 1973, 1974, 1975). Ground clearance was low (0.5 m and 0.8 m, respectively) over most of the 3.1-km and 2.4-km lengths of the two pipeline simulations in the Prudhoe Bay area, with several crossing ramps and special elevated sections ("underpasses" elevated 1.2, 1.8, and 2.4 m high) placed along the pipelines. The principal finding was that most (77–85%) of the caribou that encountered those two low pipeline simulations detoured around or retreated from them, whereas 8–18% crossed over ramps and 5–7% crossed under the elevated sections (Child 1973). A few individuals (36, or 0.7%) actually crawled under the simulated pipelines at heights of 46–76 cm (Child 1973, 1974).

Child and Lent (1973) studied the responses of reindeer in different seasons to another low pipeline simulation built across a small valley on the Seward Peninsula of western Alaska. The simulated pipeline had a ground clearance of ~0.6 m, a diameter of 0.8 m, a length of 2.3 km, and included a ramp and a single section of higher pipe arcing from 0.6 m up to a maximum of ~3.8 m before descending to 1.8 m. Reindeer were herded to the simulated pipeline to observe their responses and crossing attempts in several different trials, with mixed results. Most reindeer avoided the structure and paralleled it to the ends before crossing or else reversed course and left the area. Some crossed when snow drifts bridged the structure in late winter, and some crossings were reported during the insect season, although it was not known whether they used the ramp or crossed under the simulation.

Reges and Curatolo (1985) constructed a small-diameter (20 cm), 2.3-km-long pipeline simulation in July

1984 that was elevated to various heights during their study period (top and bottom at 108 and 88 cm, 77 and 57 cm, 51 and 31 cm, and 36 and 16 cm in combination with 77 and 57 cm) in the Kuparuk River floodplain, a well-used travel corridor where caribou were likely to encounter the simulation. Crossing frequencies were significantly lower than expected at all heights, although some caribou crossed over the pipeline at all heights. Six (0.5%) of 1,254 caribou encountering the 108-cm height jumped over but that height was an effective barrier to crossings. The percentage crossing generally increased at the lower heights, and the lower height (36 cm at the top) in the combined-height trial was crossed significantly more than expected. Caribou appeared to notice the simulation when ~100 m away, and most of the caribou approaching the simulation moved parallel to it within 20 m and detoured around the ends.

A few other reports of caribou crossing under low pipelines were found in the literature in addition to the account by Child (1973). Adult bulls harassed by oestrid flies were observed crossing or standing under the TAPS pipeline in 1975–1976 at heights as low as 1.1 m (Roby 1978) and 31 (4%) of 711 caribou crossings under the Endicott pipeline during 1987–1990 occurred at heights below 1 m (Lawhead et al. 1993a); three of those crossings were made under pipe <0.5 m high by fly-harassed yearlings. Pipeline <1 m high was crossed significantly less than was available (Lawhead et al. 1993a). Caribou during spring migration in northern Canada were observed to jump over pole fences as high as 1.8–2 m (Miller et al. 1972) and to detour around other fences (McCourt et al. 1974, cited in Jakimchuk 1980).

Pipelines elevated 0.4–1.1 m above ground level in the older portions of the Prudhoe Bay field posed barriers to caribou crossings (Smith and Cameron 1985a, Shideler 1986) in the absence of crossing ramps (whether by design or at roadways under which pipe was buried). Most of the pipelines in the Prudhoe Bay field were constructed in the 1970s before the 1.5-m minimum height was stipulated. Pollard et al. (1992) gave an account of a large-scale movement of ~4,000 Central Arctic Herd (CAH) caribou through the Prudhoe Bay field from the northwest to the south on 16 July 1991, requiring crossings of multiple corridors, which included several newer pipelines >1.5 m high in addition to older pipelines elevated ~1 m or less. The low pipelines were crossed using ramps (up to 95% of the 3,000–3,500 caribou observed crossing used one ramp) and a few crossings also occurred where pipelines crossed a stream drainage at heights above 1 m.

Despite unusual occurrences of caribou crawling under or jumping over low structures, the evidence demonstrates overwhelmingly that caribou crossing success is blocked or significantly reduced when the clearance beneath elevated pipelines is 1 m or less. The information available on the effects of simulated and actual pipelines located on or near the ground leaves little doubt that low-elevation pipelines pose serious impediments or complete barriers to caribou movements; therefore, they should not be considered for use in caribou range.

Pipelines Elevated 1.5 M And Higher

Roby (1978: Appendix G) recorded 41 crossings of the TAPS pipeline on the North Slope at heights up to 5.1 m in the first two years after it was built (1975–1976), but did not specifically analyze the effects of height. We calculated the mean pipe height for 32 crossings he described as 2.2 m, and the mean height for 5 other attempts that apparently failed was 1.2 m (although pipe height data were lacking for other failed crossings); no data on the availability of various pipe heights were included, however. Most of the crossings he described occurred in winter, but no data on snow depth were presented. Roby described several repeated attempts at crossings where the pipe was higher at the crossing than at the first approach. He noted that bulls seemed to accommodate to the pipeline and nearby vehicle activity in summer when harassed by oestrid flies. Most of the crossings involved milling, deflections, and repeated attempts on the approach side of the pipeline. The crossing attempts described by Cameron and Whitten (1976, 1977) are the same as were reported by Roby, and a few more anecdotal accounts were listed by Cameron and Whitten (1978).

Fancy (1983) presented results on crossing success from his second season of study at Prudhoe Bay Drill Sites 16 and 17 on the floodplain of the Sagavanirktok River delta (Fancy 1982), but did not include data from the first year (Fancy et al. 1981), presumably because no pipelines were in place then. Fancy included no data on pipe height in his paper other than to note that state regulations dictated a minimum height of 1.5 m, and the roads and pipelines in his study area were "each elevated approximately 2 m" (Fancy 1983: 193). He defined a crossing as successful if caribou crossed the first structure they encountered (either pipeline or access road) and reported an overall success rate of 70.7%, but did not differentiate between the two structures. Hence, his definition of crossing success did not permit analysis of the success of caribou in crossing the entire pipeline/road corridor, so definitive comparison with other studies is problematic (Smith and Cameron 1985a).

The first detailed examinations of crossing success in the North Slope oilfields that included specific data on pipeline height were conducted along the newly constructed Kuparuk pipeline in 1981–1983 by Curatolo et al. (1982), Curatolo and Murphy (1983), and Curatolo (1984). The findings of those studies were published by Curatolo and Murphy (1986), along with additional data collected along gathering pipelines in the western Kuparuk oilfield by Murphy and Curatolo (1984) and Murphy (1984). Curatolo and Murphy (1986) reported that the mean height (301 cm) of pipe under which caribou crossed in one of their three plots in 1981, the first year the Kuparuk pipeline was in place, was significantly higher than the mean height (261 cm) of pipeline available in that plot. For five other combinations of plots and years, the mean height under which caribou crossed did not differ from the mean height available in the plots (which was 182 cm and 186 cm in their other two plots). They concluded that "pipe height was not an important factor in crossing site selection" within the range of pipe heights they studied (Curatolo and Murphy 1986: 222) and that topography may have influenced caribou to cross where the pipeline was higher. The pipeline plot where higher pipe was selected in 1981 included very high pipe (to 4.3 m) because it crossed the Kuparuk River floodplain, which was a well-used travel corridor by caribou.

The caribou monitoring study for the Endicott Environmental Monitoring Program provided the second set of data that specifically analyzed caribou crossings in relation to pipeline height. The four years of that study (1987–1990, for which separate annual reports were prepared) were summarized in a final synthesis report by Lawhead et al. (1993a). They concluded that the use of 7 height categories (in 50-cm increments, range 38–335 cm) differed significantly from availability in all years over all plots combined and within two of three plots over all years; use did not differ from availability in the other plot. Pipeline heights below 1 m (on ridges, dunes, and next to crossing ramps) were crossed significantly less than expected.

Using a draft data set (n = 661 crossings) obtained before the final synthesis (Lawhead et al. 1993a) was completed, Cronin et al. (1994) reanalyzed the Endicott pipe-height data set using 1.5 m as a threshold height and concluded that pipeline heights below 1.5 m were used significantly less than expected. They also concluded that pipeline elevated higher than 2 m was selected over pipe 1.5–2 m high. We repeated their analysis using the final Endicott data set (n = 711 crossings) divided into 5 height categories (Figure 2) instead of the original 7 categories, and found a significant difference among height categories for all plots and years combined ($X^2 = 29.9$, df = 4, $P < 0.001$). The number of crossings in the <100-cm category was lower than expected ($P < 0.01$) and the number in the 150–199 cm category was higher than expected ($P < 0.05$). In no other category did the number of crossings differ significantly from expected values ($P > 0.05$). In plot 1, significantly fewer crossings occurred in the <100-cm category ($P < 0.01$) and more than expected occurred in the 200–249-cm category ($P < 0.01$); use of no other category was significantly different from expected ($P > 0.05$). There were no significant differences from expected values for any height category in plot 2 ($P < 0.097$). In plot 3, significantly fewer crossings occurred in the <100-cm category ($P < 0.01$) and more than expected occurred in the 150–199-cm category ($P < 0.01$); use of no other category was significantly different from expected ($P > 0.05$). There were significant differences in use among height categories in 1987 ($X^2 = 13.1$, df = 4, $P = 0.011$) and 1988 ($X^2 = 21.3$, df = 4, $P < 0.001$), but not in 1989 or 1990 ($P > 0.05$). In 1987 and 1988, the significant difference resulted from fewer-than-expected crossings in the <100-cm category ($P < 0.01$). In the overall combined sample, the number of crossings differed significantly between pipe heights <150 cm and ≥150 cm ($X^2 = 18.8$, df = 1, $P < 0.001$), as Cronin et al. (1994) reported. Contrary to their results, however, we found no significant difference in use between the 150–199-cm and ≥200-cm categories ($X^2 = 0.05$, df = 1, $P = 0.822$), indicating no selection for pipe higher than 2 m during summer.

Johnson and Lawhead (1989) used focal-group sampling to investigate the responses of caribou groups to Kuparuk oilfield infrastructure in summer 1988. Although they did not collect pipe-height data, all of the pipelines in their study area were elevated at or above the required minimum height of 1.5 m. They reported high crossing success for the 198 corridor crossings they observed, based on both groups (82% overall for groups in which >50% of the members crossed) and total caribou (83% overall). Their definition of crossing success differed somewhat from other studies because they did not use study plots. Only groups that approached corridors closely (<100 m) were included, and success was calculated only for groups in which at least one caribou crossed; thus, the crossing success percentages they reported were primarily measures of group cohesion. Deflections also were recorded, however, and all groups that deflected eventually crossed. This study was the only one to examine crossing success in terms of the number of adjacent pipelines. No difference was found between corridors with 1–5 pipes and those with

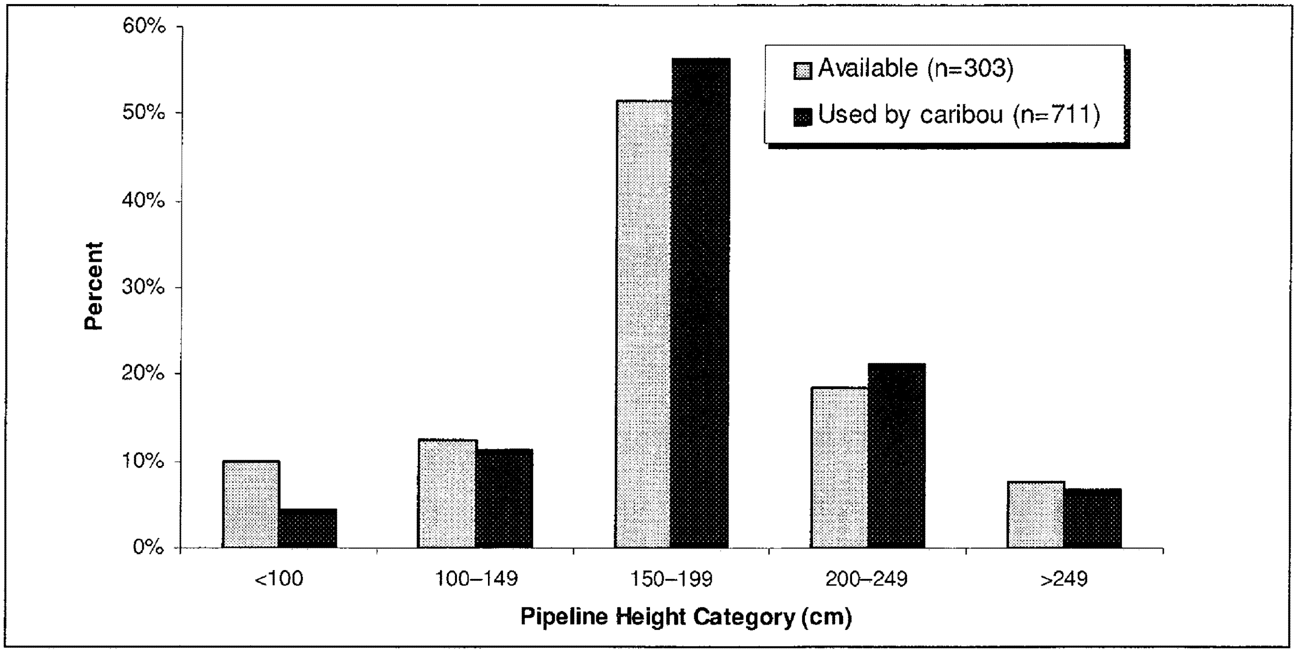

Figure 2. Pipeline-height categories used for crossings by caribou in relation to availability. Data were combined for 3 study plots during 1987–1990 (Lawhead et al. 1993).

6–10 pipes, but no successful crossings were recorded at corridors with 11–15 adjacent pipes (a category that was restricted to a relatively small portion of the oilfield) except when oestrid flies were active, and the only attempted crossing of 16–19 adjacent pipelines was unsuccessful. Large numbers of adjacent pipelines tend to occur along busy stretches of road near major processing facilities, so traffic may exert an effect on crossing attempts in such locations.

Along the roadless Badami pipeline corridor, Coltrane and Lanctot (2001) studied caribou crossing success to evaluate whether it differed between VSM intervals with and without pipeline oscillation dampeners that hung down 51–94 cm at two points within each interval, over 21% of the pipeline length. Although they did not evaluate the effect of pipeline height, all but ~182 m of that 40-km pipeline was elevated to the required minimum height of 1.5 m. They reported that, although group success (using the criterion of >50% of members crossing) did not differ significantly between sections with (37%) and without (58%) oscillation dampeners, fewer caribou individuals crossed intervals with dampeners (27%) than intervals without (63%). The latter tests used individual animals as replicates, however, and they concluded that their study design was not conducive to drawing firm conclusions due to the difficulty of determining "intent" to cross the pipeline and to the possible confounding effects of buried pipeline in riparian habitat near one of their plots and of traffic near the other plot. Use of video cameras did not allow quantification of crossing success, but similar numbers of caribou were recorded crossing under pipeline with dampeners (813 caribou) and without them (639 caribou). A follow-up study on the Badami pipeline (Noel et al. 2002) did not attempt to evaluate crossing success, but concluded that the mean numbers of caribou crossing under the elevated pipeline (3.8 caribou per day) did not differ from those crossing sections of pipeline that were buried in riparian habitats (5.4 caribou per day).

In south-central Alaska, Eide et al. (1986) studied the movements of the Nelchina Caribou Herd in relation to the TAPS pipeline during the first winter of operation (1977–1978), and crossings of the TAPS pipeline by that herd during spring and fall migration in 1981–1983 were studied by Carruthers et al. (1984; results published as Carruthers and Jakimchuk 1987). Together with Cameron and Whitten (1976, 1977, 1978) and Roby (1978), those studies are the only sources of pipeline height data on caribou crossings outside of the postcalving and insect seasons. Eide et al. (1986) reported that caribou selected against elevated pipeline heights below 2.1 m and tended to select those above 2.1 m. They speculated that pipeline crossings by caribou might be inhibited or blocked in a severe winter with deep snow.

Carruthers and Jakimchuk (1987) reported that 93% of the length of above-ground pipeline in their study area was elevated to 1.8 m or higher. The mean height of pipeline crossed by caribou during migrations (2.5

m) was similar to the mean height available (2.3 m). Although this difference was statistically significant, the authors pointed out that there was little variation in height over long sections of the pipeline and most groups (92%) crossed the corridor at the first point of encounter, regardless of buried or above-ground pipeline mode or height, and thus showed little indication of height selection. Snow depth (<44–52 cm in spring and 25–33 cm in fall) was 32% lower on the TAPS right-of-way than in undisturbed habitat nearby and was not considered to be an important factor influencing crossing locations. Neither Eide et al. (1986) nor Carruthers and Jakimchuk (1987) found indications of diminished use of traditional migration routes after TAPS construction, and both found that a long buried section intentionally placed in a traditional spring migration route was used heavily. Shorter crossing structures (short burials called "sag bends" and short "designated big game crossings" elevated ~3 m) were used little and were not preferred by caribou.

The presence of deep snow drifts adjacent to roads in the Kuparuk Oilfield eliminated the space for caribou to pass beneath pipelines in years of late snowmelt such as 1982 (Smith and Cameron 1985a) and 2001 (B. Lawhead, personal observation), creating a potential barrier until the drifts melted. No studies have quantified the potential effects of snow drifting on caribou crossing success in the North Slope oilfields, in part because few CAH caribou winter that far out on the coastal plain. Nevertheless, the issue of adequate clearance under pipelines in winter emerged during the permitting process for the Kuparuk DS-2P (Meltwater) project in winter 2000–2001.

As a result of that concern, Pullman and Lawhead (2002) measured snow depth under pipelines separated from roads and elevated at least 1.5 m in the western Kuparuk field and on the Colville River delta to examine the clearance between elevated pipelines and the snow surface. They found that landform, pipeline orientation with respect to prevailing winds, and pipe clearance could be used to predict where significant accumulations of snow might occur under pipelines. Most snow depth measurements (59% in March and 55% in April 2001, a winter of slightly above average snowfall) did not differ from background levels located upwind. Snow depth was significantly greater than background levels at about a quarter of the sampling sites (24% in March and 27% in April), and was significantly less than background at 18% of the sites. Snow accumulation was greater in thaw basins and in some riverine habitats, under east–west-oriented pipelines as they converged on the prevailing wind direction, and where clearance below pipelines was lower. The last point suggested a feedback mechanism: "Decreased clearance between an elevated pipeline and the ground enhances the windbreak effect of the pipeline" and greater accumulations were found where clearances already were reduced (Pullman and Lawhead 2002: 18). Plowing of an ice road immediately adjacent to one of the pipelines in that study caused increased snow depth under the pipe, which reduced clearance.

In summary, the available data on pipe-height selection by caribou demonstrate that pipelines elevated to the minimum height of 1.5 m are adequate to accommodate crossings by caribou during snow-free periods (Curatolo and Murphy 1986, Lawhead et al. 1993a, Cronin et al. 1994). Although fewer data are available on crossings of elevated pipelines in winter, they indicate that pipeline heights in the range of 2.1–2.5 m are more likely to be used by caribou than lower heights (Cameron and Whitten 1976, 1977, 1978; Roby 1978; Eide et al. 1986; Carruthers and Jakimchuk 1987). The responses of caribou to pipelines depend largely on other factors that influence crossing success, however, as described in the next section.

Other Factors Affecting Crossing Success

All investigations of caribou crossing success are faced with the difficulty of isolating the contribution of individual factors in highly complex situations that often defy statistical analysis. The following sections briefly review other, potentially confounding factors that have been evaluated in studies of crossing success, recognizing that attempts to isolate the effects of specific factors risk oversimplifying the complex nature of caribou responses to pipeline/road corridors. More discussion of most of these factors is available in other reviews and papers, such as Smith and Cameron (1985a), Curatolo and Murphy (1986), Shideler (1986), Lawhead et al. (1993a), and Cronin et al. (1994).

Infrastructure Design

The design and layout of infrastructure (see Appendix C for descriptions of North Slope infrastructure) affect the responses of caribou to oilfields. One of the most important design elements is the distance to and traffic levels on roads adjacent to elevated pipelines. Studies of crossing success in the Kuparuk Oilfield (summarized by Curatolo and Murphy 1986 and Cronin et al. 1994) quickly demonstrated the effect of road proximity and traffic levels on crossing success (described separately below under Traffic). Most pipelines in the portions of the North Slope oilfields built in the 1970s and 1980s are within 20–30 m of roads. Curatolo and Reges (1986) found that crossing success was significantly lower than expected at separation distances <91 m (300 ft) and recommended that the minimum separation distance should be 122 m (400 ft). That recommendation was expanded to 152 m (500 ft) by Cronin et al. (1994). Consequently, the basic design of pipeline/road corridors was changed to separate pipelines from roads at distances consistent with these recommendations. For example, the mean separation distance between the access road and pipeline rack for the recently constructed Kuparuk DS-2P (Meltwater) project is 188 m (range 157–257 m; Lawhead et al. 2004). In the 1980s, the North Slope Borough specified that the maximum separation distance between pipelines and roads should be no more than 305 m (1,000 ft), primarily out of concern for leak detection. With the advent of more sophisticated leak detection methods such as monitoring from aircraft equipped with thermal imaging (Forward-Looking Infrared, or FLIR) equipment, newer pipelines (most notably the Alpine and Badami pipelines) have been constructed without any gravel roads nearby.

Pipelines in the North Slope oilfields typically are placed on the upslope sides of roads to enhance spill containment in the event of pipeline leaks. For east–west-oriented roads, this practice usually means that pipelines are located on the southern sides of road corridors and thus are the first structures encountered by mosquito-harassed caribou moving north to coastal relief habitat. The order of encounter is reversed for caribou moving inland to foraging areas. Although most of the crossing studies we reviewed examined crossing success by caribou moving inland after insect harassment subsided, none attempted to evaluate the effect of pipeline placement in relation to roads. The net effect of encountering pipelines first can be hesitation, delays, and potential deflections of insect-harassed caribou where pipelines at least 1.5 m high are located within 100 m of roads with moderate to high levels of traffic (Curatolo and Reges 1986, Johnson and Lawhead 1989). Caribou encountering the pipelines often hesitate and then are disturbed and crossings interrupted by approaching traffic, as described by Curatolo and Murphy (1986).

The location and directional orientation of pipeline/road corridors in relation to caribou movement patterns also can affect crossing success. Infrastructure located at or near the Beaufort Sea coast is in a zone that is the destination for mosquito-harassed caribou, meaning that caribou may not need to cross to achieve relief from harassment. The Oliktok Point and Milne Point roads make similar transitions from inland areas to coastal insect-relief habitat, and large numbers of CAH caribou usually cross annually during large-scale movements in the insect season (Johnson and Lawhead 1989). The orientation of the Endicott pipeline/road corridor changes from east–west (generally perpendicular to most caribou movements) on the inland portion of the corridor to northeast–southwest (more parallel to movements) along the outer portion near the coast. Lawhead et al. (1993a) noted that insect-harassed caribou that encountered the corridor at shallow angles of movement in the outer portion appeared to deflect and did not need to cross the corridor to reach relief habitat. Jakimchuk (1980) noted a tendency for migrating caribou in northern Canada to deflect onto seismic lines after shallow-angle approaches, which is consistent with the tendency of caribou to seek the path of "least topographic resistance" (LeResche and Linderman 1975) or "least energetic resistance" (Bergerud et al. 1984).

Crossing Ramps

Observations of caribou responses to simulated pipelines (Child 1973), the TAPS pipeline (Cameron and Whitten 1976, 1977, 1978), and pipelines in the Kuparuk field (Curatolo et al. 1982; Curatolo and Murphy 1983, 1986; Smith and Cameron 1985a, 1985b) led to requirements in the late 1970s and 1980s that crossing ramps be built over pipelines as mitigative measures to accommodate caribou crossings. Research focused on the effectiveness of ramps in the Kuparuk field (Murphy 1984, Murphy and Curatolo 1984, Curatolo and Reges 1986) and the Endicott pipeline/road corridor (Lawhead et al. 1993a)

Studies demonstrated that crossing ramps, including buried sections of pipe at road crossings, were preferred by caribou for pipeline/road crossings (Child 1973; Curatolo et al. 1982; Curatolo and Murphy 1983, 1986; Smith and Cameron 1985a, 1985b; Shideler 1986; Lawhead et al. 1993a; Cronin et al. 1994), and indeed appeared to be the only reasonable option for crossings in areas of low pipelines in the Prudhoe Bay field (Pollard et al. 1992, Cronin et al. 1994). Although ramps tended to be preferred by caribou crossing pipelines, the results were equivocal as to whether they were necessary for caribou to cross pipelines elevated at least 1.5 m above the ground. Curatolo and Reges (1986) found no difference in crossing success of the Oliktok Point Road corridor after they blocked ramps in their study plots. The amount of time spent in study plots did not differ between caribou groups that crossed ramps and those that crossed under elevated pipeline, indicating that ramps did not expedite crossings (Lawhead et al. 1993a). The utility of ramps in facilitating pipeline/road crossings by large groups was mixed, with some studies reporting crossings by large groups and hypothesizing that they may promote crossings by large groups that otherwise were having difficulty (Curatolo and Murphy 1986, Smith and Cameron 1985a, 1985b). In contrast, Lawhead et al. (1993a) found that the mean size of groups crossing under elevated pipeline was larger than that for groups crossing ramps.

Based on the results of applied research and changes in corridor design, ramps have not been used as mitigative measures in more recent developments, although they clearly are still necessary in the portions of the Prudhoe Bay field where pipelines are lower than 1.5 m. Separation of pipelines from adjacent roads has been used as a mitigative measure instead of ramps in recent projects on the North Slope, resulting in more effective mitigation along much longer stretches of pipeline. Murphy and Lawhead (2000) suggested that ramps be considered where topography or infrastructure could funnel caribou movements into specific locations where crossings might be impeded, whereas Gilders and Cronin (2000) suggested that eliminating ramps was itself a mitigative measure to reduce direct impacts on wetlands and surface water flow caused by placement of gravel fill.

Traffic

Research in the North Slope oilfields has confirmed that the most important factor affecting caribou crossing success at pipeline/road corridors is traffic on nearby roads. Crossing success in study plots with pipelines alone (elevated to the minimum height of 1.5 m) did not differ significantly from that in control plots or with roads alone, but crossing success was significantly reduced in study plots containing an elevated pipeline next to a busy road. The combination of high-traffic roads (15 or more vehicles/hr) adjacent to elevated pipelines created a synergistic effect that reduced caribou crossing success (Curatolo et al. 1982; Curatolo and Murphy 1983, 1986; Murphy 1984; Murphy and Curatolo 1984, 1987). Several early reports indicated that caribou apparently preferred to cross roads where berm height was lower (Hanson 1980, Cameron and Whitten 1976, 1977, 1978). The similarity of 1.5-m height of road berms to the 1.5-m height of adjacent pipelines can create a visual obstruction, similar to concealing cover for predators. The potential for delays is high when roads are nearby because caribou hesitating at pipelines are more likely to be disturbed by approaching vehicles and retreat from the pipeline (Curatolo and Murphy 1986).

The level of traffic that results in reduced crossing success has been quantified in several studies. Curatolo and Murphy (1986) reported that crossing success was low at the Spine Road with an average rate of 15 vehicles/hr. Lawhead et al. (1993a) found that crossing success was significantly lower above a median rate of 18.6 vehicles/hr in 1987, the year of highest traffic in their Endicott study, and over all four years when the rate exceeded 15 vehicles/hr. Several other comparisons did not detect significant differences for the three other years when the median rate was lower, although a uniform trend for lower crossing success at higher traffic rates was evident. Traffic was a confounding variable in the anecdotal account by Smith and Cameron (1985b), who reported average rates of 20–21 vehicles/hr on the Spine Road when they observed two large groups having difficulty crossing the Kuparuk pipeline. Murphy and Curatolo (1984) reported significantly reduced crossing success where traffic averaged 32 vehicles/hr.

Crossing success of caribou encountering only roads or only pipelines did not differ from crossing frequencies in control plots without infrastructure in the Kuparuk studies summarized by Curatolo and Murphy (1986). Consequently, those authors recommended separating pipelines from adjacent roads to make the two types of structures easier to cross in separate encounters. Along the Oliktok Point Road, Curatolo and Reges (1986) found that crossing success was significantly lower where the separation distance between pipelines and the road was <91 m. In the Kuparuk oilfield, 91% of the deflected crossings observed by Johnson and Lawhead (1989) occurred at corridors where the pipeline/road separation distance was <100 m.

Group Dynamics

Group leadership has been recognized as an important factor maintaining group cohesion in caribou crossings of linear features (Miller et al. 1972), and successful crossings of pipeline/road corridors often were initiated by bolder individuals (Curatolo et al. 1982). The frequency of instantaneous behavioral reactions of caribou to human-related stimuli increases greatly within 100 m of disturbing stimuli (most of which were vehicles; Curatolo and Murphy 1986, Johnson and Lawhead 1989, Lawhead et al. 1993a), so the frequency of reactions increases substantially during crossing attempts. Child (1973) noted that the responses of groups tended to be influenced by the most reactive individual, and Curatolo et al. (1982) noted that yearlings often balked at crossing under the Kuparuk pipeline. In one instance, fewer than 5 reactive individuals appeared to precipitate the failure of 107 bulls to cross the Oliktok Point Road corridor on 8 July 1992, the only ones that failed to cross out of an aggregation of ~6,000 caribou (Lawhead and Flint 1993).

A tendency approaching an all-or-none response was noted in crossing success along the Endicott pipeline/road corridor (Lawhead et al. 1993a: Figure 3-7); all group members crossed in 41–43% of the groups included in their plot and road samples and no group members crossed in 41–42% of the remaining groups in the same samples. This tendency suggests that the definition of crossing success based on >50% of the individuals in a group crossing is reasonable. High levels of crossing success can result if a cohesive pattern of crossing becomes established and is not interrupted by traffic (Johnson and Lawhead 1989, Lawhead et al. 1993a).

Large groups of caribou (usually defined as >100 individuals) have been noted to have difficulty crossing pipeline/road corridors (Child 1973; Smith and Cameron 1985a, 1985b; Curatolo and Murphy 1986; Shideler 1986), but firm conclusions are difficult to draw because results varied among studies and were confounded by insect conditions and traffic (Child 1973, Curatolo and Murphy 1986, Lawhead et al. 1993a, Cronin et al. 1994). Caribou respond to mosquito harassment by forming large groups (White et al. 1975, Roby 1978, Lawhead 1988), which usually take longer to cross pipeline/road corridors, thereby increasing the probability of disturbance by traffic or other stimuli that may interrupt or interfere with pipeline crossings (Curatolo and Murphy 1986). Although large groups tended to be less successful than smaller ones in the early Kuparuk pipeline studies, the difference was not significant (Curatolo and Murphy 1986). Crossing success among three group-size categories was variable over all years and insect conditions in the Endicott studies, but the crossing success of groups of 100 or more caribou did not differ significantly from groups of 2–10 or 11–99 caribou (Lawhead et al. 1993a). Part of the difficulty in interpreting results among studies is that large groups occurred less frequently, so sample sizes tended to be small and not always conducive to statistical analysis.

Caribou segregate into bull-dominated and cow-dominated groups throughout most of the year, but mixed groups form during the insect season and rut (breeding season) (Roby 1978). Cows with young calves are widely recognized as being sensitive to human disturbance, but Child (1973) noted that cow groups crossed simulated pipelines more readily than did bull groups during the insect season. On the other hand, bulls were regarded as being more tolerant of human disturbance during TAPS construction (Roby 1978; Cameron and Whitten 1976, 1977, 1978). All sexes and ages have been recorded crossing under pipelines that meet the 1.5-m minimum height requirement, with no consistent trend in crossing success by sex and age across all studies. Curatolo and Murphy (1986) and Cronin et al. (1994) reported no difference in crossing success among different group types. Group type does not appear to be an important variable affecting pipeline-crossing success during the insect season, when group dynamics are highly variable over short time spans.

Insect Harassment

Harassment by mosquitoes (*Aedes* spp.) and parasitic flies of the family Oestridae—warble flies (*Hypoderma tarandi*) and nose-bot flies (*Cephenemyia trompe*), together known as oestrid flies—exert profound influences on caribou behavior and movements on the Arctic Coastal Plain of Alaska during the summer insect season (White et al. 1975, Roby 1978, Shideler 1986, Murphy and Lawhead 2000). Mosquitoes emerge by late June and harass caribou on warm, calm days until late July, whereas oestrid flies emerge later in early to mid-July and harass caribou into mid-August. Caribou aggregate into large groups and move to the sea coast in response to mosquito harassment, but groups break up and disperse in response to fly harassment (White et al. 1975, Roby 1978, Lawhead 1988).

There is a qualitative difference in the response of caribou to infrastructure during the insect season. Caribou harassed by mosquitoes move rapidly and appear to be highly motivated to cross pipeline/road corridors, but crossing success can be highly variable, depending on traffic and other disturbing stimuli (Child 1973, Johnson and Lawhead 1989, Lawhead et al. 1993a, Cronin et al. 1994). Caribou moving inland again after harassment subsides generally exhibit high crossing success, although the rate of movement is slower in the absence of insect harassment, and crossing events can be more protracted (Murphy and Curatolo 1987, Johnson and Lawhead 1989, Lawhead et al. 1993a).

The behavioral responses of caribou to infrastructure under oestrid fly harassment constitute a confounding factor in interpreting crossing success because gravel pads, buildings, and pipeline/road corridors often attract caribou seeking to avoid flies. Caribou often seek shade under pipelines and may cross under them repeatedly in this season (Roby 1978, Curatolo and Murphy 1986, Johnson and Lawhead 1989, Pollard and Noel 1994, Lawhead et al. 1993a). Mosquito-harassed groups tend to detour around gravel pads and across roads, with a high incidence of deflections, whereas fly-harassed caribou often move onto gravel structures and have higher crossing success (Smith and Cameron 1985a, Curatolo and Murphy 1986, Johnson and Lawhead

1989, Smith et al. 1994). For instance, Lawhead et al. (1993b) reported that 4,600 caribou (~20% of the Central Arctic Herd at the time) congregated on three gravel pads in the western Kuparuk Oilfield on 14 July 1993 when flies were active. Therefore, this attraction must be considered when considering the effects of pipelines on crossing success.

Differing or conflicting responses of caribou to different insect pests help to explain some apparent contradictions in findings about crossing success. For example, Lawhead et al. (1993a) noted the anecdotal account of two large groups that had difficulty crossing the Kuparuk pipeline/road corridor (Smith and Cameron 1985b) also appears to have been confounded by the presence of oestrid flies as well as by traffic, judging from data on insect activity collected in the same area at the same time (Curatolo et al. 1982, Curatolo and Murphy 1983). Lawhead et al. (1993a) found that crossing success was significantly higher when caribou were harassed by mosquitoes alone (before the seasonal onset of widespread oestrid fly harassment) than when both mosquitoes and oestrid flies were active. Under those conditions, large groups that reached the pipeline/road corridor often milled about and stood or walked on the road or under the pipeline as though responding primarily to flies, whereas those that crossed and moved away resumed a higher rate of movement directed toward the coast, as though responding primarily to mosquitoes. On the other hand, Johnson and Lawhead (1989) found that group cohesion during crossings was higher for groups under simultaneous harassment by mosquitoes and oestrid flies than it was when only mosquitoes were active.

Season

Nearly all of the studies described thus far regarding caribou crossing success in northern Alaska oilfields were conducted during snow-free periods, focusing on the summer insect season (late June to mid-August) because that is the period when caribou of the Central Arctic Herd repeatedly encounter infrastructure while moving to and from mosquito-relief habitat at or near the Beaufort Sea coast (Murphy and Lawhead 2000). Little effort was made to study crossing success before calving in spring (Cronin et al. 1994), when movement rates were low and few caribou were in the oilfield region, and maternal cows with newborn calves generally avoided roads (Dau and Cameron 1986, Lawhead 1988, Cameron et al. 1992), so little crossing information could be collected during that period.

The studies conducted on the Nelchina Herd in relation to TAPS (Eide et al. 1986, Carruthers and Jakimchuk 1987) provided the best information on crossings in relation to pipe height in winter. Along with the anecdotal observations in fall and winter along TAPS in northern Alaska (Cameron and Whitten 1976, 1977, 1978; Roby 1978), those studies suggest that caribou prefer higher sections of pipeline when snow cover is present. Even where pipelines are elevated to a minimum of 1.5 m, such as in the Kuparuk field, drifting of snow under elevated pipelines near roads may create an obstruction that impairs crossings in "late" springs when snowmelt is delayed, such as in 1982 (Smith and Cameron 1985a) and 2001 (ABR, Inc., unpublished observations). Although Pullman and Lawhead (2002) did not collect data on caribou crossings, they found that the pipe-to-snow clearance beneath North Slope pipelines in late winter was reduced below 1.5 m along about a quarter of the length of pipeline stretches they sampled. They noted that clearance was more likely to be reduced under lower pipe and where snow-clearing on ice roads along pipelines created berms. That study also found that adequately separating pipelines from roads eliminated the drifting under pipelines that is commonly seen in older parts of the oilfields where pipelines are close to roads.

Habitat And Topography

The amount of experience that caribou have had with tall vegetation has been considered to affect their responses to pipelines (Klein 1980, Eide et al. 1986, Carruthers and Jakimchuk 1987). Klein (1980) thought that the visual effects of overhead structures such as elevated pipelines were greater in tundra than in forested landscapes, but also noted that responses were much stronger to human activity than to infrastructure.

Although habitat influences have been mentioned as possible confounding factors in assessing crossing success under elevated pipelines, few attempts have been made to account for the potential effect of habitat, which poses difficult problems in study design. Curatolo et al. (1982) found that caribou tended to use higher-elevation pipe than was generally available in their study plot, but the high pipe was located on the floodplain of the Kuparuk River, which was a heavily used travel corridor. They concluded that topography was an important factor influencing crossing locations because caribou tended to follow ridges and streams in their study areas. Noel et al. (2002) found that the number of caribou crossing the Badami pipeline did not differ significantly between paired sites at river channels and at riparian tundra habitats nearby (~0.2–0.6 km apart); that study was not designed to compare riparian areas with tundra habitats away from rivers. Carruthers et al. (1984) and Carruthers and Jakimchuk (1987) found that the habitat characteristics and vegetation at crossing sites used by the Nelchina Caribou Herd did not differ from those in the surrounding area.

Because the surface of the ground is not flat or even, a pipeline elevated to 1.5 m at adjacent VSMs may be closer to the ground in the intervening interval than at the VSMs. In practice, however, there are no indications that this a problem, as microtopography rarely rises and falls abruptly within a span of 18 m. In fact, the opposite appears to be true in the Kuparuk field, where the 1.5-m minimum height has resulted in average heights greater than 1.5 m (Curatolo and Murphy 1986). Comprehensive data on the range and average of pipeline heights in the North Slope oilfields has not been compiled, but would provide valuable information for oilfield management and planning.

Habitat effects may be expressed differently in different seasons. Snow depth differed according to habitat type in the snow accumulation study by Pullman and Lawhead (2002) on the western North Slope. Snow accumulations under pipelines were greater where they passed through thaw basins than on adjacent tundra.

Habituation

Habituation is the waning over time of response to a stimulus after repeated exposure (Cronin et al. 1994, Murphy and Lawhead 2000). Over the years, a number of researchers (Child 1973, 1974; Cameron and Whitten 1976; Roby 1978; Curatolo and Murphy 1986; Shideler 1986) recognized that individuals may react differently to infrastructure after repeated exposure, but that effect is difficult to measure. Researchers who have worked on the North Slope for the past several decades have noted that CAH caribou appear to have habituated to certain aspects of the infrastructure (Murphy and Lawhead 2000), as evidenced by the lower frequency now of strong instantaneous reactions to overhead pipe than was observed in the first few years of development in the Kuparuk field (Curatolo et al. 1982; Curatolo and Murphy 1983, 1986). Quantitative comparisons have not been conducted to compare the current reactions of CAH caribou with those recorded in the early 1980s. Habituation to human structures and activities likely depends on the perception of threat by caribou, and there is no evidence to suggest that maternal cows have habituated to vehicles when their calves are less than ~3 weeks old (Lawhead et al. 2004). This lack of habituation to predator-like stimuli is reasonable in an evolutionary context because animals that habituate to such stimuli are likely to have lower survival.

In addition to considering other confounding factors such as traffic and insect harassment, the responses of caribou to elevated pipelines among studies should be interpreted in the context of previous exposure to infrastructure. The use of significantly higher pipeline for crossings in one plot studied by Curatolo and Murphy (1986) occurred in the first year after the Kuparuk pipeline was built; no selection was noted the next year. The difficulty experienced by two large groups of CAH caribou attempting to cross the Kuparuk pipeline/road corridor (Smith and Cameron 1985b) occurred in the first and second summers after that pipeline was built. Currently, it is likely that all of the adult and yearling members of the CAH encountering elevated pipelines each year have done so before, and the majority of older adults probably have encountered infrastructure annually for years, whereas the Teshekpuk Caribou Herd (TCH) has had little exposure to oilfield infrastructure. For instance, anecdotal observations of Teshekpuk Herd animals south of the Prudhoe Bay field in fall 2003 revealed numerous strong behavioral responses to traffic on the Dalton Highway (R. Shideler, ADFG, pers. comm.). The available evidence indicates that the behavioral reactions of caribou to infrastructure are greater in the first few years of encounters than later on; the rate of habituation cannot be estimated with confidence but is likely to depend on the frequency and duration of encounters.

CONCLUSIONS

The evaluation of crossing success for caribou encountering pipeline/road corridors is complicated by the interaction of the factors described in this report and by the complex group dynamics of caribou, especially during the summer insect season. Except for low pipelines elevated ~1 m or less, it is difficult to isolate pipeline height as a separate variable in the analysis of crossing success, so the evaluations performed to date have necessarily focused on comparisons of the height of pipe at locations crossed by caribou, rather than being able to conclusively identify the specific contribution of pipe height to crossing success or failure.

After examining the available literature, we conclude that pipelines elevated to the minimum height of 1.5 m are high enough to accommodate crossings by caribou during snow-free periods, corroborating the conclusions of Curatolo and Murphy (1986), Lawhead et al. (1993a), and Cronin et al. (1994). Data supporting the selection by caribou of pipeline higher than 1.5 m during snow-free periods were scant, limited to specific locations in single years of multi-year studies in the Kuparuk and Endicott areas (Curatolo and Murphy 1986, Lawhead et al. 1993a). Our reanalysis of caribou crossings in the pipe-height categories of 150–199 cm versus ≥200 cm in the Endicott study area does not support the conclusion by Cronin et al. (1994) that the higher category was selected by caribou. To be as effective as possible, elevated pipelines should be separated at or beyond the recommended minimum distances of 122–152 m from roads experiencing moderate to high levels of traffic (Curatolo and Reges 1986, Cronin et al. 1994). The available data (Curatolo and Murphy 1986) indicate that elevating pipelines to the 1.5-m minimum at VSMs results in average heights that are greater than 1.5 m. When constructing pipelines, the minimum height should be measured at the VSMs rather than being averaged over the length of the pipeline.

The ability of the 1.5-m minimum height to accommodate caribou crossings in winter has assumed greater importance recently due to the year-round presence of portions of the Teshekpuk Caribou Herd in areas of NPR-A that currently are being leased, explored, and developed. The limited data available on winter crossings (Cameron and Whitten 1976, 1977, 1978; Roby 1978; Eide et al. 1986; Carruthers et al. 1987) indicate that pipeline heights in the range of 2.1–2.5 m are more likely to be crossed by caribou than are lower heights. Therefore, the minimum pipeline height of 2.1 m recently mandated by BLM for NPR-A development is supported by the available data.

Because of the tendency for greater snow depths to accumulate beneath lower pipe (Pullman and Lawhead 2002), elevating pipelines higher than 1.5 m will decrease the risk of reduced clearance between the snow surface and the bottom of pipelines, especially in severe winters. In addition to reducing traffic interference with caribou crossings, separating roads from pipelines also achieves the important purpose of eliminating snow drifts under pipelines next to roads.

A promising method to address the selection of pipeline height by caribou would be to compare detailed movement tracks of caribou collared with GPS transmitters with detailed digital elevation data for ground surface and infrastructure, thus allowing collection of data over large areas without being confined to study plots. This analysis should be possible for the existing North Slope oilfields, and perhaps portions of TAPS, and could be verified and corrected by field measurements of pipeline height. This approach would have the disadvantage of not observing caribou behavioral responses to elevated pipelines, however. Where road networks are present, the effectiveness of behavioral observations would be enhanced by using focal-group sampling during road surveys (Johnson and Lawhead 1989) to follow groups until they cross or retreat, rather than by using plot-based tower observations.

Observational studies of existing pipelines have inherent limitations. To truly determine the optimal pipeline height for caribou passage, more experimental studies would need to be conducted. Experimental manipulations of pipe height using realistic simulations that can be varied in height would be useful as well (Cronin et al. 1994), but would pose practical problems. Ideally these studies would change pipeline heights in the same area at different times or provide a variety of available pipeline heights within one area with multiple replicates.

Research Needs

The pace of mitigation-related research on caribou crossing success at pipeline/road corridors in the 1990s declined from the 1970s and 1980s, so the accumulation of information on the success of caribou crossing pipelines has slowed as well. The mitigation research conducted since the early 1990s focused on questions other than pipeline height, such as the effect of oscillation dampeners and riparian corridors (Coltrane and Lanctot 2001, Noel et al. 2002), snow depth under elevated pipelines (Pullman and Lawhead 2002), and traffic convoying as a potential measure to decrease displacement of maternal caribou with young calves (Lawhead et al. 2004). Nevertheless, the topic has been a prominent one for local residents on the North Slope of Alaska as development has spread westward, and more questions and ideas for further research became evident during this literature review. The following list presents our view of needs for further information regarding the effects of pipeline height on caribou crossing success.

1) *Adequacy of 1.5-m-high pipeline in winter.* Shideler (1986) identified this as a research need in his review nearly 20 years ago. The study by Pullman and Lawhead (2002) is the only one to address pipeline clearance in winter on the Arctic Coastal Plain, and it contained no information on caribou crossings. This issue is important for development in NPR-A because of the year-round presence of members of the TCH on the coastal plain (Philo et al. 1993, Prichard et al. 2001, Prichard and Murphy 2004), in contrast to the CAH, which winters far south of the oilfields. The available data from studies of TAPS pipeline crossings indicate that pipelines elevated to 2.1–2.5 m are high enough to accommodate crossings in winter, but those data are scant. Studying caribou crossings in winter would be difficult due to the constraints imposed by weather, short days, and low movement rates by caribou, so such an analysis

would best be done retrospectively by examining the characteristics of pipelines in areas that were crossed by caribou equipped with GPS collars.

2) *Effects of habituation.* This issue is especially relevant to development in NPR-A because of the difference between CAH caribou, which are experienced at negotiating infrastructure, and TCH caribou, which are relatively naïve and have had little exposure to linear developments. It will be important to document the behavioral responses of TCH caribou early in the NPR-A development process because the greatest behavioral effects are most likely to occur then, judging from the CAH experience. For the CAH, behavioral studies could be repeated to quantify changes over time in the proportions of strong reactions, but repeating studies in old sites—e.g., the Kuparuk sites used by Curatolo and Murphy (1986) or the Sagavanirktok River delta sites studied by Fancy (1983) and Lawhead et al. (1993a)—would be difficult because additional infrastructure has been added since those studies were done.

3) *Reflectivity of pipeline sheathing.* This factor has not been evaluated because it emerged in public testimony and permitting discussions relatively recently, and nonreflective sheathing has been used in only one project to date (Kuparuk DS-3S). Therefore, the options for designing a study to assess this design feature are limited; the DS-3S pipeline is elevated to 2.1 m, so discriminating between the effect of sheathing and the effect of higher pipe would be problematic. The nonreflective pipeline does not shine as brightly in the sun as the older reflective sheathing, but the profile of the pipeline overhead is identical to other pipelines. In the final analysis, pipeline reflectivity is an issue that involves visual effects on humans as much as on caribou, so taking measures to reduce it would be a proactive measure to mitigate the concerns of local residents at little or no additional cost.

4) *Other confounding factors.* The emphasis in mitigation-related research has been placed on factors that were reasonably simple to observe and quantify—mainly visual stimuli—but the potential contribution of other stimuli is unknown (e.g., Banfield et al. 1981). For instance, the effects of noise (from wind and irregular flow of fluids through pipelines) and olfactory influences such as "pheromone trails" and alarm signals from previous groups passing through an area (Müller-Schwarze et al. 1979) have not been evaluated. It is unknown whether these additional factors, which would be difficult to isolate from the overall effect of an overhead structure, could cause deflections if sudden noises from an overhead pipeline or olfactory indications of previous disturbances startle and delay caribou trying to cross.

5) *Adequacy of pipeline height for subsistence users.* In the final analysis, elevated pipelines constructed in areas used by subsistence hunters and trappers or by other travelers using snowmobiles must be high enough to safely allow crossings beneath the pipes. Pullman and Lawhead (2002) estimated that clearance of 1.4–1.5 m between the snow surface (disregarding compaction by the machine) and the bottom of a pipeline was the minimum safe height for this purpose. Thus, the decision to build pipelines higher than 1.5 m must consider this need as well as caribou crossing success, but the solution to both problems may be the same. Pipelines high enough to safely accommodate snowmobile riders in the deepest winter snows also should be high enough to allow crossings by caribou under those conditions.

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APPENDIX A. MEASUREMENT UNITS AND ACRONYMS

Measurement Conversions

1 m = 3.2808 ft	1 ft = 0.3048 m	5 ft = 1.524 m	7 ft = 2.1336 m
1 cm = 0.3937 in.	1 in. = 2.54 cm	1 m = 1.0936 yd	1 yd = 0.9144 m
1 km = 0.6214 mi	1 mi = 1.6093 km		
1 km^2 = 0.3861 mi^2	1 mi^2 = 2.590 km^2	1 acre = 0.4047 ha	1 ha = 2.4711 acres

Acronyms Used

ADFG	Alaska Department of Fish and Game
ADNR	Alaska Department of Natural Resources
AOGA	Alaska Oil and Gas Association
BLM	Bureau of Land Management
CAH	Central Arctic Herd
DS	Drill Site (prefix used in alphanumeric designations of specific gravel pads)
GIS	Geographical Information System
GPS	Global Positioning System
IAP/EIS	Integrated Activity Plan/Environmental Impact Statement
NPR-A	National Petroleum Reserve–Alaska
NSB	North Slope Borough
PVD	Pipeline Vibration Damper (oscillation dampener; see TVA)
TAPS	Trans-Alaska Pipeline System
TCH	Teshekpuk Caribou Herd
TVA	Tuned Vibration Absorber (oscillation dampener; see PVD)
USFWS	U.S. Fish & Wildlife Service
VSM	Vertical Support Member

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APPENDIX C. INFRASTRUCTURE IN ALASKA NORTH SLOPE OILFIELDS

Elevated pipelines (Figure C-1) are used throughout the North Slope oilfields, both for mixed-phase (oil, gas, and water) gathering lines from drill sites to and from processing facilities and also for shipment of sales-quality oil to TAPS via the Kuparuk, Endicott, Alpine, and Badami pipelines. The gathering pipelines constructed in the original Prudhoe Bay field were low, elevated only to heights of 0.4–1.1 m (Smith and Cameron 1985a, Shideler 1986). That height range was determined to be inadequate to allow free passage by caribou (as is discussed earlier in this review), so a standard minimum height of 1.5 m above ground level was established by the State of Alaska in 1979 (Shideler 1986), as oil development was beginning to expand beyond the original Prudhoe Bay field. All of the pipelines west of the Kuparuk River were constructed to meet this minimum-height requirement. In the early 1980s, ADFG and the Alaska Department of Natural Resources (ADNR) debated whether new pipelines planned for the Milne Point field should be raised higher to 2.1 m above ground level, but the lower height was chosen. Short sections of pipeline elevated to 2.4 m were proposed to be constructed as mitigative measures on the gathering lines for Kuparuk DS-3T, a project for which baseline data on caribou movement patterns were collected (Lawhead and Flint 1993) but which was never constructed.

Not all pipelines in the North Slope oilfields are elevated. Some gathering pipelines were buried within road berms (which are themselves elevated ~1.5 m above ground level, depending on terrain) in portions of the Milne Point oilfield constructed in the mid- to late 1980s by Conoco, Inc., the original developer of the Milne Point field. That design has not been used subsequently by BP Exploration (Alaska) Inc., the current operator of the Milne Point field, or by ConocoPhillips Alaska, Inc. (formerly Phillips Alaska and ARCO Alaska) on its recent projects in the western Kuparuk field, primarily due to concerns about thermal and structural stability, spill detection, and the increased amount of gravel needed to construct road berms thick enough to accommodate buried pipelines.

Gravel crossing ramps were constructed in the Prudhoe Bay, Kuparuk, and Milne Point fields and along the Endicott pipeline/road corridor. Ramps are specially constructed, short (typically ~30 m) stretches of gravel placed over low pipe to enhance crossing success by caribou (Murphy 1984, Murphy and Curatolo 1984, Curatolo and Murphy 1986, Shideler 1986, Cronin et al. 1994). The rationale for ramps came from early studies (Child 1973, Cameron and Whitten 1976, 1977, 1978) that suggested that caribou preferentially crossed over elevated pipelines at buried sections. Short (~18 m) sections of buried pipe called "sag-bends" were placed at intervals along the TAPS, as were short sections of higher-than-normal pipe called Designated Big Game Crossings (DBGCs) (Eide et al. 1986, BLM 2002). Ramps have not been used in new development on the North Slope since the late 1980s, having largely been replaced as mitigative measures by separating pipelines from roads for as much of their length as possible.

Differences in interpretation regarding the 1.5-m minimum height requirement resulted in some discrepancies in pipeline height among projects. Pipelines constructed in the Kuparuk and Milne Point fields were a minimum height of 1.5 m measured at the VSMs, whereas the Endicott pipeline built on the Sagavanirktok River delta appeared to have been built to an average (rather than a minimum) height of 1.5 m, resulting in sections of pipeline along that 16-km corridor that are lower than 1.5 m, especially on ridges and other raised topographic features (Lawhead et al. 1993a). The 40-km pipeline built in winter 1997–1998 to connect the Badami project facilities to the Endicott pipeline has three short stretches of pipe, totaling ~182 m (600 ft), that is lower than the required minimum (Coltrane and Lanctot 2001, Noel et al. 2002).

The diameter of VSMs typically is in the 30–46 cm (12–18 in.) range, but larger diameter supports are used in crossing river floodplains such as the Kuparuk and Colville. The spacing of intervals between consecutive VSMs typically is in the 12–18 m (40–60 ft) range. The diameters of pipelines range from ~20 cm (8 in.) up to 91–122 cm (36–48 in.), plus ~20 cm of additional diameter from the insulation covering.

Most pipeline corridors in the North Slope oilfields contain more than one pipe, ranging up to a maximum of 26 adjacent pipelines. Single pipelines comprised only 16% of the total length of existing corridors in 2001 and 75% of the total length consisted of four or fewer pipelines (NRC 2003: Appendix E). When more than about 6 pipes are present, additional pipe racks are constructed next to existing racks, adding more width to the pipeline corridor and contributing to a tunnel effect under the pipelines. The greatest numbers of adjacent pipes typically occur near processing facilities, as gathering lines from multiple drill sites converge on a central location.

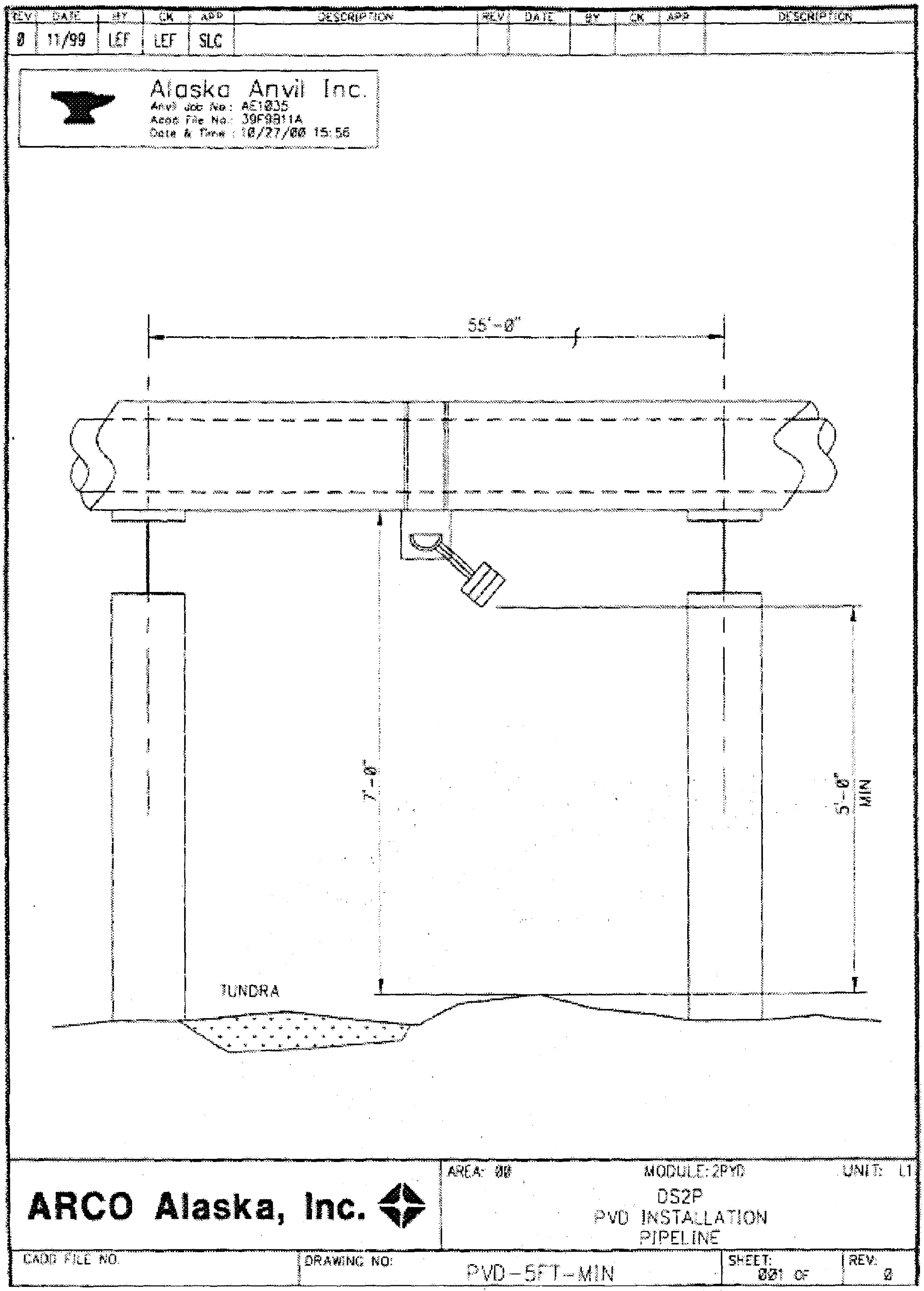

Figure C-1. Elevated pipeline design (2.1-m [7-ft] minimum clearance) with "potato-masher" style oscillation dampeners, or TVAs (1.5-m [5-ft] minimum clearance), for the Meltwater Project (Kuparuk DS-2P). Figure reproduced from PAI (2001).

Pipelines are typically located within 20–30 m of roads in most of the Prudhoe Bay, Kuparuk, Milne Point, and Endicott development areas that were built in the 1970s and 1980s. Pipelines in newer developments (1990s to present) are separated from adjacent roads, based on recommendations from mitigation-related research for a minimum distance of 122 m (Curatolo and Reges 1986) or 152 m (Cronin et al. 1994) and within the 305-m maximum distance required for leak detection. Pipelines in the oilfields typically are located on the upslope sides of roads to take advantage of the potential spill containment value of the road berm.

Expansion loops are constructed to accommodate thermal expansion and contraction of pipelines throughout the year. Loops usually consist of horizontal elbows to allow longitudinal flexing of the pipelines, but vertical loops were used on the Alpine pipeline. Those vertical loops were installed to eliminate the need for check valves and their attendant potential for corrosion, but they also provided short but highly visible, higher-than-normal sections of pipeline that potentially could be used by caribou.

Because pipelines are susceptible to wind-induced vibration, oscillation dampeners (also called pipeline vibration dampers, or PVDs, and tuned vibration absorbers, or TVAs) often are attached to pipelines (Figure C-2). The older design of these devices consisted of a heavy metal sphere suspended by an articulated strap, but newer designs have been developed to avoid hanging down as far—as much as 94 cm (Coltrane and Lanctot 2001)—beneath the pipeline. In some locations, the newer styles of oscillation dampeners have been attached to the top of pipelines instead of beneath them.

The reflectivity of the metal sheathing used to protect pipeline insulation (Figure C-2) has been identified as a concern by residents of Nuiqsut and other North Slope villages. Because of that concern, a nonreflective, dull-finished coating was used on the Kuparuk DS-3S ("Palm") pipelines constructed in 2002 (Figure C-3). Thus far, those pipelines are the only ones with nonreflective sheathing in the North Slope oilfields, and no comparisons of crossing success with reflective-coated pipelines have been done.

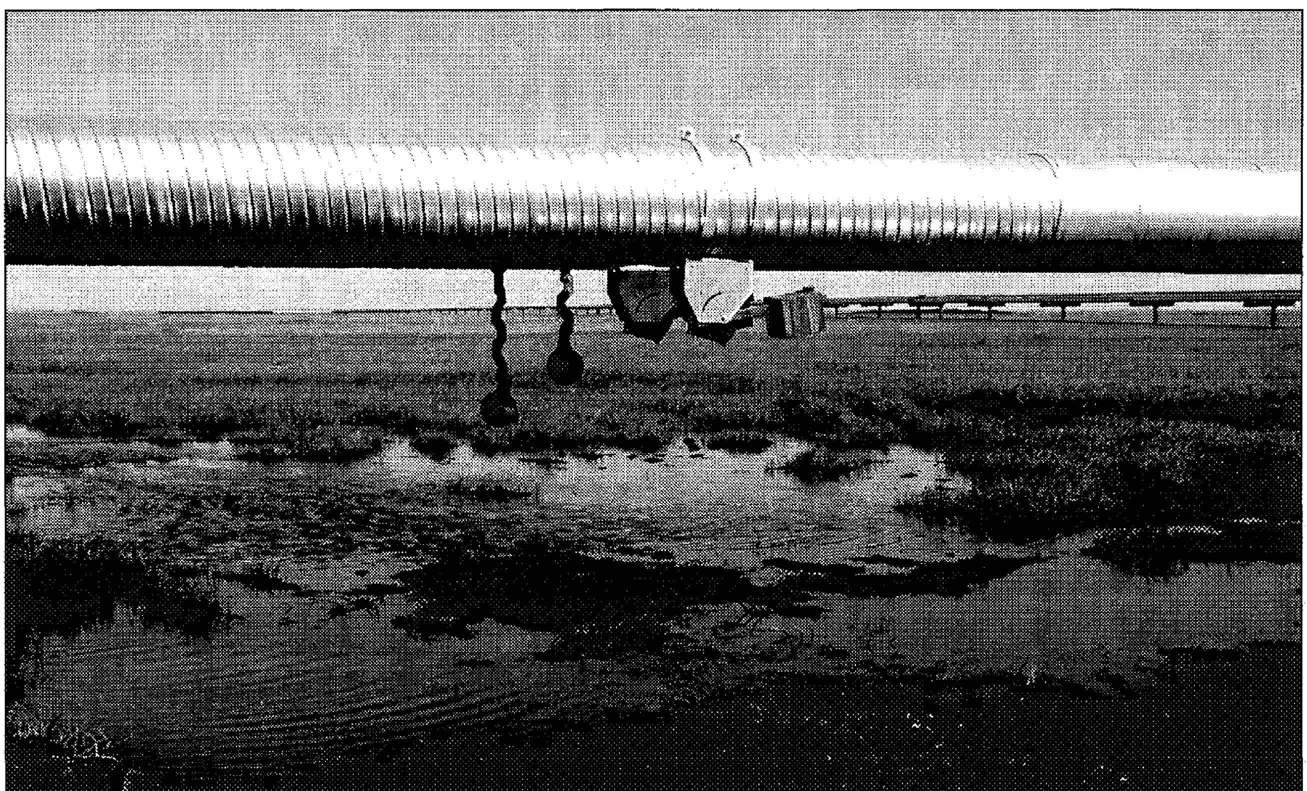

Figure C-2. Kuparuk DS-2L pipeline elevated to 1.5-m minimum height and showing older spherical style and newer "potato-masher" style of vibration oscillation dampeners, and reflectivity of standard sheathing. Photo by B. Lawhead, ABR, Inc. Copyright ConocoPhillips Alaska, Inc.

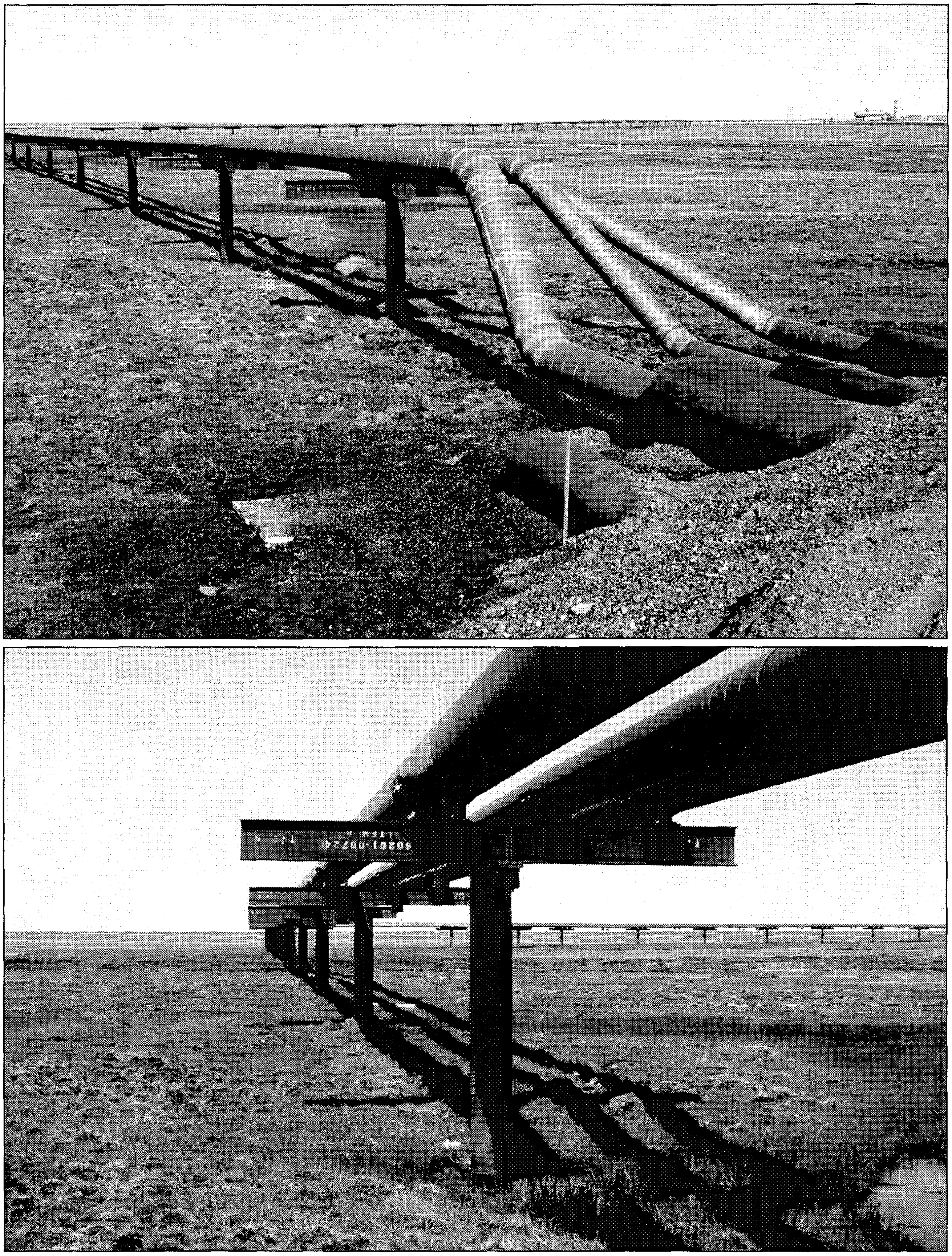

Figure C-3. Pipelines with nonreflective sheathing and elevated to a minimum height of 2.1 m, constructed in winter 2001–2002, Kuparuk DS-3S project, northern Alaska. Photos by B. Lawhead, ABR, Inc. Copyright ConocoPhillips Alaska, Inc.

APPENDIX D. ANNOTATED BIBLIOGRAPHY

Cameron, R. D., and K. R. Whitten. 1976. First interim report of the effects of the Trans-Alaska Pipeline on caribou movements. Special Report Number 2. Joint State/Federal Fish & Wildlife Advisory Team, Anchorage. 39 pp.

Study Location/Herd:
- Alaska; North Slope; Haul Road (Dalton Highway); Central Arctic Herd

Dates of Study:
- Study conducted between July 1974 and December 1975

Pipeline Characteristics:
- Not specified; Trans-Alaska Pipeline System (TAPS) construction began during this study in early August 1975

Study Design:
- Aerial surveys to determine distribution, productivity, and movements of herd
- Behavioral observations related to pipeline crossing behavior were recorded during road surveys along the Haul Road
- Inferred crossings from track observations near road

Objectives:
- Determine herd identity, general population size, productivity, and seasonal movements of caribou in the vicinity of the pipeline corridor
- Identify segments of corridor featuring high use by caribou
- Characterize crossing behavior of caribou encountering the Haul Road, pipeline, and construction-related activities
- Assess effectiveness of special crossings to allow unrestricted caribou movements

Only the last two objectives are addressed in this annotation

Data Quantity:
- 200 road crossings
- After construction of pipeline began, 23 group crossings by 74 individual caribou were recorded (August-December)

Analytical Methods:
- Conducted aerial surveys and road surveys of TAPS corridor
- Used descriptive statistics to compare caribou calf numbers near the road to away from the road
- Compared road berm height at road crossing locations to berm heights available in the area
- Collared and relocated caribou
- Compared latitude and longitude of caribou groups using t-tests

Results:
- 77% of crossings were east-southeasterly
- 8 sag-bend crossings are proposed within study area and their effectiveness will be evaluated at the end of the 1976 construction season
- Mean (+/- SD) berm height at crossing sites was 1.43 +/- 0.59 m compared to 1.70 +/- 0.76 m at the measured road profile, a significant difference
- Maximum crossing rates of the road and pipe/construction pads occurred during June-August and relative frequency of crossings decreased from north to south
- Includes detailed appendix of all crossing attempts and includes observation date, location, whether observation was visual or from track, group composition, direction of travel, pipeline height at attempted crossing, and comments as to caribou behavior and activity prior to crossing attempt
- High crossing rates during the summer corresponded to high insect rates, possibly reflecting a greater tendency for random movement and higher crossing probability
- All caribou observed crossing the pipeline were single bulls
- 16 crossings involving 1–15 caribou were inferred from tracks; cows and calves were present in at least 3 of these groups

- Bulls were seen standing in shade of pipeline and made repeated crossings beneath elevated pipe as low as 1.1 m during periods of high temperatures and low wind velocities
- Several crossing attempts involved some milling, running, or group separation as animals approached the pipeline; only one set of tracks indicated caribou crossed without a disturbance reaction and these tracks followed those of a group that had previously crossed
- 12 group deflections were recorded
- Some caribou were diverted at least 1.5 km; 6 crossings appeared to involve selection for areas of higher pipe clearance
- 1 bull was seen paralleling the pipeline and crossing a short section where no pipe was in place; track records indicated 2 similar crossings

Conclusions:

- Caribou tended to select crossing sites where road berms were lower
- Authors avoid making generalizations regarding the behavioral response of caribou to the pipeline until further studies are complete
- In general, at the time of this study, authors felt "free passage and movement" requirement was not being satisfied
- Data in this report were intended to be baseline data; however, investigations were conducted during some of the early stages of pipeline construction

Peer Reviewed: No

Cameron, R. D., and K. R. Whitten. 1977. Second interim report of the effects of the Trans-Alaska Pipeline on caribou movements. Special Report Number 8. Joint State/Federal Fish & Wildlife Advisory Team, Anchorage. 34 pp.

Study Location/Herd:

- Alaska; North Slope; Central Arctic Herd

Dates of Study:

- Spring; calving; postcalving; insect period; fall; rut; March–November 1976

Pipeline Characteristics:

- Elevated, with some below-ground sections
- Held on VSMs, spacing unspecified
- Diameter 122 cm
- Height 1–5 m above ground

Study Design:

- Recorded observations of crossing behavior during road surveys conducted along the Haul Road (Dalton Highway)
- Track surveys

Objectives:

- Determine herd identity, general population size, productivity, and seasonal movements of caribou in the vicinity of the pipeline corridor
- Characterize crossing behavior of caribou encountering the Haul Road, pipeline, and construction-related activities
- Assess effectiveness of special crossings to allow unrestricted caribou movements

Only the last two objectives are addressed in this annotation

Data Quantity:

- 16 group crossings by 135 caribou

Analytical Methods:

- Conducted aerial surveys and road surveys of TAPS corridor
- Used descriptive statistics to compare caribou calf numbers near the road to away from the road
- Collared and relocated caribou

Results:

- Crossing rate of Haul Road by caribou was lower in 1976 than in 1975

- Fewer caribou were seen near the Haul Road in 1976, and those present crossed less often compared to 1975
- Contact of caribou with pipeline varied among seasons, with wide differences in snow cover, habitat, insect conditions, and construction-related activities
- Includes detailed appendix of all crossing attempts and includes observation date, location, whether observation was visual or from tracks, group composition, direction of travel, pipeline height at attempted crossing, and comments on caribou behavior and activity before crossing attempt
- 5 of 135 caribou that approached the pipeline were deflected from crossing
- 11 groups totaling 110 caribou were observed, while remainder of crossing attempts were inferred from tracks
- Of successful crossings by individual caribou, 80 were bulls, 3 were cows, and 1 was a short yearling
- No crossings by cows with calves were apparent from tracks
- Few caribou were seen near the pipeline during insect season, whereas the majority of crossings in 1975 occurred during that period
- In 1976, most crossings of the pipeline were during late spring in an area where dust from Haul Road accelerated snow melt, exposing plants and stimulating early new growth of *Eriophorum*
- Although many pipeline crossings in 1975 occurred during and after fall rut, only 2 crossings occurred during this period in 1976
- Only one specially designated big game crossing (DBGC; consisting of higher-than-normal pipe elevation) was used for crossing
- No observations of caribou using sag bends (other crossing structures)
- Several crossing occurred in short sections where no pipeline was yet in place

Conclusions:
- Marked differences between 1975 and 1976 caribou interactions with the pipeline
- Interpretation of results was difficult due to differences in length of pipe constructed and the amount of construction activity between years
- Authors concluded that caribou generally avoided the corridor
- Majority of crossings occurred where pipe was buried
- Local traffic and human activity may have prevented caribou from crossing pipeline
- Buried pipe did not seem to impede caribou movements in the absence of human activity

Peer Reviewed: No

Cameron, R. D., and K. R. Whitten. 1978. Third interim report of the effects of the Trans-Alaska Pipeline on caribou movements. Special Report Number 22. Joint State/Federal Fish & Wildlife Advisory Team, Anchorage. 29 pp.

Study Location/Herd:
- Alaska; North Slope; Haul Road (Dalton Highway); Central Arctic Herd

Dates of Study:
- Spring; summer; calving; postcalving, insect period; fall; rut; March–November 1977

Pipeline Characteristics:
- Trans-Alaska Pipeline north of Pump Station 4; dimensions of study area not specified

Study Design:
- Crossings were inferred from track surveys

Objectives:
- Determine herd identity, general population size, productivity, and seasonal movements of caribou in the vicinity of the TAPS corridor
- Characterize crossing behavior of caribou encountering the Haul Road (Dalton Highway), pipeline, and construction-related activities
- Assess effectiveness of special crossings to allow unrestricted caribou movements

Only the last two objectives are addressed in this annotation

Data Quantity:

- 11 group/single crossings as inferred from tracks

Analytical Methods:

- Conducted aerial surveys and road surveys of TAPS corridor
- Used descriptive statistics to compare caribou calf numbers near the road to away from the road
- Collared and relocated caribou

Results:

- Seasonal trends and sighting frequency of caribou near the road/pipeline corridor in 1977 were similar to 1976
- Summer and fall sighting frequencies for both 1976 and 1977 were substantially lower than initial (1975) values
- Crossing frequencies of the corridor during all seasons were higher in 1977 than in 1976
- Whereas 1977 spring crossing frequency was near zero, summer rates were similar to 1976
- Crossing rates in fall 1977 were higher than in both fall 1975 and 1976 and may be related to a reduction in human activity along the corridor during this period
- In 1977 fewer surveys specifically designed to detect caribou crossings of the pipeline/road corridor were conducted than in previous years
- Includes detailed appendix of all crossing attempts and includes observation date, location, whether observation was visual or from track, group composition, direction of travel, pipeline height at attempted crossing, and comments as to caribou behavior and activity prior to crossing attempt
- Tracks indicated use of a sag-bend crossing
- Cows with calves appeared to avoid the corridor, so few observations of crossing attempts were seen, but there was little evidence that cows with calves were making unrestricted movements across the pipeline corridor

Conclusions:

- Infrequent use of the pipeline/road corridor continues to limit conclusions about effectiveness of crossing structures
- Factors influencing behavioral responses of cows with calves should receive priority attention
- In the absence of human activity, buried pipe allowed caribou to freely cross the pipeline
- Vehicles and other human activities along the corridor represent a greater source of disturbance to caribou than do structures
- Excessive berm height may prevent caribou from crossing Haul Road
- Free passage and movement of caribou across the road/pipeline corridor cannot be demonstrated with this study

Peer Reviewed: No

Carruthers, D. R., and R. D. Jakimchuk. 1987. Migratory movements of the Nelchina caribou herd in relation to the Trans-Alaska Pipeline. Wildlife Society Bulletin 15: 414–420.

Study Location/Herd:

- Southcentral Alaska; Trans-Alaska Pipeline System (TAPS) miles 620–660; Nelchina Herd (see Carruthers et al. 1984 for more extensive description of study area and background information on the Nelchina Herd)

Dates of Study:

- October; November; April; fall; spring; 1981–1983

Pipeline Characteristics:

- Trans-Alaska Pipeline
- Elevated to average height of 2.4 m above ground; 92.6% of length >1.8 m in height
- Pipe diameter 122 cm
- VSMs spaced at 18-m intervals
- Crossing structures included sections of buried pipe, specially designated big-game crossings (DBGCs), and sag-bends (short sections of buried pipe)

- Buried sections ranged in length from 2.4 to 3.2 km wide, comprising 39% of pipeline length in study area
- 30 elevated underpasses, designated big game crossings (SBGC); average height >3.3 m and 18 m long
- 6 sag-bends; all <18 m wide
- Right of way (ROW) averaged 30 m wide, including 7-m-wide gravel pad about 1 m thick

Study Design:
- Track surveys with pipe mode and height, snow depth, and vegetation type recorded at each trail
- See report by Carruthers et al. 1984 for presentation of same data

Objectives:
- Describe crossing locations of caribou in relation to characteristics of the pipeline and surrounding environment
- Compare crossing locations of the herd after pipeline construction with crossing locations before pipeline construction

Data Quantity:
- 11 surveys by truck or snowmachine over the course of 3 years
- Estimated 7,909 caribou on pipeline right-of-way

Analytical Methods:
- Chi-square goodness-of-fit tests of habitat use and use of buried pipe sections, by area and season

Results:
- Estimated 7,909 caribou on pipeline right-of-way, with all but 4 crossing the pipeline
- Spring crossing zones were associated with lowlands, whereas fall crossing zones were associated with hilly terrain and mixed woodland forest; vegetation types at specific crossing sites did not differ statistically from the availability of vegetation within crossing zones
- Continuity of pipeline mode was consistent over long distances, so caribou were rarely presented with a choice of pipe mode, but in some sections, caribou showed preference for above-ground elevated pipe in spring and buried pipe in fall, whereas there was no relationship in other areas
- Mean pipeline height at crossing sites was 2.5 m, compared with a mean availability of 2.3 m, within spring and fall crossing zones
- Elevated sections >3 m high and sag-bends received little use
- Caribou used the same migration routes before and after pipeline construction
- See Carruthers et al. (1984) for full report on this study

Conclusions:
- Crossing zones were associated with physiographic features distinctive for each season
- Pipe mode and height did not appear to influence the location of crossing zones, but in sections where a choice was available, there was much variability
- Caribou tended to cross at whatever pipe mode or height they encountered, so unless special crossing structures were within the migratory corridor of the herd, they may not have been used

Peer Reviewed: Yes

Carruthers, D. R., R. D. Jakimchuk, and C. Linkswiler. 1984. Spring and fall movements of Nelchina caribou in relation to the Trans-Alaska Pipeline. Final report prepared for Alyeska Pipeline Service Company, Anchorage, by Renewable Resources Consulting Services Ltd. 102 pp.

Study Location/Herd:
- Southcentral Alaska; Trans-Alaska Pipeline System (TAPS) miles 620–660; Nelchina Herd

Dates of Study:
- October; November; April; migration; fall; spring; 1981–1983

Pipeline Characteristics:
- Trans-Alaska Pipeline
- Elevated, average height 2.4 m above ground; 92.6% of length >1.8 m in height
- Pipe diameter 122 cm

- VSMs spaced at 18-m intervals
- Crossing structures included sections of buried pipe, specially designated big-game crossings (DBGCs), and sag-bends (short sections of buried pipe)
- Buried sections ranged in length from 2.4 to 3.2 km wide, constituting 39% of pipeline length in study area
- 30 elevated underpasses, designated big game crossings (DBGCs); average height >3.3 m and 18 m long
- 6 sag-bends; all <18 m wide
- Right-of-way (ROW) averaged 30 m wide, including a 7-m-wide gravel pad, about 1 m thick

Study Design:

- 11 track surveys over the course of 3 years by truck or snowmachine and 213 hours of direct observation during 1981
- Every third set of tracks was measured to determine their configuration within 20 m (200 m during 1981) of TAPS ROW
- Only tracks that could be followed across the corridor were characterized, which may have biased results toward direct crossings of pipeline
- Successful crossing was defined as any caribou that approached the pipe and moved across to the other side
- Pipe mode and height at point of crossing was measured and compared with "as-built" pipeline specifications
- Vegetation was classified and snow depth was measured at crossing sites
- Six control surveys were conducted in areas of high caribou use; walked transect parallel to ROW and 500 m away and series of 250 m transects perpendicular to pipeline

Objectives:

- Document crossings of TAPS corridor by Nelchina Herd during spring and fall migration
- Document and describe physical characteristics of pipeline crossing sites used by caribou
- Assess use of special crossing structures by caribou
- Quantify crossing success and behavior of caribou encountering pipeline corridor
- Document group characteristics that may affect crossing success
- Document habitat use by caribou adjacent to the pipeline corridor

Data Quantity:

- Estimated 7,909 caribou on pipeline right-of-way from track surveys
- 122 groups comprising 880 caribou were observed crossing TAPS ROW

Analytical Methods:

- Compared use of buried pipelines to availability with a chi-square test
- Descriptive statistics of pipeline height
- Described caribou activity on TAPS right-of-way

Results:

- Seasonal movements were described, but are not summarized in this annotation
- Of 122 caribou groups observed crossing ROW, 105 (86%) crossed at buried pipe and 17 (14%) at above-ground pipe
- In spring, 66% of caribou crossed under a 20-km section, and during fall, 80% of caribou crossed under a 20-km section
- Topographic features of spring and fall crossing sites differed, with spring sites occupying depressed flat terrain adjacent to uplands, whereas fall crossing sites were associated with uplands and sloped topography
- Trails were not associated with particular vegetation types, but reflected topographic differences between seasonal migrations
- No relationship between forage quality and the frequency of caribou crossings was found
- Maximum snow depths during study were normal or below normal except November 1981 to January 1982, when snow depth exceeded normal by 10–20 cm; considered doubtful that snow depths would restrict caribou movements during spring or fall

- Snow depths during 1981–1983 were 32% lower on TAPS ROW than in adjacent areas
- Snow depth at major spring crossing sites was low (<44 cm) and was intermediate (range 25–38 cm) at fall crossing sites
- Spring migration corridors were located in sections of TAPS with high proportion (76%) of above-ground pipe
- Fall migration corridors were in areas where most of pipe (65%) was buried
- Only one section of pipeline presented caribou with a choice of pipe mode, and no selection was evident for elevated or buried pipe
- Distribution of pipe heights did not differ between spring and fall crossing zones
- Most pipe at crossing sites was >1.8 m, with height ranging from 1.0 to 5.1 m
- Median pipe height at sites crossed in spring and fall was 2.3 m and mean height crossed by caribou was 2.5 m
- Presence of predators in the ROW was discussed, but is not presented in this annotation
- 29% of caribou used some sort of special crossing structure (pipeline burial, DBGCs, sag-bends)
- Buried sections were used most (27% of crossings) because they were situated in a major spring crossing zone; all other structures were used little, probably because they were placed outside of major crossing zones
- All structures were used less in fall than spring
- Of estimated 7,905 caribou approaching pipeline, all trails but one crossed; 49% of trails crossed at above-ground pipe
- All 149 caribou groups observed directly during spring and fall 1981 crossed TAPS
- At above-ground pipe, there was a significant change in travel direction (~7.2 degrees) where caribou crossed TAPS compared with areas away from TAPS
- In 92% of crossings, caribou crossed ROW directly with <25 m of lateral movement, but some trails paralleled 25 m from pipeline, approached or departed the pipe on old cutlines, or encountered a transition between above-ground and buried pipe
- No differences were seen in approach and departure orientations between pipe modes
- Paralleling elevated pipe during approach occurred on ROW during 2 (7%) trials for an average of 51 m; occurred off ROW during 5 (17%) for average of 88 m
- Paralleling elevated pipe during departure occurred on ROW during 9 (30%) trials for average of 111 m compared to 5 (17%) trials over average of 52 m at buried pipe
- At 17 (35%) of above-ground crossing sites, a cutline intersected and crossed ROW at 90 degrees with caribou encountering cutline off ROW and following it directly across pipeline
- Visibility of ROW varied depending on forest type, but visibility declined rapidly >50 m from ROW and was seldom visible to researchers beyond 125 m
- No relationship was found between angle of caribou trails relative to TAPS for either elevated pipe or buried pipe
- All 122 groups directly observed from October to November crossed TAPS; 14% at elevated pipe and 86% at buried pipe
- Regardless of pipe mode, groups spent average of 7.6 minutes on ROW before departing, with small groups generally spending less time on ROW than large groups
- 92% of 59 groups were led by adult females, 5% of groups were led by bulls, 3% were led by calves
- Although not significant, caribou spent more time feeding (44%) and less time standing (28%) at elevated pipe than at buried pipe (20% and 38%, respectively)
- Proportions of different caribou groups observed at elevated and buried pipe did not differ significantly
- 91 caribou in 15 groups showed alarm behavior, including 4 groups at elevated pipe and 11 at buried pipe

Conclusions:

- Caribou followed traditional migratory corridors and seldom used special crossing structures, probably because they were located outside of major migratory corridors
- Where both pipe modes were available, there was no preference for buried or elevated pipe

- Distribution of height along TAPS was so uniform that no analysis could be made to test for selection of height at crossing sites
- Caribou often crossed at median pipe height
- Caribou tended to cross elevated pipe where they encountered it
- Factors other than pipe height are likely to influence where caribou cross elevated pipe, with the foremost being topography
- Conclusions on preferences for crossing sites depend on what components researchers decide are available to animals
- Inconclusive nature of studies regarding selection of pipe height at crossing sites of moose and caribou reinforce the hypothesis that factors other than height are important

Authors list management recommendations:

- Study caribou movements over long periods of time, taking into account changes in population status, and determine where major caribou movements will intersect proposed pipelines
- Route selection should be aimed at allowing pipe burial at crossings or elevated pipes within height ranges presented in this report
- Snow conditions along route should be analyzed to ensure that adequate pipe heights for crossing will be available during winter
- Hunting should not be allowed near pipelines
- Specially designated big game crossings and sag-bends were not necessary to enable successful crossings of pipeline by caribou

Peer Reviewed: No

Child, K. N. 1973. Reactions of barren-ground caribou *(Rangifer tarandus granti)* to simulated pipelines and pipeline crossing structures at Prudhoe Bay, Alaska. Report prepared for Alyeska Pipeline Service Company and British Petroleum Alaska, Inc., Anchorage, by Alaska Cooperative Wildlife Research Unit, University of Alaska, Fairbanks. 51 pp.

Study Location/Herd:

- Alaska; North Slope: coastal plain; Prudhoe Bay; Central Arctic Herd

Dates of Study:

- Summer; no dates specified; 1971 and 1972

Pipeline Characteristics:

First simulation by Alyeska Pipeline Service Company

- Simulated elevated pipeline made of snow fencing with burlap stapled to one side to form an optical barrier similar to a real pipeline
- Height of snow fencing was 4 ft to simulate a 48-in.-diameter pipeline
- Height 20 in. above ground
- VSMs were spruce poles spaced at 25-ft intervals
- Length 10,200 ft
- Crossing structures included 2 gravel ramps and 4 underpasses
- Ramps 75 and 100 ft in length, 2:1 side slopes, aligned with axis of fence
- 3 underpasses were 100 ft long and 7 ft 8 in. high, 1 underpass was 150 ft long and 4 ft high; all underpasses were constructed with 2 parallel spans of fencing
- Design changed during 1972 (second year of study), ramps were reconstructed to be equal in length with 1:5 slopes that fanned out 360 degrees from fence; 3 of 4 underpasses were increased in length to 200 ft; and at 2 of 4 underpasses, burlap/fencing were replaced by 32-in. galvanized culverts to remove disturbing stimulus of burlap blowing in wind
- Barrier constructed to prevent caribou from walking around simulation and to help funnel caribou into the pipeline area

Second simulation by British Petroleum Alaska, Inc. (BP Alaska)

- Simulated elevated feeder pipeline, 3,600 ft long, made of culverts suspended on water-filled oil drums, height not specified

- 24-in. diameter
- 600 ft of pipeline was raised to provide a variety of ground clearances (4–8 ft)
- Expansion loop simulated, dimensions 20 by 40 ft, eastward inclination of loop had 6- and 8- ft clearances above the road and tundra, respectively
- Included structures to channel caribou towards the simulated pipeline
- In 1972, lengthened the simulation another 3,500 ft and adding 2 ramps as crossing structures, also used 10-in.-diameter spruce logs instead of culverts
- Ramps were 2,000 ft apart, each with 1:10 slopes; length of ramps unspecified; structure included 100-ft cable leads positioned 45 degrees to axis of road bed to intercept and lead caribou over ramps

Study Design:

- Behavioral observations conducted from 14-ft-high towers; 1 tower at each simulation
- Crossing defined as successful when animal negotiated structures at a ramp or underpass, or crawled under pipeline; groups of caribou were considered successful when 100% of the group crossed the pipeline simulation

Objectives:

- Study behavior of animals by sex and age and by size and composition in the vicinity of man-made objects
- Study reactions of caribou when presented with deflection or choice situations
- Study reactions of maternal cows and calves when confronting man-made structures

Data Quantity:

- 5,599 caribou approached Alyeska's simulated pipeline structure in 1971 and 1972
- 1,362 caribou approached BP's simulated pipeline structure in 1971 and 1972

Analytical Methods:

- Crossing success and group size were compared using chi-square tests
- Crossing success was compared by insect activity, elapsed time, and number of encounters with pipeline (but not pipeline height) using multiple linear regression
- Numbers of caribou using ramps and underpasses presented using descriptive statistics

Results:

- Groups and individuals encountering the pipeline tended to parallel at an average distance of 50 m
- Of 5,599 caribou approaching Alyeska simulation, 994 (17.6%) used ramps; 273 (4.9%) used underpasses; 36 (0.7%) crossed beneath the fence; 1,924 (34.4%) reversed original direction of travel at the pipeline; 2,372 (42.4%) moved to termini of structure
- Of 1,362 caribou approaching BP feeder pipeline simulation, 92 (6.8%) passed beneath the pipe; 113 (8.3%) used low-profile ramps; 129 (9.5%) reversed their movements; 1,028 (75.4%) moved to termini of structure
- As group size increased, crossing success decreased, with 27 (24.5%) of 110 groups crossing the Alyeska simulation using ramps and underpasses, whereas 83 groups (75.5%) did not use either structure to cross
- Groups of 2–10 were more likely to investigate and use ramps (12.9%) than were larger groups (7.5%)
- Larger groups did not negotiate crossings as entire group; rather, they moved to termini of structure, reversed travel direction, or separated into subgroups before crossing at various locations
- 21 (69.0%) of 34 individual animals that approached pipeline used ramps or underpasses to cross
- Groups of adult bulls or mixed herds with high numbers of bulls frequently bypassed all crossing structures and paralleled the simulation to termini
- Nursery bands mostly paralleled the structure or reversed direction of travel (especially large groups), but remained longer in vicinity of the pipeline and investigated crossing structures, using them more often than bull groups
- 3 of 23 groups (35%) that separated to cross the pipeline reunited on the other side; in 3 instances, distinct groups approaching simultaneously coalesced; typically, inter- and intra-group dynamics maintained some synchrony of activities between different groups attempting to cross, usually resulting in caribou moving to termini of structures

- Groups led by females used ramps to cross pipelines significantly more often than groups led by bulls, which tended to avoid structures by making wide detours to termini of structures
- Crossing success of caribou was significantly correlated with increasing densities of insects, number of occasions when animals were present at the simulations, and time of season
- Multiple regression analysis showed density of biting insects to be the one environmental factor that greatly influenced crossing success
- During both years, caribou that successfully crossed Alyeska simulation used ramps more frequently than elevated underpasses, which were avoided
- Of 42 cow-calf pairs seen encountering the simulation, 23 pairs successfully crossed
- Although calves tended to be more inquisitive than adults, they never initiated crossings, but followed their dams

Conclusions:

Author made management recommendations:

- Use aerial photos to identify and map traditional trail systems used by caribou and to identify areas of potential conflict
- 3 or more crossing structures should be included equidistant from each other in areas where pipelines intersect caribou trails
- Crossing structures should be as wide as possible to give caribou the maximum chance to find the structure and to provide for the passage of large groups
- Above-ground pipelines should be elevated to a minimum ground clearance to minimize the visual barrier presented to caribou
- Crossing structures should be situated along terrain features followed by caribou such as river channels, edges of lakes, and ridges of polygons
- If building a crossing structure is not feasible, pipelines should not be <50 yards from waterbodies to reduce the chances of confinement between waterbody and the pipeline
- A discontinuous pipeline profile created by building as many crossing facilities as possible may encourage caribou to investigate the structure
- Gravel ramps should be constructed with maximum width and slopes not exceeding 1:6; more work should be done to study the effectiveness of lead fences to channeling caribou towards crossing structures; leads should be made of stationary material so wind cannot cause movement
- Simulating trails over ramps may facilitate use; during winter, black powder could be spread over the ramp to look like a trail, snowmachines could be used to put in a trail, or planks could be placed along ramps to funnel caribou over them
- Vegetated ramps are feasible, but impractical due to maintenance costs and the possibility of attracting stationary groups of caribou
- Further research is needed regarding accumulation of snow around features and whether or not a seasonal response of caribou to pipelines may occur

Peer Reviewed:

Child, K. N. 1974. Reaction of caribou to various types of simulated pipelines at Prudhoe Bay, Alaska. Pages 805–812 in V. Geist and F. Walther, editors. The Behaviour of Ungulates and Its Relation to Management. IUCN New Series Publications No. 24, Volume II. Morges, Switzerland. 940 pp.

Study Location/Herd:

- Alaska; North Slope: coastal plain; Prudhoe Bay; Central Arctic Herd

Dates of Study:

- Calving; postcalving; insect season; 8 June to 8 August 1971

Pipeline Characteristics:

First simulation by Alyeska Pipeline Service Company

- Simulated elevated pipeline made of snow fencing with burlap stapled to one side to form an optical barrier similar to a real pipeline
- Width of snow fencing 4 ft to simulate a 48-in. diameter pipeline

- Height 20 in. above ground
- VSMs were spruce poles spaced at 25-ft intervals
- Length 10,200 ft
- Crossing structures included 2 gravel ramps and 4 underpasses
- Ramps 75 and 100 ft in length, 2:1 side slopes, aligned with axis of fence
- 3 underpasses were 100 ft long and 7 ft 8 in high, 1 underpass was 150 ft long and 4 ft high; all underpasses were constructed with 2 parallel spans of fencing

Second simulation by British Petroleum Alaska, Inc. (BP Alaska)

- Simulated elevated pipeline, 3600 ft long
- Culverts suspended on water-filled oil drums, 30 in. high
- 24-in. diameter
- 600 ft of pipeline was raised to provide a variety of ground clearances (4–8 ft)
- Expansion loop simulated, dimensions 20 by 40 ft, eastward inclination of loop had 6- and 8-ft clearances above the work-pad road and tundra, respectively
- Included structures to channel caribou toward the simulated pipeline

Study Design:

- Behavioral observations conducted from 14-ft-high towers; 1 tower at each simulation
- 16-mm cinematography used to record some behavioral sequences
- Crossing defined as successful when animal negotiated structures at a ramp, underpass, or crawled under pipeline; Groups of caribou where considered successful when 100% of the group crossed the pipeline simulation

Objectives:

- Study behavior of animals by sex and age and by size and composition in the vicinity of man-made objects
- Study reactions of caribou when presented with deflection or choice situations
- Study reactions of maternal cows and calves when confronting man-made structures

Data Quantity:

- 1,102 caribou encounters at Alyeska site (including 186 track counts)
- 605 caribou encounters at BP site

Analytical Methods:

- Descriptive statistics only

Results:

- At Alyeska simulation, 136 (12.4%) caribou used ramps, 60 (5.4%) walked through underpasses, 7 (0.6%) crawled under the fencing, and 899 (81.6%) were diverted in their movements
- At BP simulation, 101 (16.7%) reversed direction of travel, 495 (81.8%) paralleled the line to the terminus, and 9 (1.5%) crawled underneath
- On basis of 301 animals approaching Alyeska simulation from east, 42.5% of caribou used crossing structures, 43.2% moved to termini, and 13.6% returned to east; whereas 801 approaches from west resulted in 8.4% using ramps and underpasses, 19% moved to termini, and 71.8% returned to west
- At BP simulation, of 51 caribou moving east, 7.8% crossed the pipeline and 92.2% diverted to ends of simulation; of 554 approaches from west, 0.9% of caribou crawled beneath the pipe, 80.9% moved to termini, and 18.2% returned to east
- Greater proportion of cows, calves, and yearling caribou used ramps than used underpasses
- At Alyeska simulation, groups of 11–15 animals made greater use of ramps and underpasses than did larger groups
- Even though small groups usually paralleled the simulation, groups of 6–10 were more inclined to investigate potential crossing structures than were larger groups
- 83% of all animals that encountered the Alyeska simulation were diverted from their original course; smaller groups traveled to termini whereas larger groups reversed their direction of travel

Conclusions:

- Responses of caribou groups and individuals to simulated pipelines differed according to sex, age-class, group size, and group composition

- Caribou usually paralleled structures for some distance before returning to their points of origin or eventually seeking access to the other side at the terminus of the simulation
- More study is needed to determine if caribou can learn to use ramps and overpasses, and whether caribou vary in response to pipelines depending on season
- Author felt results were inconclusive and planned to address further concerns during 1972 field season (see Child 1973)

Peer Reviewed: Yes

Child, K. N. 1975. A specific problem: The reaction of reindeer and caribou to pipelines. Pages 14–32 in J. R. Luick, P.C. Lent, D.R. Klein, and R.G. White, editors. Proceedings of the First International Reindeer/Caribou Symposium. 9–11 August 1972, Fairbanks, Alaska. University of Alaska, Fairbanks.

Study Location/Herd:
- Alaska; North Slope; Arctic Coastal Plain; Seward Peninsula

Dates of Study:
- Summer 1971, 1972

Pipeline Characteristics:

First study at Prudhoe Bay:
- Simulated elevated pipeline
- Height 0.6 m above ground
- Diameter 1.2 m
- Crossing structures included ramps (buried pipeline) 21 m and 100 m in width, height 2.4 m at vertical supports, and 1:2 slope
- Two low-profile ramps with 1:10 slopes located 610 m from each other
- Three underpasses 31 m wide and 2.4 m high
- One underpass 46 m wide and 1.2 m high
- Simulated elevated feeder pipeline with height 0.7 m above ground with underpasses as crossing structures, 0.9 m and 2.4 m in height

Second study on Seward Peninsula:
- Simulated elevated pipeline
- Diameter 0.8 m
- Height unspecified
- Crossing structures included a gravel ramp with 1:4 side slope and underpass 61 m in height

Study Design:
- Not described

Objectives:
- Determine whether or not caribou would adapt to the presence of pipeline structures and successfully cross them; to study the behavioral responses of caribou to simulated pipeline structures

Data Quantity:
- Not included in paper

Analytical Methods:
- Not included in paper

Results:
- Not included in paper

Conclusions:
- Not included in paper

Peer Reviewed: Yes

Child, K. N., and P. C. Lent. 1973. The reactions of reindeer to a pipeline simulation at Penny River, Alaska. Interim report by Alaska Cooperative Wildlife Research Unit, University of Alaska, Fairbanks. 29 pp.

Study Location/Herd:

- Alaska; Seward Peninsula; semi-domesticated reindeer

Dates of Study:

- Winter; spring; summer; fall; pre-calving; post-calving; insect period; rut

Pipeline Characteristics:

- Simulated elevated pipeline, 24 in. high
- 32-in. diameter
- Vertical supports spaced at 10-ft intervals
- Crossing structures included a gravel ramp 116 ft long, 66 ft wide, 8 ft maximal height, 1:3 slope
- Immediately adjacent to ramp was an arching underpass, 323 ft long with a maximum of 12 ft and minimum of 6 ft ground clearance

Study Design:

- Behavioral observations with binoculars and 16-mm cinematography
- Reindeer were herded into area either by snowmachines or herders on foot

Objectives:

- Evaluate seasonal responses of reindeer to the pipeline
- Evaluate changes in mother-infant behavior or sex-/age-related responses associated with the pipeline

Data Quantity:

- Not specified

Analytical Methods:

- Behavioral descriptions

Results:

- Pipeline approach distance was ~50 m, but near overpass, this distance increased to 125 m, suggesting increased visual disturbance by the higher structure
- Reindeer crossed pipeline when snow formed bridges over pipeline and when under severe insect harassment
- Little behavioral information on cow-calf pairs acquired; gathered on 2 occasions when a cow was separated by the pipeline from her calf and neither attempted to cross the pipeline to reunite
- Reindeer avoided the pipeline even after long periods of undisturbed investigation and were reluctant to cross even when herded by snowmachine or people on foot
- Group reactions to the pipeline seemed to depend on the behavior of a few individuals directly adjacent to pipeline

Conclusions:

- During all seasons, reindeer displayed general avoidance of the pipeline, frequently moving parallel to structure and crossing at the structure's termini
- Failure to use crossing structures may have been due to unfamiliarity, lack of motivation to cross, optical complexity of overpass, visual contrast between snow and dark pipeline, or audible noises emanating from pipeline supports
- Authors list several suggestions for improvement of future studies with simulated pipelines

Peer Reviewed: No

Coltrane, J. A., and R. B. Lanctot. 2001. The effect of vibration dampers on caribou (*Rangifer tarandus*) crossing success rate under the elevated Badami Pipeline, Alaska, 1999. Final report prepared for BP Exploration (Alaska) Inc., Anchorage, by LGL Alaska Research Associates, Inc., Anchorage. 20 pp.

Study Location/Herd:

- Alaska; North Slope; Prudhoe Bay oilfield; Central Arctic Herd

Dates of Study:

- Summer; postcalving; insect period; 24 June to 26 July 1999

Pipeline Characteristics:

- Badami Pipeline, elevated to minimum of 1.5 m above tundra, except for 3 areas of lower pipe totaling 600 linear ft

- No road associated with pipeline
- 40 km long
- Pipeline vibration dampeners (PVDs) hung along 4 sections, or 8,284 m (21% of total pipeline length)
- 2 PVDs placed between each pair of VSMs; one at 1/2 span, or 8.4 m from VSM, and other at 1/4 span, or 4.3 m from VSM
- PVDs hang 51 cm below pipeline

Study Design:

- Behavioral observations conducted from 2 towers between 0930 and 2230 Alaska Daylight Savings Time
- Observations from 6 time-lapse video cameras taking pictures at 6–8 second intervals set up at pipeline sections that were buried, and at pipeline sections with and without PVDs
- Sampled insect abundance and also calculated insect activity index from data collected at weather stations
- Criteria used to judge a successful group crossing was not specified
- Caribou observed within a 500 m approach zone were classified as intending to cross pipeline

Objectives:

- Quantify and compare crossing success of caribou along the Badami pipeline at sections with and without PVDs
- Determine if group size, composition, and insect activity affected caribou crossing success and behavior

Data Quantity:

- 94 caribou groups comprising 3,474 individuals observed from towers
- For total caribou observed with cameras, see results below

Analytical Methods:

- Compared caribou crossing success in one area with PVDs and one area without PVDs
- Compared crossing success of groups using chi-square tests of independence
- Compared percentage of group crossing using analysis of variance (ANOVA)
- Compared crossing success of group-size categories using chi-square test of independence

Results:

- 37% of caribou near pipelines with PVDs crossed, compared with 58% of groups near pipelines without PVDs; difference was not significant
- Crossing success of individual caribou was significantly different between sites with and without PVDs; 27% of caribou near pipelines with PVDs crossed, compared with 63% near pipelines without PVDs
- No significant difference in average group size of caribou near pipelines with PVDs and without PVDs
- No significant difference in sex and age class of caribou near pipelines with PVDs and without PVDs
- No significant effect of group size on crossing success at all pipeline configurations combined
- No significant effect of group type on crossing success at all pipeline configurations combined
- Mosquitoes present on 12 sampling days and absent on 14 days; oestrid flies considered to be present for only 4 hr over 2 days
- For both pipeline configurations, mosquito presence significantly decreased likelihood of caribou crossing all pipeline configurations combined, and for sections with PVDs
- Mosquito presence had no significant effect on crossing success at sites without PVDs
- During camera monitoring, mosquitoes were present on 12 days and absent on 23 days; oestrid flies present on only 2 days
- 813 caribou recorded crossing sections of pipeline with PVDs
- 639 caribou recorded crossing sections of pipeline without PVDs
- 1,034 caribou recorded crossing sections of buried pipeline at river site

Conclusions:

- Based on tower observations, caribou may have been less likely to cross Badami Pipeline where PVDs are present

- Authors felt flaws in study design may have biased their results
- One plot with PVDs was located near the Sagavanirktok River and caribou may have been traveling through the river corridor on way to coast with no intention of crossing the pipeline located in the plot
- Another plot was located near the Endicott Pipeline and road; vehicle traffic on road may have funneled caribou into study area or altered crossing frequencies
- Cameras were only useful in recording whether caribou crossed the pipeline, but viewing angle was not large enough and pictures were not recorded frequently enough to quantify crossing success
- May have incorrectly assumed that caribou approaching within 500 m of pipeline intended to cross it; smaller approach zones would increase crossing success estimates
- This study suggested that group size and group type did not influence whether or not caribou crossed pipelines with and without PVDs
- Recommendations for future study included gathering paired observations of caribou in similar stretches of pipeline and habitats both with and without PVDs; cameras should be located at paired sites, with measurements focusing on magnitude of animals crossing, not evaluating crossing success; crossing success should be compared at same sites before and after installation of PVDs

Peer Reviewed: No

Cronin, M. A., W. B. Ballard, J. Truett, and R. Pollard. 1994. Mitigation of the effects of oil field development and transportation corridors on caribou. Final report to the Alaska Caribou Steering Committee prepared for Alaska Oil and Gas Association, U.S. Fish and Wildlife Service, Alaska Department of Fish and Game, and North Slope Borough, by LGL Alaska Research Associates, Inc., Anchorage. 113 pp.

Study Location/Herd:
- Alaska; North Slope; Prudhoe Bay; Milne Point; Endicott, Kuparuk; Central Arctic Herd; Teshekpuk Lake Herd; Porcupine Herd; Nelchina Herd

Dates of Study:
- Various dates, studies conducted within Prudhoe Bay and along the Trans-Alaska Pipeline since 1970

Pipeline Characteristics:
- Various designs

Study Design:
- Literature review of published and unpublished reports and available unpublished data sets concerning the effects of oilfield development on caribou of the North Slope

Objectives:
- Assess the impacts of oilfield development on caribou at the population and individual level
- Identify important types of mitigation measures for caribou in arctic Alaska
- Identify mitigation measures for which effectiveness has not been clearly shown or adequately evaluated
- Identify other mitigation measures that warrant consideration
- Make recommendations for future studies of possible mitigation measures

Data Quantity:
- 160 publications were reviewed

Analytical Methods:
- Literature review with some reanalysis of previous data (Kuparuk and Endicott pipeline height selection)

Results:
- Measures to mitigate the impact of pipelines on caribou passage include elevated and buried pipelines, separation of roads from pipelines, construction of gravel crossing ramps, and regulation of vehicle and foot traffic
- Elevated pipelines with minimum heights of 1.5 m (5 ft) have been effective in facilitating the movements of caribou, although heights >1.5 m (5 ft) may be preferred by caribou
- At heights of at least 2.1 m (6.9 ft) above ground, the Trans-Alaska Pipeline allows passage of the Nelchina Herd

- Crossing success of caribou encountering elevated pipelines was reduced where pipelines were located near (25–50 m) roads with high traffic rates (15 or more vehicles/hr); studies showed crossing success in these areas was ~50% lower than in reference areas
- Separation of roads and pipelines to recommended distance of at least 152 m (500 feet) decreased possibility of forming a barrier to caribou movements
- Roads without adjacent pipelines and with moderate traffic levels (<15 vehicles/hr) may not be significant barriers
- Effects of caribou group size on crossing success were variable among studies
- No conclusive evidence was found to indicate that ramps facilitate crossings of pipelines elevated at least 1.5 m or reduce time spent by caribou adjacent to pipelines; unclear whether ramps are used opportunistically or whether caribou prefer them as crossing sites
- Effectiveness of ramps may be improved by extending structures away from pipeline (because short ramps are likely to be missed by caribou) and by using low-grade slopes on all sides of ramps
- No systematic studies of effectiveness of long buried sections of pipeline had been done on the North Slope, but buried sections of the Trans-Alaska Pipeline were effective crossing structures for the Nelchina Herd
- Extended burial of pipelines along road beds may be an effective mitigation measure
- No evidence was found regarding the effectiveness of crossing structures in facilitating movements of nursery bands
- Habituation to pipeline structures may occur

Conclusions:
- Elevate all pipes at least 1.5 m (5 ft) above ground level
- Buried pipeline may be an effective alternative, but must consider cost, maintenance, suitability of substrate, and loss of wetlands
- Limit number of roads on calving areas
- Separate pipelines from roads by at least 152 m (500 ft)
- Where large groups of caribou cross pipelines, use elevated pipe with road-pipe separation, buried pipe, or possibly ramps
- Regulate vehicle traffic when caribou are moving through oilfields
- Other mitigation measures may include employing personnel in oilfields to observe interactions with caribou and enforce regulations, prohibit unauthorized public access and hunting from roads within oilfields, maintain fixed-wing aircraft flight altitudes of ≥457 m (1500 ft)
- Recommendations for future studies were provided

Peer Reviewed: Yes (steering committee)

Curatolo, J. A. 1983. Caribou movements, behavior, and interactions with oil-field development. A synthesis of pertinent research and unpublished 1982 field work in the Eileen West End, Kuparuk Oil Field, Alaska. Final report prepared for Sohio Alaska Petroleum Company, Anchorage, by Alaska Biological Research, Fairbanks. 74 pp.

Study Location/Herd:
- Alaska; North Slope; Kuparuk Oilfield; Central Arctic Herd

Dates of Study:
- Various studies, late 1970s to early 1980s

Pipeline Characteristics:
- Trans-Alaska Pipeline
- Kuparuk pipeline
- Pipeline characteristics not specified

Study Design:
- Literature review

Objectives:

- Describe caribou movements and use of Eileen West End area (western Prudhoe Bay oilfield) during calving/postcalving, mosquito season, and oestrid fly season
- Describe effects of roads, pipelines, drill rigs, production facilities, and pipeline camps on the movements of caribou
- Describe caribou reactions to aircraft
- Discuss mitigative measures in relation to oil development
- Includes appendix of annotated reports pertinent to caribou/oilfield interactions and the Eileen West End

This annotation focuses only on caribou reactions to pipelines and other linear structures

Data Quantity:

- 35 publications dating from 1959 to 1983

Analytical Methods:

- Review of literature, with mapping of caribou movements along Kuparuk River in 1982

Results:

- Four types of linear structures were evaluated—road with no traffic, road with traffic, pipeline with road with no traffic, and pipeline adjacent to road with traffic—with only the last design substantially impeding caribou movements
- Caribou often reacted strongly when crossing a road with traffic and tended to parallel roads with traffic more often than those without traffic
- Although caribou may have hesitated upon initial approach, they crossed pipelines associated with roads with no traffic at a frequency similar to natural conditions
- Caribou may parallel pipelines prior to crossing
- Major factors affecting crossing of an elevated pipeline by caribou appear to be topography and insects
- Crossing sites often occur near preferred habitat for travel such as river drainages, margins of lakes, sloughs, and ponds
- During insect harassment, caribou may leave preferred habitat and encounter pipeline at less preferred habitats
- Active selection for pipe height within the range of 60–170 in. has not been demonstrated and it appears that 5-ft-minimum pipe height in the absence of traffic allows passage of caribou
- Caribou have shown selection for crossing at ramps, perhaps due to elimination of visual stimulus of elevated pipe

Conclusions:

Author discusses mitigative measures regarding pipelines and linear structures

- Mitigative measures in place include 5-ft minimum height for elevated pipelines, installation of crossing ramps, and prohibition of construction activities during the mosquito season
- Other measures should be taken, including spatial separation of pipelines from major roads, deflection of caribou around areas of intense development, traffic control program during July to minimize disturbance to caribou traveling to the coast for relief from mosquito harassment, and use of north/south-oriented pipelines when possible to minimize encounters with caribou

Peer Reviewed: No

Curatolo, J. A. 1984. A study of caribou response to pipelines in and near the Eileen West End, 1983. Final report prepared for Sohio Alaska Petroleum Company, Anchorage, by Alaska Biological Research, Fairbanks. 32 pp.

Study Location/Herd:

- Alaska; North Slope; Kuparuk Oilfield; western Prudhoe Bay Oilfield; Central Arctic Herd

Dates of Study:

- Summer; postcalving; insect period; 25 June to 29 July 1983

Pipeline Characteristics:

- Two different elevated pipelines, the Kuparuk Pipeline (Pipe Site) and pipeline to SOHIO S Pad (S-Pad pipeline)
- Kuparuk Pipeline and S-Pad pipeline located 1.5 mi apart
- Specific diameters and heights of pipelines not given
- Distance between VSMs not specified
- Height of S-Pad pipeline at least 20 ft above ground

Study Design:

- Behavioral observations from 10-ft-high tower and an observation blind situated on a 15-ft high riverbank
- Data from a control site was collected during 1981 and 1982 (see Curatolo et al. 1982, Curatolo and Murphy 1983; methods not repeated here) and compared with data collected from 2 sites, Pipe Site and S Pad, during 1983 after completion of S-Pad pipeline
- Crossing success was not defined (presumed to be identical to Curatolo et al. 1982 and Curatolo and Murphy 1983)

Objectives:

- Determine if number and composition of caribou moving along the Kuparuk River during mosquito season differed between 1981 and 1982
- Determine whether crossing frequency and pipe-height selection of the Kuparuk Pipeline differed among 3 years of study
- Determine if caribou would cross multiple structures (2 pipelines and a road)
- Determine if caribou routes of travel differed in 1982 before S-Pad pipeline was built, compared with 1983 after construction

Data Quantity:

- 231 groups of caribou observed Pipe Site 1981–1983
- 136 groups of caribou observed at control site 1981–1982
- 36 groups of caribou observed at S-Pad pipeline 1983

Analytical Methods:

- Mapped movements in two areas
- Described frequency of pipeline crossing both before and after new pipelines constructed in 1983 in two locations by insect activity, group type, and group size
- Analyzed using chi-square tests of independence of crossing success before and after construction
- Compared pipeline height at crossing locations with available heights, and pipeline height used (greater or less than 100 in.) compared to availability within 0.125 miles
- Recorded numbers of mild, moderate, and strong reactions to pipelines

Results:

- Quantified age and sex of caribou observed near Prudhoe Bay 1983, in the S-Pad area 1983, and the Pipe Site 1981–1983 during different time periods
- Movement patterns of caribou in the Pipe Site (part of Kuparuk pipeline) were similar among all years of study (1981–1983)
- Movement patterns of caribou near the S-Pad pipeline were similar between 1982 and 1983
- The effects of mosquitoes on movement patterns and direction of travel are described
- No significant differences in frequencies of caribou groups crossing the Kuparuk Pipeline during 1981–1983
- No significant differences in crossing frequencies among Pipe Site, S Pad, and control areas for all years
- Within-site variation in crossing frequency was high, with frequencies consistently higher during periods of mosquito and oestrid fly harassment than during periods without insect activity
- During insect-free periods, caribou show more randomly directed movements
- During mosquito harassment, caribou must cross the pipeline as stimulus to reach the coast is high
- During oestrid fly harassment, caribou are attracted to pipeline for fly relief

- No differences in frequencies of crossings by different types or sizes of groups
- During all years, an apparent selection for high pipe resulted from tendency of caribou to travel in riparian habitat in the eastern portion of study area, which happened to have consistently high pipe heights
- When all pipe heights at VSMs within 0.125 miles of a group's route of travel were analyzed, no selection for high versus low pipe
- 53% of crossings occurred at pipe heights >100 in. and 47% of crossings occurred at heights <100 in
- Reactions of caribou crossing Kuparuk and S-Pad pipelines were similar among years and sites
- <20% of caribou crossing either pipeline reacted severely whereas 62% of caribou crossing a pipeline adjacent to a road with traffic reacted severely (Curatolo and Murphy 1983)
- Roads with high traffic, about 1 vehicle/4 min (15 vehicles/hr), situated next to pipelines significantly reduced crossing success of caribou

Conclusions:

- Topographic features were important factors affecting local movements of caribou
- Crossing frequencies at S-Pad and Kuparuk pipelines were similar to control situation
- Overall crossing frequency of caribou was not reduced by having to cross two separate pipelines 1.5 mi apart
- Percent of strong responses by caribou crossing both pipelines was low, indicating that pipelines alone may not be perceived by caribou to be an obstacle

Peer Reviewed: No

Curatolo, J. A. 1985. Caribou responses to the pipeline-road complex in the Kuparuk Oilfield, Alaska [abstract only]. Pages 62 in A. M. Martell and D.E. Russell, editors. Caribou and Human Activity: Proceedings of the First North American Caribou Workshop. 28–29 September 1983, Whitehorse, Yukon. Canadian Wildlife Service, Ottawa, Ontario.

Study Location/Herd:

- Alaska; North Slope; Kuparuk; Central Arctic Herd

Dates of Study:

- Summer: calving; postcalving; insect period; 22 June to 5 August 1981 and 4 June to 1 August 1982

Pipeline Characteristics:

- Not specified

Study Design:

- Behavioral observations at 4 study areas and 2 control sites

Objectives:

- Describe behavior, movement patterns, habitat preferences, and reactions to environmental and man-made stimuli

Data Quantity:

- Not described

Analytical Methods:

- Not described

Results:

- Caribou reacted with increasing intensity to road with no traffic, a pipeline, a road with traffic, and a pipeline associated with traffic
- Within the range examined, caribou did not select crossing sites on basis of pipeline height
- Insects and topography were most important factors influencing the selection of pipeline crossing sites, traveling through all habitats to escape insects, but following ridges when insects were absent

Conclusions:

- Abstract was limited to results

Peer Reviewed: Yes

Curatolo, J. A., and S. M. Murphy. 1983. Caribou responses to the pipeline/road complex in the Kuparuk Oilfield, Alaska, 1982. Final report prepared for ARCO Alaska, Inc., Anchorage, by Alaska Biological Research, Fairbanks. 81 pp.

Study Location/Herd:
- Alaska; North Slope; Kuparuk Oilfield; Central Arctic Herd

Dates of Study:
- Summer; late calving/postcalving; insect period; 4 June to 1 August 1982

Pipeline Characteristics:
- Kuparuk Pipeline, diameter 16 in., elevated to minimum of 5 ft at VSMs
- 2 study areas, each with different pipe/road characteristics
- Pipe site contained Kuparuk Pipeline and no road (Spine Road was 2 mi north of site), pipe elevated 60–170 in
- Pipe-road site contained Kuparuk Pipeline adjacent to Spine Road, pipe elevated 60–110 in

Study Design:
- Behavioral observations conducted from towers
- 4 study plots, including 2 study (treatment) plots with pipelines and 2 control (reference) plots south of each treatment plot
- Successful crossing defined as >50% of group members crossing the pipeline (and road, if present)
- Compared proportion of caribou entering the control plots and crossing the northern border (representing hypothetical pipelines) to proportion of caribou entering treatment plots and crossing the northern border (consisting of actual pipelines/roads)

Objectives:
- Determine the effects of the Kuparuk pipeline/road complex on caribou movements, emphasizing crossing success and routes of travel
- Determine whether caribou preferred certain habitats, pipeline heights, or pipeline configurations for crossing sites
- Determine reactions of caribou to pipelines and roads under different environmental conditions

Data Quantity:
- 3,723 caribou observed, classified by sex and age

Analytical Methods:
- Compared treatment sites with control sites
- Compared pipeline height to availability in 10-in. increments, using chi-square tests
- Compared crossings at pipe <100 in. to pipe >100 in., and number of crossings by different habitat types

Results:
- 22% of caribou in study area classified as yearlings
- Overall number of caribou in area decreased compared to 1981 with fewer cow-calf groups in 1982, but more bull groups than in 1981
- Crossing frequency was lowest during calving and postcalving (pre-insect emergence), although sample sizes were small
- Crossing frequency increased during the mosquito season, but was significantly lower in the pipe-road site than all other study plots, a finding consistent with 1981 data
- No significant differences in crossing frequency were found among the 4 study plots during oestrid fly harassment, compared to 1981 when crossing frequency was lowest at pipe-road site
- There was a significant seasonal difference in crossing frequency at pipe and pipe-road sites, but not in the control plots
- Crossing frequencies at pipe site during mosquito and oestrid fly seasons were similar, whereas it was considerably lower during the calving/postcalving season
- Crossing frequency at pipe-road site was similar during the calving/postcalving and mosquito season, whereas it was higher during oestrid fly season
- Multiple crossings by the same groups occurred more often during oestrid fly season

- At pipe-road site, caribou showed no preference for pipe height
- Although height selection at the pipe site was not random, there were no consistent trends toward selection of low or high pipe
- Factors other than pipe height seemed to influence crossing-site selection
- No significant differences were found in selection of low pipe (<100 in.) or high pipe (>100 in.) during either mosquito or oestrid fly harassment, although sample sizes were small
- When insects were absent, caribou used higher pipe heights significantly more
- Selection of high pipe heights during insect-free periods may be related to topography rather than pipe-height preference
- In presence of insects, harassed caribou tended to parallel pipeline, encountering a similar frequency of low and high pipeline
- Group crossings in 1981 and 1982 showed no significant difference in crossing sites based on whether or not caribou could see tundra across the pipeline, a result differing from other studies that suggested caribou avoid high berms that restrict their vision
- At pipe site, 18% and 16% of groups crossed over buried pipeline in 1981 and 1982, respectively
- At pipe-road site, 5% and 6% of groups crossed over buried pipeline in 1981 and 1982, respectively
- At both sites, buried pipeline accounted for <1% of the pipeline, so crossing frequencies were significantly greater than expected based on availability
- Pipe configuration at pipe-road site may have contributed to smaller percentage of caribou using buried sections; pipe crossed under road, but when it reappeared on the other side of the road, it paralleled it before crossing back
- Groups tended to fragment at the pipe-road site, which may have been related to traffic on road; yearlings tended to be left behind and often appeared disoriented
- Overall rates of movement were significantly different between seasons
- Caribou were relatively sedentary during calving and postcalving compared to mosquito and oestrid fly seasons; rate of movement was highest during insect harassment
- No significant differences were found in movement rates among study plots during calving/postcalving
- No significant differences were found in movement rate between pipe site and pipe control, but caribou at pipe-road site traveled significantly faster than caribou in the pipe-road control
- During the oestrid fly season, caribou spent more time standing
- No significant differences were found in movement rates between study areas during oestrid fly harassment
- East–west travel, indicating that caribou were paralleling the Kuparuk pipeline, was greater at both treatment sites during 1981 and 1982 than controls, but differences were not significant
- Groups attempting to cross in the pipe-road site often paralleled the pipeline, with vehicles causing caribou to run away from road
- During late July–early August 1981 and 1982, 90% of the distance traveled by caribou groups was on gravel surfaces, such as roads, pads, and well sites, corresponding with presence of oestrid flies
- Caribou showed least reaction to crossing roads, followed by a pipeline alone, a road with traffic, and a pipeline paralleling a road with traffic
- Caribou showed significantly more strong reactions when crossing pipeline associated with traffic compared with any other linear structure
- 91% of 4,668 caribou that crossed roads with no traffic showed no reaction, 3% showed mild reactions, and 1% showed moderate reactions
- 55% and 76% of 2,263 caribou that crossed the pipeline showed no or mild reactions during mosquito and oestrid fly harassment, respectively
- 75% of 2,263 caribou crossing buried section of pipe showed no behavioral reaction and 25% crossing under elevated pipeline showed no reaction
- 5,016 caribou were observed crossing roads with traffic, and mainly exhibited moderate or strong reactions during all seasons

- 91% and 17% of 341 caribou crossing a pipeline associated with traffic showed moderate or strong reactions during the mosquito and oestrid fly season, respectively
- Average rate of vehicle passage on Spine Road was 1 vehicle/4 min (15 vehicles/hr)
- Strength of behavioral reactions by caribou depended on proximity of vehicles; most strong reactions occurred when caribou encountered vehicles while crossing roads

Conclusions:

- Most caribou showed no reaction when crossing road with no traffic
- Although caribou freely crossed a road with traffic and a pipeline, strong reactions were more frequent when crossing roads with traffic
- Caribou crossed pipelines associated with road and traffic at significantly lower frequencies than either structure by itself, and showed an increase in number and strength of reactions upon approach and crossing, increased rate of movement, increase in paralleling of pipeline, and increase in group splitting
- Crossing sites may have been influenced more by habitat than by pipe height, with caribou selecting drier habitat for travel
- Although caribou under mosquito harassment had high crossing frequencies, the greatest number of strong reactions to linear structures were recorded during this period
- Caribou did not react as strongly to linear structures when under oestrid fly harassment, showing an increase in multiple pipeline crossings, use of gravel, decreased reactions when crossing pipelines associated with traffic, and increased crossing success

Management recommendations include:

- Separating roads with traffic from elevated pipelines
- Strategic placement of crossing ramps or other sections of buried pipe
- Conduct a region-wide analysis of caribou movements, distribution, and habitat use, to provide basis for determining where site- specific mitigation measures would be most effective

Peer Reviewed: No

Curatolo, J. A., and S. M. Murphy. 1986. The effects of pipelines, roads, and traffic on the movements of caribou, *Rangifer tarandus*. Canadian Field-Naturalist 100: 218–224.

Study Location/Herd:

- Alaska; North Slope; Arctic Coastal Plain; Kuparuk Oilfield; Central Arctic Herd

Dates of Study:

- Insect period; late June; July; early August; 1981–1983

Pipeline Characteristics:

- Elevated to minimum height of 1.5 m
- Diameter 40 cm
- Areas bordering roads and pads with varying traffic levels
- Ramps created as crossing structures by burying pipelines; ramp widths 20, 30, and 50 m

Study Design:

- Behavioral observations conducted from towers; no set schedule for observations, rather an effort to observe caribou when present for as long as present
- Observations conducted at 7 sites, including 2 control (reference) sites
- Groups were considered successful in crossing the pipeline (and road, if present) if >50% of group members crossed
- Compared proportion of caribou entering the control sites and crossing the northern border (representing hypothetical pipelines) with proportion of caribou entering study plots and crossing the northern border (consisting of actual pipelines/roads)

Objectives:

- Quantify crossing frequency of caribou encountering pipelines and roads
- Evaluate whether pipeline height affected selection of crossing sites
- Evaluate whether ramps were preferred as crossing sites

Data Quantity:

- 794 caribou groups comprising 21,912 caribou were observed at 7 different study sites, including 2 control sites

Analytical Methods:

- Compared crossing success in 7 plots with pipelines, roads and pipelines, or controls (hypothetical pipelines)
- Compared crossing frequencies with chi-square tests and compared pipeline height selection with Mann-Whitney tests

Results:

- Number and movement patterns of caribou near pipelines depended on presence of insects
- When mosquitoes were present, caribou traveling north represented 80% of observations and when mosquitoes were absent, 77% of observations were caribou traveling south
- When oestrid flies were present, caribou exhibited nondirectional movement, resulting in repeated crossings of pipeline by groups; caribou tended to seek relief from flies in shade of pipeline
- Caribou reacted more severely when crossing the road bordered by a pipeline compared to either a road or a pipeline
- Crossing frequency was lowest where traffic frequency next to the pipeline was highest
- There was no difference between the percentage of cow-calf groups and bull groups that crossed the pipeline
- Large groups (>100 caribou) tended to be less successful in crossing pipelines bordered by a road than smaller groups, but there was no difference in crossing frequency at sites with only a pipeline
- Mean pipeline height at crossing sites did not differ significantly from the mean pipeline height
- Crossing ramps were used more frequently than expected based on availability

Conclusions:

- Caribou readily crossed a single structure such as a pipeline or a road, but less frequently crossed a pipeline bordered by a road
- Separation of pipelines and roads may facilitate caribou passage
- The minimum pipeline height of 150 cm was adequate to accommodate caribou crossings
- Caribou used ramps to cross the pipeline, although ramps may have been less effective in areas with heavy traffic

Peer Reviewed: Yes

Curatolo, J. A., S. M. Murphy, and M. A. Robus. 1982. Caribou responses to the pipeline/road complex in the Kuparuk Oilfield, Alaska, 1981. Final report prepared for ARCO Alaska, Inc., Anchorage, by Alaska Biological Research, Inc., Fairbanks. 63 pp.

Study Location/Herd:

- Alaska; North Slope; Kuparuk Oilfield; Central Arctic Herd

Dates of Study:

- Summer; postcalving; insect period; 22 June to 5 August 1981

Pipeline Characteristics:

- Kuparuk Pipeline
- Pipe site study plot (1.5 mi long by 0.5 mi wide) contained a pipeline and no road, pipeline height range 60–170 in.
- Pipe-road study plot (1.25 mi long by 0.5 mi wide) paralleled the Spine Road, distance unspecified, pipeline height range 60–110 in.
- Diameter of pipeline unspecified

Study Design:

- Behavioral observations conducted from towers in plots
- Crossing was considered successful if >50% of group members crossed the pipeline (and road, if present)

- Movement data was compared to two control sites similar in area to study sites and located 1–2 mi south of each study site
- Compared proportion of caribou entering the control areas and crossing the northern border (representing hypothetical pipelines) to proportion of caribou entering study plots and crossing the northern border consisting of actual pipelines/roads

Objectives:

- Evaluate effects of Kuparuk pipeline/road complex on caribou movements, emphasizing crossing success and routes of travel
- Evaluate specific pipe configurations, places, or heights that caribou selected for crossing
- Quantify reactions of caribou to pipeline and road under different environmental conditions

Data Quantity:

- 5,229 caribou were observed and classified to sex and age during the study

Analytical Methods:

- Chi-square tests of crossing success at 4 different plots (2 pipeline sites, 2 controls) and among different height categories
- Conducted chi-square tests of use of areas of buried pipe
- Used Kruskal-Wallis test to compare rate of group movement among plots
- Used chi-square test to compare direction of travel among sites

Results:

- 65% of 221 groups observed in the pipe site crossed the pipeline at least once, compared with 67% of 92 groups which crossed the corresponding boundary of the control site
- 41% of 113 groups observed in the pipe-road site crossed the pipeline at least once, compared with 67% of 69 groups which crossed the corresponding boundary of the control site
- Impossible to know what percent of caribou classified as unsuccessful actually "intended" to cross the pipeline
- During mosquito and oestrid fly harassment, crossing success at pipe site, pipe control, and pipe-road control were similar and significantly higher than at the pipe-road site
- At pipe site, 58% of 67 groups that entered study area from south and exited to north crossed the pipeline, compared with 48% of 29 groups at control site
- At pipe-road site, 27% of 37 groups that entered study area from south and exited to north crossed the pipeline, compared with 83% of 12 groups at control site
- Percentage of crossings at each site was similar among cow-calf groups, bull groups, and various group size categories
- Repeated crossings of pipeline involved 70% of individuals and 30% of groups of 2–11 caribou and occurred mostly during oestrid fly harassment
- At pipe-road site, no significant differences were found in frequency of pipeline crossings among pipe-height categories
- At pipe-road site, <1% of pipe length was buried, but 7% of groups crossed this section, significantly greater than availability
- At pipe-site, significant differences were found in crossing frequency among pipe heights; heights 70–79, 80–89, and 110–119 in. were used less than expected, whereas heights >130 in. were used more than expected
- At pipe-site, <1% of pipe length was buried, yet 17% of groups crossed this section, significantly greater than availability
- Habitat within each study site was quantified
- East–west travel within both pipeline sites was significantly greater than within the control sites, indicating paralleling movements
- Rate of group movement for the entire period and both insect periods was significantly greater at pipeline sites than at control sites, but there were no differences between pipeline sites or between controls
- Average rate of movement during oestrid fly harassment was greater than during mosquito harassment

- Cow-calf groups moved faster than bull groups
- Few behavioral reactions of caribou to roads without traffic were noted
- Caribou spent significantly more time standing and traveling on roads during oestrid fly harassment than during mosquito harassment
- In the absence of traffic, 44% of 32 caribou showed no reaction while crossing the Kuparuk pipeline, 19% showed mild reactions, 16% moderate reactions, and 22% strong reactions
- In the presence of traffic, 28% of 25 caribou showed mild reactions while crossing the corridor, 16% showed moderate reactions, and 56% showed strong reactions
- Caribou approaching the pipeline as a vehicle passed usually retreated in the opposite direction
- Caribou generally moved greater distances in reaction to vehicles during the mosquito season than during the oestrid fly season
- Caribou often approached the pipe slowly, then trotted under the pipe for several meters, and slowed again after crossing
- Some caribou crossed by crouching with legs bent and head low to the ground even though the pipeline afforded sufficient clearance
- Caribou that showed strong reactions, often yearlings, during crossings often were left behind on the south side of the pipeline
- Crossing by a group of caribou often was initiated by a single individual

Conclusions:
- Elevated pipeline at pipe site did not appear to affect caribou movements
- Caribou responded to pipelines more often during mosquito harassment than during fly harassment
- Caribou tended to select crossing sites at heights >130 in., but this may have been due to local topography
- Vehicles moving on road adjacent to a pipeline evoked disturbance behavior
- Caribou showed strong selection for crossing buried sections of pipeline

Authors made these suggestions:
- Use ramps in areas of concentrated caribou movements
- Regulate vehicle traffic during mosquito season to reduce disturbance to caribou by consolidating work into localized areas, limiting numbers of vehicles along roads, allowing heavy traffic at night when mosquito levels are low
- Separate road and pipeline by at least 1 mi
- Consider making pipeline design consistent with natural topography and environmental stimuli

Peer Reviewed: No

Curatolo, J. A., and A. E. Reges. 1986. Caribou use of pipeline/road separations and ramps for crossing pipe/road complexes in the Kuparuk Oilfield, Alaska, 1985. Final report prepared for ARCO Alaska, Inc., and Kuparuk River Unit, Anchorage, by Alaska Biological Research, Fairbanks. 106 pp.

Study Location/Herd:
- Alaska; North Slope; Kuparuk Oilfield; Oliktok Point Road; Central Arctic Herd

Dates of Study:
- Summer; postcalving; insect season; 27 June to 31 July 1985

Pipeline Characteristics:
- Elevated pipeline
- 6 study plots located along Oliktok Point Road, with different road/pipe and ramp configurations
- Ramps ranged in length 120–280 ft, width 30–38 ft, and thickness 8–12 ft
- Mean pipeline/road separation distance for each area ranged from 223 to 676 ft

Study Design:
- Behavioral observations conducted from towers or from pickup trucks parked on road

Objectives:
- Compare the effectiveness of pipeline/road separations with the effectiveness of conventional crossing ramps

- Compare the effectiveness of pipeline/road separations including ramps with the effectiveness of pipeline/road separations lacking ramps
- Determine minimum separation distance required between a pipeline and road to increase crossing success
- Examine the impact of traffic on crossing success
- Evaluate the effectiveness of a new ramp design

Data Quantity:
- Observations of 15,822 caribou among 6 study plots

Analytical Methods:
- Compared caribou reactions and crossing success among plots with different road/pipeline separation distances using chi-square tests
- Used chi-square tests to compare crossing success before and after blocking access to ramps

Results:
- Most (62%) observations occurred during periods of no insect activity; 18% and 20% occurred during periods when mosquitoes and oestrid flies were present, respectively
- General lack of mosquitoes in 1985 season resulted in few observations during that important insect condition, compared with previous years
- Most caribou that displayed strong behavioral reactions to pipeline and vehicles were within 300 ft of stimuli
- 8.9% showed strong reactions to vehicles, 5.9% to both pipelines and vehicles, and 2.9% to pipelines
- 80% of caribou displayed strong reactions to vehicles within 400 ft; 19% reacted strongly at 400–800 ft; beyond 800 ft, almost no caribou reacted strongly
- 65–99% of caribou crossed pipeline/road complexes, except in one study area where traffic rates exceeded 5 vehicles/hr and insects were absent; separation distance between pipeline and road in this area did not exceed 300 ft, while in other areas at least 42% of pipeline length was >300 ft from road
- Number of caribou crossings was significantly less than expected for pipeline/road separation distances <300 ft.
- Blocking ramps midway through study did not seem to affect the proportion of caribou successfully crossing the pipeline

Conclusions:
- Caribou frequently crossed pipeline/road complexes in all study plots, except in one plot where traffic rates were high
- Recommended minimum separation distance of 400 ft between pipeline and road for areas of high traffic and heavy use by caribou
- Sections of adequate separation (>400 ft) should be at least 1/4- to 1/2-mi long
- Dimensions of pipeline/road separations should be site-specific to allow for variations in caribou movement due to insect activity, traffic rates, geographic location, and directional orientation of pipeline/road corridors
- Although caribou used ramps preferentially, they were not necessary for successful crossings; authors suggested that the ramps they studied should be lower and longer to facilitate their use by caribou

Peer Reviewed: No

Eide, S. H., S. D. Miller, and M. A. Chihuly. 1986. Oil pipeline crossing sites utilized in winter by moose and caribou in southcentral Alaska. Canadian Field-Naturalist 100: 197–207.

Study Location/Herd:
- Alaska; southcentral; Copper River drainage; Gulkana River drainage; Nelchina Herd

Dates of Study:
- Winter; 2–5 survey days monthly during October–April

Pipeline Characteristics:
- Trans-Alaska Pipeline
- Elevated pipeline, average height at VSMs 7.4 ft, range 1–13 ft

- Pipeline diameter 5 ft (including insulation)
- Vertical support members (VSM) spaced at 60-ft intervals
- Crossing structures included underpasses >10 ft high and 60 ft long; buried sections averaging 0.7 mi in length; short buried sections (sag-bend crossings) <60 ft long

Study Design:

- Track surveys to identify where moose and caribou crossed the pipeline

Objectives:

- Evaluate use of crossing structures designed to allow free passage of moose and caribou
- Evaluate where animals chose to cross pipeline

Data Quantity:

- 1,309 moose track encounters
- 6,304 caribou track encounters

Analytical Methods:

- Compared pipeline height at crossing sites with pipeline height availability in 1-ft categories, and amount of buried vs. elevated pipeline, using chi-square goodness-of-fit tests
- Subdivided study area into smaller subsections and tested separately

Results:

- 148.1 km of pipeline was surveyed, with 7.3% of segments (defined as area between two adjacent VSMs with height of section calculated by averaging heights at the 2 VSMs) at least 3.1 m (10 ft) above ground
- Average height of designated big game crossings (DBGCs) 10.3 ft, with range of 6.5–14.8 ft
- For both moose and caribou, 82% and 75%, respectively, of average heights at the two VSMs bordering crossing points were within ~1 ft of the height at the actual crossing point, indicating that it was appropriate to use "as-built" specifications to estimate the availability of vertical clearance heights under the pipeline
- Moose did not cross under sections of pipeline with vertical heights in proportion to their occurrence, selecting against sections <5 ft in height; only 10 crossings occurred at heights <5 ft
- For all sections of pipeline <11 ft height, 42 (3.2%) of moose encounters were considered deflections where moose approached, but did not cross; no deflections occurred at buried sections
- 16% of moose that were classified as deflecting eventually crossed the pipeline after paralleling it for several sections
- 65% of sections moose used to cross the pipeline were crossed by a single set of tracks, with a maximum of 8 tracks at a DBGC
- Moose used sections with buried pipe significantly less often than sections with elevated pipe
- Moose did not select for DBGCs
- 70.3% of caribou tracks recorded were eastbound during fall migration
- In some areas, the frequency distribution of heights measured at crossings differed significantly from expected values based on distribution of available pipeline heights
- Overall, caribou selected against vertical clearances <7 ft; pattern for positive selection was less clear, but seemed to select for clearances >8 ft
- In analysis by subsections of pipeline, caribou showed negative selection for lowest clearance categories and positive selection for higher categories
- 2.7% of caribou approaching the pipeline deflected, with 99% of these occurring at elevated pipe
- Deflections by caribou were seen at all pipeline heights, except for those <5 ft and >12 ft, but crossings at these heights were rare
- In 1.4% of all crossings, caribou crossed under a pair of VSMs rather than in the section between them, meaning that they had about half the vertical clearance because of the cross members on the VSMs
- Lowest vertical height of a caribou crossing was 3.2 ft and under a VSM
- 13 caribou crossings occurred at heights <4 ft, all of which were under a VSM
- 5 or more sets of caribou tracks were observed at 33.7% of crossed segments

- In some sections, caribou selection for buried pipe was highly significant, using those sections 2–4 times more often compared to expected values
- This result may not mean that caribou actively looked for buried sections, however, because most buried sections were located in corridors known to be used by caribou before construction
- Only 2 deflections of caribou from buried sections were seen
- Caribou did not select for DBGCs; 30 caribou deflected at 2 DBGCs, both of which had vertical clearances >10 ft
- 23 caribou crossings occurred at 2 sag-bends; 19 caribou crossed under an elevated section adjacent to a sag-bend while 17 caribou also crossed over this same sag-bend; one caribou deflected at a sag-bend

Conclusions:

- Studies demonstrating selectivity for or against pipeline features are complicated by the nonrandom distribution of the features
- Caribou readily used buried segments, which may indicate active selection or continued use of traditional migration routes in which those special crossings were placed
- No consistent pattern of selection was seen for moose crossings, but caribou tended to avoid pipeline <7 ft in height
- No evidence that moose or caribou crossings were facilitated by DBGCs or sag-bends, but caribou might use sag-bends if they occurred more frequently and were longer
- Both moose and caribou populations appeared unaffected by the presence of the pipeline
- Authors suggested movements could be inhibited during severe winters with deep snow and suggest further study of this possibility

Peer Reviewed: Yes

Fancy, S. G. 1982. Movements and activities of caribou at Drill Sites 16 and 17, Prudhoe Bay, Alaska: The second year. Final report prepared for Prudhoe Bay Unit Owners, by LGL Alaska Research Associates, Inc. 48 pp.

Study Location/Herd:

- Alaska; North Slope; Prudhoe Bay; Central Arctic Herd

Dates of Study:

- Summer; postcalving; insect period; 1 July–10 August 1981

Pipeline Characteristics:

- Flow lines from drill sites elevated ~2 m above ground on VSMs; spacing interval unspecified; diameter unspecified
- Study area contained both a pipeline bordered by a road and a pipeline separated from the road by ~1 km

Study Design:

- Behavioral observations conducted from towers in a 9-km² study (treatment) plot and a 9-km² control (reference) plot
- Successful group crossing was not defined, but author mentioned that if a group split while attempting to cross a structure, the movements of each new group were recorded; however, report does not directly discuss proportions of groups successfully crossing structures
- Crossing behavior of groups passing within 500 m of a structure were analyzed
- Roads, pipelines, drill pads, and buildings collectively referred to as structures
- Observations mostly made during daytime hours

Objectives:

- Determine if caribou movements through the area of Drill Sites 16 and 17 were random or whether they show preferred movement patterns
- Determine if caribou avoided drilling structures and associated human activity
- Determine if the distance between caribou groups and infrastructure affected movement and activity patterns, and if so, to approximate the distance at which this change occurred

- Determine if response of caribou groups to drilling structures and human activity differs according to sex and age composition of group
- Assess combined effects, if any, of flow lines, roads, traffic, human activities, and drilling structures on caribou; provide rationale for assessment

Data Quantity:

- 99 groups approached within 500 m of road, pipeline, or drill pad

Analytical Methods:

- Chi-square tests of crossing categories (no encounter, crossed structure directly, detoured around structure, reversed direction; groups crossing after turning >90 degrees dropped from analysis) by group size, presence or absence of calves, insect category, entry location; mapping of movements

Results:

- This report focused on movement patterns of caribou in the eastern Prudhoe Bay Oilfield under varying insect conditions and is not applicable to the effects of pipeline height on crossing success of caribou
- In addition, no distinction was made between pipelines, roads, drill sites, and buildings
- Results are not summarized in this annotation; see annotation for Fancy (1983)

Conclusions:

- Conclusions are not summarized in this annotation; see annotation for Fancy (1983)

Peer Reviewed: No

Fancy, S. G. 1983. Movements and activity budgets of caribou near oil drilling sites in the Sagavanirktok River floodplain, Alaska. Arctic 36: 193–197.

Study Location/Herd:

- Alaska; North Slope; Prudhoe Bay; Central Arctic Herd

Dates of Study:

- Summer; postcalving; insect period; 1 July–10 August 1981

Pipeline Characteristics:

- Dimensions of pipeline in study area not specified
- Study area contained both a pipeline bordered by a road and a pipeline separated from the road by ~1 km

Study Design:

- Behavioral observations from towers in a 9-km^2 study (treatment) plot and a 9-km^2 control (reference) plot
- Successful crossing was not defined, but author mentioned that if a group split while attempting to cross a structure, movements of each new group were recorded; however, proportions of groups successfully crossing structures were not specifically reported
- Crossing success of structures was recorded with roads, pipelines, drill pads, and buildings collectively referred to as structures
- Crossing behavior of groups passing within 500 m of a structure were analyzed
- Observations mostly made during daytime hours
- This publication originated from a report (Fancy 1982)

Objectives:

- Determine if movements and activities of caribou were significantly altered by presence of drilling structures and human activities
- Disturbances included roads, pipelines, drill pads, buildings, vehicle traffic, presence of humans

Data Quantity:

- 1,035 caribou were observed in the drill-site study plot, compared with 998 in control plot
- 99 groups approached within 500 m of road, pipeline, or drill pad

Analytical Methods:

- Mapped movements; recorded movement rates, activity budgets

- Compared movement rates and activity budgets with analysis of covariance (ANCOVA), using proportion of calves as a covariate
- Used descriptive statistics to compare crossing success in drill-site plot with crossing success in control plot (hypothetical infrastructure)

Results:

- Mean movement rates by caribou in drill-site plot during periods of low and high insect levels were not significantly different than those in the control plot
- No relationship between rate of movement and proportion of calves in groups during periods of low and high insect levels
- In both plots, groups harassed by mosquitoes and/or oestrid flies moved significantly faster than unharassed groups
- 17 caribou groups crossed both the control grid and drill site grid and remained intact; movement rate for these groups on the drill site was less than that on the control grid
- Proportion of time spent lying and feeding on drill site grid was not significantly different from that on the control grid during periods of low and high insect harassment
- Insect harassment has significant effect on activity with caribou spending less time lying and feeding during high insect levels compared to low insect levels
- During high insect levels, proportion of calves in group was not significantly related to proportion of time lying and eating, but during low insect levels, there was a significant inverse relationship on both grids
- Most groups encountering elevated pipeline hesitated briefly before quickly crossing underneath
- Caribou sought out relief from insects in the shade of infrastructure, but insect-relief areas are commonly available on the delta, making the benefit of these structures unknown
- 70.7% of caribou crossed the first structure encountered, 19.2% detoured around the drill site, and 10.1% reversed direction and left the grid
- Groups that detoured around the drill site appeared to alter their movements while >2 km away from nearest structure
- Structures of the drill grid were superimposed on a map of the control site; 8% of 87 groups detoured around the hypothetical "structure", and 1.1% reversed their direction and left the grid
- Used the above figures for the control grid to adjust those determined for the control site, concluding that 20% of groups altered their movements in response to infrastructure
- Calf percentage on the drill grid in 1980 was 23.9%, similar to ADFG regional estimate of 21% calves
- Calf percentage on the control (10.5%) and drill sites (12.5%) in 1981 was lower than the ADFG regional estimate of 28%
- Traffic levels during the last week of July 1980 were nearly twice those in 1981, which may have contributed to the difference; both gravel pads were enlarged in 1980, creating noise from construction and higher levels of human activity
- Low calf percentage was likely explained by annual variation in use of drainages near study area rather than by maternal cow avoidance of infrastructure

Conclusions:

- Results should be interpreted carefully because individual caribou that were sensitive to human activities were able to detour around the east side of the study area
- Pipeline in study area was elevated ~2 m above ground to allow for passage of caribou; however, in some areas of oilfield pipe heights are not sufficiently elevated

Peer Reviewed: Yes

Fancy, S. G., R. J. Douglass, and J. M. Wright. 1981. Movements and activities of caribou at Drill Sites 16 and 17, Prudhoe Bay, Alaska. Final report prepared for Prudhoe Bay Unit Owners, Anchorage, by LGL Alaska Research Associates, Inc. 48 pp.

Study Location/Herd:

- Alaska; North Slope; Prudhoe Bay; Central Arctic Herd

Dates of Study:

- Summer; postcalving; insect period; 1 July–15 August 1980

Pipeline Characteristics:

- No flow lines (feeder pipelines) in place yet at these newly constructed drill sites, although VSMs and gravel work pads were present
- Characteristics of pipelines that may have been present during this first year of study were not described
- Study area contained roads along which flow lines would be constructed

Study Design:

- Behavioral observations from towers in a 9-km^2 study plot
- Successful group crossing was not defined, but author mentioned that if a group split while attempting to cross a structure, movements of each new group were recorded; however, report does not directly discuss proportions of groups successfully crossing structures
- Crossing behavior of groups passing within 500 m of a structure were analyzed
- Roads, pipelines, drill pads, and buildings collectively referred to as structures
- Observations mostly made during daytime hours

Objectives:

- Determine if caribou movements through the area of Drill Sites 16 and 17 were random or whether they showed preferred movement patterns
- Determine if caribou avoided flow lines, roads, associated structures or adjacent areas
- Estimate the distance at which caribou began to respond to structures
- Determine if response of caribou groups to drilling structures and human activity differed according to sex and age composition of group

Data Quantity:

- 2,432 observations of 80 caribou groups

Analytical Methods:

- Compared rate of movement at two-minute intervals for caribou groups with distance from infrastructure
- Direction of movement was compared using circular statistics
- Extreme autocorrelation in the data set precluded many statistical analyses
- Used group means of rate of movement to compare rate of movement and distance from infrastructure
- Compared crossing pattern categories of groups with sex and age classification, group size, and direction of movement using chi-square tests

Results:

- High levels of construction activity, averaging 340 vehicles/day on drill-site roads
- Impossible to separate effects of structures from effects of human activity, so authors felt study objectives had not been met
- Movements of caribou through area were not random
- Of groups approaching within 500 m of structures, 31% detoured around it or reversed direction
- Crossing pattern was not significantly affected by group size, study area entry location, or group composition
- During low levels of mosquito harassment, there was an inverse relationship between rate of movement and distance from structure; caribou farthest from structures bedded down more often, and ran and walked less
- Rate of movement was not significantly related to distance from structures
- Level of mosquito harassment had greatest effect on rates and direction of caribou movements, with rate being significantly higher and direction of movement being northerly during periods of high mosquito levels
- Groups composed of only females had the highest movement rates whereas bull groups had lowest movement rates

- Group size was inversely related to rate of movement, with smaller groups moving faster than larger groups

Conclusions:

- There was no control plot in this study, limiting extrapolation of data (see Fancy 1982, 1983 for results of second year of study)
- There was considerable construction activity during the study; distance from caribou to nearest structure was usually different than distance to nearest human activity
- Because human activities may affect caribou behavior, results of this study are of questionable value

Peer Reviewed: No

Hanson, W. C. 1981. Caribou (*Rangifer tarandus*) encounters with pipelines in northern Alaska. Canadian Field-Naturalist 95: 57–62.

Study Location/Herd:

- Alaska; North Slope; Prudhoe Bay; Central Arctic Herd

Dates of Study:

- Summer 1971, 1972

Pipeline Characteristics:

- Pipe diameter 1.2 m
- Fully to partially buried, resulting in 0.8–1.7 m barrier resulting from berms after fill placement
- Berms with 3:1 slope
  Sections with 3-m-tall metal deflection poles
- Pipeline adjacent to facility with diesel generators and haul road with traffic

Study Design:

- Behavioral observations from platform

Objectives:

- Record reactions of caribou encountering the berm of a buried pipeline

Data Quantity:

- 21 encounters

Analytical Methods:

- Behavioral description of caribou encounters with berms

Results:

- Caribou readily crossed areas where berm was <1.2 m
- Crossing behavior varied among different caribou
- Caribou avoided areas where large pools of water formed due to melting snow and subsidence
- Most caribou were wary of deflection poles

Conclusions:

- Berms may form visual barriers to traveling caribou, preventing them from crossing
- Disturbance may be moderated by creating berms <1.2 m in height

Peer Reviewed: Yes

Hemming, J.E. Undated. Wild reindeer and pipelines in north central Siberia. Unpublished report of an exchange visit under terms of USA/USSR Environmental Protection Agreement. Project V-2 Ecosystems of Northern Regions. 8 pp.

Study Location/Herd:

- Russia; central Siberia; wild reindeer

Dates of Study:

- Late 1960s, early 1970s

Pipeline Characteristics:

- 2 low-elevation pipelines built parallel to one another, separated by 0.3 to 2.5 mi

- 28-in. diameter
- Height unspecified
- Crossing structures included a few wooden ramps over the pipeline, and elevated loop crossings (portals) 200–325 ft wide and 10–20 ft high and adjacent to each other in both pipelines
- Pipelines built during 1968–1972 from Messoyakha to Norilsk and parallel to existing railroad
- Pipelines bisect portion of migratory route of Taimyr Peninsula wild reindeer herd

Study Design:
- Report on visit to Siberia to meet with Soviet biologists
- Discussed common interests in management and ecology of domestic and wild reindeer

Objectives:
- Report observations related to the effects of large-diameter pipelines on movements of wild reindeer

Data Quantity:
- Various interviews with Russian officials during 20 August–5 September 1974

Analytical Methods:
- Behavioral descriptions only

Conclusions:
- Most problems crossing pipeline were confined to fall and early winter migration period when snow was absent or light
- During spring migration, extensive portions of pipeline were drifted over with snow and reindeer readily crossed such areas
- Although some reindeer moved through elevated portals, most animals were deflected
- Damage to lichen forage adjacent to pipelines occurred due to trampling and overgrazing where animals became concentrated
- Numerous reindeer became trapped between pipelines until fences were constructed between the pipelines to provide corridors to guide animals from elevated loops in one line to elevated loops in the opposite pipeline; however, most reindeer still deflected around the pipelines
- Successful crossings occurred where pipelines crossed ravines and small stream valleys, usually areas where pipes were 20 ft or more off the ground
- Reindeer successfully crossed where pipe was buried or drifted by snow
- Only ~1/4 of animals that approached pipelines successfully crossed, whereas the rest were deflected and entered complexes of mines, smelters, roads, and railroads around the city of Norilsk
- Plans at the time this report was written included building a fence to divert reindeer completely around the Norilsk area, meaning reindeer would be diverted 100 mi or more before resuming their normal migration

Johnson, C. B., and B. E. Lawhead. 1989. Distribution, movements, and behavior of caribou in the Kuparuk oilfield, summer 1988. Final report prepared for ARCO Alaska, Inc. and Kuparuk River Unit, Anchorage, by Alaska Biological Research, Inc., Fairbanks. 71 pp.

Study Location/Herd:
- Alaska; North Slope; Kuparuk Oilfield; Central Arctic Herd

Dates of Study:
- 11 June to 10 August 1988

Pipeline Characteristics:
- Elevated pipelines, mostly closely paralleling roads in Kuparuk Oilfield
- Crossing structures included ramps and some areas of pipeline/road separation
- Some areas had multiple pipelines (feeder lines) running parallel to one another

Study Design:
- Behavioral observations conducted from pickup trucks during systematic road surveys before insect emergence, then using focal-group sampling after insect emergence; conducted by 1 to 2 observers between 06:30 and 24:00

- Entire Kuparuk Oilfield road system west of junction of Milne Point and Spine roads
- Before insect emergence, surveys conducted every 3 days because movement rates of caribou were low
- Caribou within 1 km of roads were recorded
- Crossing behavior was recorded both opportunistically and during instantaneous-scan sampling
- Groups were considered to have crossed a corridor successfully if >50% of individuals in group crossed
- Caribou groups were considered to have attempted to cross a corridor if one or more caribou in the group crossed; thus, if no members of a group crossed, the group was not included in calculations of crossing success; this definition was considered more a measure of group cohesion during crossings than a measure of crossing success in the sense used in other North Slope mitigation studies
- Number of deflections were recorded and defined as obvious changes in direction within 100 m of a corridor; these groups were tallied but were not included in calculation of crossing success

Objectives:

- Describe distribution of caribou in parts of the oilfield, including number, density, sex/age composition, and distance from facilities experiencing different levels of human activity, during periods of little or no movement (before insect emergence)
- Quantify activity budgets and movement rates of focal groups of caribou among different insect and disturbance conditions and evaluate indicator variables for disturbance
- Describe movements of focal groups through the oilfield, focusing on crossing success of linear structures, overt responses to disturbance, and rates of movement
- Describe size, composition, and movements of large aggregations forming during the insect season, with specific regard to their responses to oilfield facilities and activities

Only the third objective, which relates to the crossing success of caribou encountering linear structures, is summarized in this annotation

Data Quantity:

- 198 crossings of linear structures (pipelines and/or roads) were recorded, involving 179 groups totaling 35,403 caribou

Analytical Methods:

- Descriptive statistics of caribou crossing success (group cohesion)

Results:

- Proportions of group types observed crossing were 44% cow/calf, 24% bull, 28% mixed, 3% cow/yearling, and <1% unclassified
- Crossings of corridors occurred more frequently during insect harassment than prior to insect emergence
- Prior to insect season, 9 of 33 (27%) groups crossed at least one corridor during observations, compared to 90 of 196 (46%) groups crossing during the insect season
- 33% of crossings during the insect season occurred during mosquito harassment, 22% during oestrid fly harassment, 10% during simultaneous mosquito and oestrid fly harassment, and 35% during periods of no insect activity
- Overall crossing success (cohesion) was high, at 82% of groups and 83% of total individuals, respectively
- Cow/calf groups were most successful during simultaneous harassment by flies and mosquitoes and least successful during mosquito harassment
- Mixed groups, which contained many calves, were most successful during mosquito harassment and least successful during insect-free conditions
- Bulls were more successful under insect-free periods than when harassed by mosquitoes
- Except for cow/calf groups not harassed by insects, groups crossing corridors without pipelines were more successful than those crossing corridors with pipelines
- Deflections were most common during mosquito harassment, with cow/calf groups deflecting most often during this period as well as during all insect conditions combined

- No deflections occurred at corridors without pipelines
- Overall crossing success for all groups was nearly identical among all insect conditions ranging from 79–84% for groups and 80–86% of individuals
- No deflections were noted during periods of simultaneous harassment by mosquitoes and flies
- For all insect conditions combined, groups of <10 individuals had highest crossing success (93% of groups and 92% of total individuals)
- For most group-size categories, crossing success tended to be lower during insect-free periods and higher during mosquito or simultaneous mosquito and fly harassment
- Crossing success for individuals in groups of >1,000 caribou was lowest during insect-free periods and highest during mosquito harassment
- Regardless of insect conditions, crossing success for all size categories was highest at corridors without pipelines
- 114 of 152 crossing attempts occurred where 1–5 pipes were present; no objective way was identified to analyze use in relation to availability of various categories of number of adjacent pipelines
- Individual and group success were slightly higher where 6–10 pipes were present versus 1–5 pipes; may be artifact of small sample sizes
- No crossings of 11–15 adjacent pipelines were observed except a few that occurred during fly harassment; one attempt at crossing 16–19 adjacent pipes was unsuccessful
- 71% of deflections were at sites with 1–5 pipes, 25% occurred at sites with 6–10 pipes
- Separation of roads and pipelines did not seem to influence crossing success during insect-free periods
- Deflections were high at separation distances of 100 m or less, especially during mosquito harassment
- Most groups crossing corridors crossed only one (83%) corridor; 17% of groups attempted to cross more than one; one group crossed as many as 8 corridors
- 80% of multiple corridor crossings were observed during periods of insect harassment
- No crossings of >2 corridors were observed during insect-free conditions
  Data indicated that groups crossing more than one corridor had more difficulty crossing the first few, but that subsequent crossings became easier
- 12 crossings of ramps were recorded, involving caribou from 10 separate groups; half of these crossings occurred during periods without insect harassment
- A group of 3,384 caribou was observed crossing near a ramp during insect-free conditions; 69% of group members successfully crossed the pipeline; 2% crossed the ramp
- A group of 1,815 caribou was observed crossing near a ramp during mosquito harassment; 99% of group members successfully crossed the pipeline; <3% crossed the ramp
- Two groups of 89 and 560 caribou were observed crossing near ramps under simultaneous mosquito and fly harassment; all members of both groups crossed; 44% and 1% of those groups, respectively, crossed the ramps

Conclusions:

- Large caribou groups were able to cross road corridors successfully, but reductions in size were common as portions of groups deflected or delayed crossings long enough to prevent them from rejoining their groups, possibly increasing their exposure to insect harassment
- Successful arrival of caribou at insect-relief habitat may have important energetic benefits, especially to lactating cows
- Very little use of gravel crossing ramps was observed
- During mosquito harassment, approximately 1 of every 5 groups successfully crossed more than one corridor
- Both measures of crossing success (based on groups and on total caribou) were high, averaging 80% (range 54–100%) among various group types and sizes under different insect conditions
- Adverse behavioral reactions, deflections, delays lasting several minutes to several hours, and splitting of groups were common during crossings of pipeline/road corridors, especially crossings along the Spine Road and Oliktok Point Road, both of which had high traffic levels

- Effects of oilfield activities and facilities on the distribution and movements of caribou were most pronounced during insect-free periods; however, in the absence of high traffic, sensitivity of caribou to oilfield activities and facilities decreased under the influence of insect harassment

Peer Reviewed: No

Klein, D. R. 1971. Reaction of reindeer to obstructions and disturbances. Science 173: 393–398.

Study Location/Herd:
- Scandinavia; Norway; Sweden; Finland; various domestic and wild reindeer herds

Dates of Study:
- No specific study dates

Pipeline Characteristics:
- This review does not specifically mention pipelines, but discusses other linear features such as roads, railways, and fences

Study Design:
- Information based on personal trips to Scandinavia in 1965, 1967, 1970
- Conversations with Lapp reindeer herders, government consultants, advisors to reindeer herders, biologists, and government officials
- Includes information from printed reports and publications

Objectives:
- Provide a basis for anticipating the problems that may be encountered by caribou exposed to industrial development in North America, including highways, railways, hydroelectric developments, forestry, fences, snowmobiles, and air pollution and lichens
- Only reactions to linear structures are included in this annotation

Data Quantity:
- 4 personal communications, 7 published papers and reports

Analytical Methods:
- Personal observations and interviews

Results:
- Highways transect domesticated reindeer ranges throughout Scandinavia and have not been reported to significantly interfere with movements except under special circumstances
- In Norway, well-traveled highways and railroads may have obstructed the movements of a herd of wild reindeer between summer and winter range; after a highway and railroad bisected the range, herd continued to use areas on both sides of the transportation corridor for a few years, but as train traffic increased, reindeer ceased to migrate through the corridor; reindeer milled around near tracks for long periods and were repeatedly frightened away when trains passed
- Reindeer in poor body condition may be easily disrupted and abandon traditional ranges, whereas healthy animals are more likely to adjust to disturbance
- Feeding reindeer did not seem disturbed by highways with traffic
- 2-m-high fences are used to direct reindeer movements because the animals tend to parallel fences; some reindeer are reluctant to be forced into large herds in unfamiliar terrain, so fences must be used in conjunction with traditional patterns of movement
- Also summarized reindeer reactions to hydroelectric development, forestry, and snowmobiles, and discussed effects of air pollution on lichens

Conclusions:
- In general, highways and railways in Scandinavia have not created barriers to movements by domestic reindeer, but many are struck and killed by vehicles
- Construction of a railway adjacent to a highway caused some disruption of movements by wild reindeer in Norway

Peer Reviewed: Yes

Klein, D. R. 1980. Reaction of caribou and reindeer to obstructions—A reassessment. Pages 519–527 in E. Reimers, E. Gaare, and S. Skjenneberg, editors. Proceedings of the Second International Reindeer/ Caribou Symposium. 17–21 September 1979, Røros, Norway. Direktoratet for vilt og ferskvannsfisk, Trondheim, Norway.

Study Location/Herd:

- Alaska; North Slope; Russia; Siberia; Norway; Prudhoe Bay; wild reindeer; Central Arctic Herd

Dates of Study:

- Late 1960s–early 1970s

Pipeline Characteristics:

- Norilsk-Messoyakha natural gas pipelines in Taimyr region of northcentral Russia
- Low-elevation pipelines set on wooden supports; height to top of pipes ~1 m above ground; diameter 0.7 m
- Two parallel pipelines, ~1–2 km apart, also paralleling highway and railway
- Crossing structures included wooden ramps and underpasses elevated 3–6 m above ground, 75–100 m in length
- Lead fences were constructed to guide animals to crossings; fences also constructed to lead animals unsuccessful in crossing away from the pipeline and the area surrounding Norilsk
- Trans-Alaska pipeline, elevated, diameter and height unspecified (but see annotations of Cameron and Whitten 1976, 1977, 1978; Eide et al. 1986; Carruthers and Jakimchuk 1987)
- Various simulated elevated pipelines, diameters and heights unspecified (but see annotations of Child 1973, 1974, 1975; Child and Lent 1973)

Study Design:

- Literature review

Objectives:

- Summarize existing literature concerning reactions of caribou and reindeer to railways, roads, hydro-electric development, and pipelines
- This annotation addresses pipeline information only

Data Quantity:

- Literature review

Results:

- Norilsk-Messoyakha pipeline was complete barrier to wild reindeer, except where it crossed ravines or streams or where covered by snow drifts
- During spring migration, some herds were able to cross the adjacent road and railroad, but ran parallel to the pipeline until they found areas to cross that were drifted over by snow or where ravines were deep enough to cross under the pipeline
- One survey in May showed 20,000 reindeer (herd ~100,000 animals), mostly pregnant cows, milling near structures
- Train traffic was reduced to minimum during night hours, which helped some reindeer cross; however, many groups, mostly bulls, failed to cross
- After completion of second pipeline, lead fences were built between pipelines to guide caribou and provide access to crossing structures, but only ~25% of caribou were successful in crossing pipelines
- 54 km of fence eventually was built to guide caribou completely around these structures and the city of Norilsk
- Rangelands east of Yenisei River became largely unavailable to reindeer, but herd continued to grow, causing range damage due to extensive overgrazing and trampling in areas adjacent to pipelines where reindeer became concentrated
- Most studies showed general avoidance of Haul Road/TAPS corridor in northern Alaska by cows with calves until the rutting period in the fall, but avoidance seemed to be related more to highway activities than to the pipeline itself

- Reactions of caribou to the Dempster Highway in Canada were summarized, including effects of traffic speed, quantity, habitat, and height of road berms
- Author summarizes research carried out near Prudhoe Bay on the reactions of caribou to a simulated low-elevation pipeline (not summarized in this annotation, but see Child 1973)
- Reindeer on the Seward Peninsula avoided a simulated low-elevation pipeline during winter and summer, only crossing during periods of insect harassment (see Child and Lent 1973)
- Caribou tend to follow trails packed in snow by vehicles, such as seismic exploration lines and snowmachine trails

Conclusions:
- Linear structures can block, delay, or deflect movements of caribou with effects depending on mode of construction and degree of alteration of existing terrain
- Elevated pipelines are more visible in open terrain, meaning caribou may react to them sooner than to pipelines in forest; caribou cross more easily under elevated pipeline in forested habitat than open tundra
- Human activity, such as traffic level, associated with pipelines and roads is a major factor influencing reactions of caribou to human objects
- Reactions to obstructions vary among seasons of the year; generally females with calves show stronger avoidance than during winter, caribou cross more frequently during insect harassment, spring migration, and fall rut
- Caribou of different sex and ages react differently to obstructions, with adult males appearing to accommodate more rapidly to their presence, and large groups and females with calves showing more avoidance
- Caribou that reside in areas with obstructions are more likely to habituate to their presence than are animals that encounter obstructions on a seasonal basis
- Reactions to obstructions vary among subspecies of caribou, with woodland caribou showing less sociality than tundra forms and making less extensive migrations, which may make them less motivated to cross obstructions
- Local overgrazing may occur in areas near obstructions
- Population level effects may be seen if obstructions preclude access to calving grounds or insect-relief areas
- Obstructions may contribute to increased energetic losses to caribou seeking to travel around obstructions

Peer Reviewed: Yes

Klein, D. R. Undated. Ecology and management of wild and domestic reindeer in Siberia. Unpublished report of an exchange visit under terms of USA/USSR Environmental Protection Agreement. Project V-2 Ecosystems of Northern Regions.

Study Location/Herd:
- Russia; central Siberia; Taimyr wild reindeer

Dates of Study:
- Late 1960s–early 1970s

Pipeline Characteristics:
- Norilsk-Messoyakha natural gas pipelines
- Low-elevation pipelines on wooden supports; ground clearance 30–50 cm, but >2 m where pipe crossed ravines
- Diameter 70 cm
- Two parallel pipelines, separated by ~1 km
- Crossing structures consisted of wooden ramps and underpasses elevated 3–6 m above ground
- 250 km in length
- Constructed 1968–1969

Study Design:
- Report on visit to Siberia to meet with Russian biologists
- Discussed management and ecology of domestic and wild reindeer

Objectives:
- Discuss common interests between Russian and American biologists in management and ecology of domestic and wild reindeer

Data Quantity:
- Various interviews with Russian officials during 20 August–5 September 1974

Analytical Methods:
- Behavioral descriptions only

Results:
- This annotation focuses on reindeer and gas pipelines, but author also provides overview of domestic reindeer management in Russia, describes reindeer research organizations, describes techniques used in reindeer husbandry, and discusses effects of industrial pollution on vegetation.
- Pipelines transect migration route of portions of Taimyr wild reindeer herd
- Problems in crossing pipelines generally restricted to fall; extensive snow drifts in spring allowed reindeer to pass over pipes
- After reindeer were delayed in their movements, wooden ramps were constructed over pipeline, as were portals elevated 3–6 m above ground and 75–100 m wide
- Crossing structures were used only by some animals, while most were deflected; lichen forage was overgrazed and trampled near pipelines
- More reindeer successfully crossed pipeline following installation of portals at 30–40 km intervals, in addition to natural passages where pipeline was elevated above ravines
- Many reindeer crossed one pipeline, but were unable to cross the second, becoming entrapped between the two
- Fences were constructed to lead reindeer from one portal to a corresponding portal on second pipeline
- After crossing structures were added, only ~25% of reindeer successfully crossed pipelines, with many deflecting into city of Norilsk and its mines, smelters, and roads
- Administration planned to construct two long lead fences, 42 km and 12 km long, to prevent reindeer deflected by pipeline from entering Norilsk, because Russian biologists felt little more could be done to increase crossing success

Conclusions:
- Russian scientists acknowledged that thousands of wild reindeer were deflected by pipelines and that there might be long-term consequences as a result; however, their main conclusion was that reindeer had successfully adapted to the pipelines because Taimyr reindeer herd continued to grow

Peer Reviewed: No

Lawhead, B. E., L. C. Byrne, and C. B. Johnson. 1993. Caribou synthesis, 1987–1990. 1990 Endicott Environmental Monitoring Program Final Report, Vol. V. U.S. Army Corps of Engineers, Alaska District. Final report prepared for Science Applications International Corporation, Anchorage, by ABR, Inc., Fairbanks. 114 pp.

Study Location/Herd:
- Alaska; North Slope; Sagavanirktok River delta; Endicott Project; Central Arctic Herd

Dates of Study:
- Postcalving; insect season; 25 June to 31 July 1987–1989; 25 June to 27 July 1990

Pipeline Characteristics:
- Elevated pipeline, average height ~1.5 m at top of metal pilings (VSMs), diameter unspecified
- Pipeline 25–30 m adjacent to a road with traffic
- VSMs spaced at intervals of 12–14 m
- Road averaged 10 m wide and 2 m thick, 2:1 side slopes, with small pullouts located along road

- Crossing structures were three 30-m-wide ramps, bordered by 60-m-long sections of elevated pipeline that gradually decreased in height near the ramp to assist caribou in finding ramps

Study Design:

- Behavioral observations conducted from 3 elevated towers, each overlooking a plot 1.6 km long by 0.8 km wide
- Behavioral observations from road surveys along the pipeline/road corridor 1–4 times daily
- Aerial surveys of caribou distribution on the Sagavanirktok River delta using systematic strip-transects during periods of high insect activity

Objectives:

- Monitor caribou use of crossing ramps compared to crossings under nearby elevated pipeline, including an assessment of the effects of insects and traffic on crossing frequency
- Monitor caribou encounters with the pipeline/road corridor between the Endicott security checkpoint and the base of the causeway (~10 km)
- Monitor the distribution of caribou throughout the development area on the Sagavanirktok River delta
- Evaluate predictions of environmental impact statement for Endicott Development Project

Data Quantity:

- Time spent observing caribou from towers: 72 hr in 1987, 100 hr in 1988, 86 hr in 1989, 76 hr in 1990
- Time spent observing caribou along road/pipeline corridor: 196 hr 1987, 184 hr in 1988, 158 hr in 1989, 113 hr in 1990
- Number of caribou observed 1987–1990 during tower observations: 843 groups comprising 11,420 caribou
- Number of caribou observed 1987–1990 during road surveys: 2,366 groups comprising 16,116 caribou

Analytical Methods:

- Compared pipeline height at crossing locations (used) with pipeline heights (50-cm height categories) in study plots (available), using chi-square goodness-of-fit tests
- Crossing success compared using ratio estimation and multiple regression

Results:

- Mosquitoes emerged 8 July 1987, 7 July 1988, 29 June 1989, 19 June 1990
- Oestrid flies emerged 10 July 1987, 15 July 1988, 11 July 1989, 4 July 1990
- Each year, periods of no insect activity were recorded
- Maximum number of caribou observed per day decreased over course of study period: >4,000 in 1987, 3,100 in 1988, 328 in 1989, and 113 in 1990
- Caribou formed large groups of >100 during periods of mosquito harassment, but formed groups of 5–7 during fly harassment
- Number of mosquito-harassment days was similar during all study years; decreased caribou numbers in study area during monitoring period was interpreted as an eastward shift in distribution due to factors other than development; the largest numbers of caribou in the study area were observed during construction of the Endicott pipeline (highest amount of human activity)
- Sex/age composition each year was skewed toward bulls
- Calf:cow ratios varied among years: 74–78 calves:100 cows in 1987, 57–59:100 in 1988, 30–35:100 in 1989, 35–43:100 in 1990
- Traffic rates were highest in 1987 (final year of construction), averaging 15.4 vehicles/hr
- Traffic rates decreased to 6.9 vehicles/hr in 1988, 5.8 vehicles/hr in 1989, and 5.4 vehicles/hr in 1990
- Traffic rates varied throughout the day, with the highest volume in the morning and afternoon periods (06:00-18:00) and the lowest volume during early morning hours (00:00–06:00)
- In general, the proportion of caribou crossing the pipeline/road corridor was lower at traffic rates above median levels; however, only in 1987 (when traffic rates were highest) was the difference significant
- Proportion of caribou crossing in plots when traffic was >15 vehicles/hr was significantly lower than at <15 vehicles/hr

- Vehicles were the most common source of behavioral disturbance, resulting in moderate or strong reactions among caribou, accounting for 75% of events; large vehicles accounted for more than half of these reactions
- Elevated pipeline was the second most common stimulus, with 11% of caribou exhibiting moderate or strong reactions
- Humans on foot, though rare in study area, elicited immediate disturbance reactions from caribou
- 87% of reactions occurred within 100 m of pipeline/road corridor
- 6% of all caribou and 16% of all groups that crossed pipeline/road corridor in plots used ramps, significantly higher than predicted based on availability
- Mean size of groups crossing ramps was smaller than mean size of groups crossing under elevated pipeline
- Amount of time spent within 400 m of pipeline/road before crossing was similar between caribou using ramps and those crossing under the pipeline
- Crossings by caribou in different pipe-height categories differed significantly from availability; pipe heights <1 m were used least, with no evidence of selection of heights above 1.5 m
- Insect harassment was the primary factor influencing crossings, with the highest proportion of caribou crossing during mosquito harassment
- No consistent trend was seen in proportion crossing among groups of different sizes, but significantly higher proportion of groups of >100 caribou crossed successfully during mosquito harassment (94%) than during periods of combined mosquito and oestrid fly harassment (31%)

Conclusions:

- Although small numbers of caribou used them, ramps were preferred as crossing sites during all insect conditions
- Whether ramps increased crossing success or simply provided crossing sites for caribou that would have crossed under the pipeline had the ramps been unavailable could not be determined; no consistent trends in crossing frequencies were seen in portions of plots with and without ramps
- Data did not indicate that ramps expedited crossings
- When traffic rates were high, ramps did not seem to facilitate crossings of the pipeline/road complex by large groups
- Overall, ramps played a minor role in accommodating crossings of the pipeline/road corridor by caribou
- Amount of previous experience with pipelines, which could not be measured in this study, may have been an important factor affecting crossing frequency
- Harassment by mosquitoes and oestrid flies had the most profound effects on proportion of caribou crossing the road/pipeline corridor; proportion crossing increased as group size increased, a significantly different result than was reported by Smith and Cameron 1985a, 1985b
- During simultaneous mosquito and fly harassment, caribou seemed to react first to mosquitoes by quickly approaching the pipeline, but then milling around the elevated gravel road, crossing and recrossing, as if reacting to fly harassment
- Annual variability in proportion of caribou crossing pipeline/road corridor was high
- 15 vehicles/hr was considered the threshold above which caribou crossing success of the corridor was negatively affected
- Although caribou avoided crossing areas of pipe <1 m above ground, there was no height selection at or above 1.5 m

Peer Reviewed: No

Miller, F., C. J. Jonkel, and G. D. Tessier. 1972. Group cohesion and leadership response by barren-ground caribou to man-made barriers. Arctic 25: 193–202.

Study Location/Herd:

- Canada; Northwest Territories; Kaminuriak Herd

Dates of Study:

- Spring migration; May 1967

Pipeline Characteristics:

- No pipeline, but a corral made of fencing was constructed to capture caribou
- Corral built on a spit of land in a lake near traditional migratory routes
- Spit was 700 m long and 110 m wide at head of spit
- Fencing was 2.8 m high
- Lower 120 cm was covered with square mesh wire
- Entrance to corral was 5 m wide
- Barrier fences, height 2.2 m, were built to funnel caribou
- Drift fences, height 1–1.5 m, were erected to direct caribou
- Snowmachine trails were laid in a single line from the corral entrance and extended 3 km away from corral
- Several converging lateral trails were laid out to guide caribou onto the main trail leading into the corral

Study Design:

- Behavioral observations conducted from blind

Objectives:

- Provide preliminary insight into possible impact of human-made barriers on migrating caribou

Data Quantity:

- 6 groups totaling 47 caribou

Analytical Methods:

- Behavioral descriptions

Results:

- First group (2 cows, 1 calf, 1 yearling) followed snowmachine trail to corral entrance; lead cow investigated within 3 m of entrance, then crossed drift fence, where she turned abruptly, perhaps catching scent of investigators, and led group back the way they came
- Second group (3 cows and a juvenile) followed snowmachine trail to entrance, stopped 3 m from entrance, but eventually entered, then escaped when door failed to close properly
- Third group approached corral without using snowmachine trail; may have been same caribou from first and second group as the composition was the same; lead female approached within 30 m of entrance, tightly circled the group, then crossed a drift fence and paralleled a barrier fence
- Fourth group (11 cows and 8 juveniles) did not use snowmachine trail for approach; lead cow crossed a drift fence and the others followed, then crossed the barrier fence by crawling under the bottom cross piece (40 cm high); others followed
- An observer startled the group and the female jumped between the top and second cross pieces of the fence (space between poles was 38 cm and at a height of 180 cm)
- Observers attempted to herd this group into the corral and in doing so, the lead female jumped the barrier fence, breaking the top pole (2.2 m high) and other caribou leapt through that break
- Fifth group approached within 125 m of entrance before veering across a drift fence; lead caribou eventually led the group under the bottom bar of the barrier fence where the fourth group had crossed a few days before
- Sixth group (5 adults and 2 juveniles), traveling along the trail used by fourth group, crossed a drift fence and then crossed under the barrier fence

Conclusions:

- Caribou were persistent in trying to cross the lake despite the presence of man-made barriers
- Caribou followed snowmachine trail on an established migration path, but were reluctant to enter brush (where corral was located)
- Experience with terrain may play an important role in migratory movements
- Caribou facing barriers may either wait until environmental conditions allow passage, possibly delaying movements, or they can deviate from traditional routes and attempt a new course

- Delays caused by barriers may prevent cows from reaching calving grounds in time to give birth or may cause females to leave calves behind as they migrate to calving grounds

Peer Reviewed: Yes

Murphy, S. M. 1984. Caribou use of ramps for crossing pipe/road complexes, Kuparuk Oilfield, Alaska, 1984. Final report prepared for ARCO Alaska, Inc., Anchorage, by Alaska Biological Research, Fairbanks. 61 pp.

Study Location/Herd:
- Alaska; North Slope; western Kuparuk Oilfield; Ugnuravik River drainage; Central Arctic Herd

Dates of Study:
- Calving; postcalving, insect period; 2–28 July 1984

Pipeline Characteristics:
- Pipeline elevated; average height at vertical support members 72 in.
- Pipeline parallel to and 30 ft from road with traffic
- Crossing structures included 3 ramps that spanned pipelines and road; 2 of 3 ramps spaced 0.3 mi apart
- Ramps 100 ft wide with 1:20 slope on one end and a 1:10 slope on the other end, 10:1 side berms
- Ramps 100 by 100 ft, with gravel extensions 100 ft perpendicularly north and south of road
- South side of 2 ramps were extended 30 ft whereas the berm of the Spine Road served as the northern access point of the third ramp

Study Design:
- Second year of study (see Murphy and Curatolo 1984)
- Behavioral observations conducted from 3 towers
- No set schedule; rather, caribou observed whenever they were in the 5-mi^2 study area

Objectives:
- Determine caribou crossing frequencies of 2 pipe/road corridors
- Identify factors influencing crossing frequencies
- Determine whether ramps increase crossing success of caribou compared to elevated pipelines
- Evaluate different ramp designs in terms of minimizing cost and habitat alteration while maximizing caribou crossing

Data Quantity:
- 27 field days; 94 groups comprising 1,846 caribou, with 87% of caribou being recorded on first 4 days of sampling

Analytical Methods:
- Chi-square tests were used to test for differences in direction of movement under different insect conditions, and to test for differences in pipeline and road crossing frequencies
- Successful group crossing defined as >50% of a group crossing the pipeline/road corridor
- Mapped caribou movements through study area

Results:
- Cow-calf groups were the most abundant group type in study area
- Caribou movements were predominantly to south when no insects were present and to north/northeast when insects were present
- Movement rates were greatest when mosquitoes were present; movements were slower when oestrid flies were present, similar to insect-free conditions
- Traffic levels on Spine Road were high (1 vehicle/1.1 min) and were lower on the DS-2D and DS-2X access roads (1 vehicle/10 min and 1 vehicle/12 min, respectively)
- Vehicles were the most common cause of moderate and strong reactions by caribou
- Over 50% of the caribou that crossed elevated pipelines/roads showed moderate or severe reactions, compared to <10% for caribou using ramps
- Over 90% of all strong group reactions occurred within 300 ft of pipe/road complexes

- Crossing frequencies (based on groups and total caribou) were similar to those recorded before pipeline construction
- Crossing frequencies were greatest at pipeline/road complexes with the least traffic
- 48% of all caribou that crossed the Spine Road used ramps, a significant increase in use compared with 1983; however, group crossing frequencies were similar, indicating use of ramps by large groups
- The DS-2D ramp contributed little to the overall crossing frequency of the DS-2D pipeline/road complex
- Small gravel extensions installed on the road side of ramps did not appear to increase caribou use of ramps compared to those without extensions

Conclusions:
- Rigorous evaluation of the effectiveness of ramps was hampered by small sample sizes, but ramps elicited fewer strong reactions from caribou than did elevated pipelines
- Whether ramps increased crossing frequency or simply provided caribou intent on crossing with a preferred site remains unsolved
- Ramps facilitated the crossing of road/pipeline complexes by large groups of caribou, justifying the use of ramps as a mitigation strategy in areas where pipelines are not separated from roads
- The increase in overall crossing frequency compared with 1983 may have been inflated, due to a higher percentage of small groups attempting to cross in 1984, differences in traffic patterns, habituation, and the use of a larger study area in 1984
- Placing ramps in optimal locations was considered a major factor contributing to overall use, which may have accounted for the low use of the DS-2D ramp

Peer Reviewed: No

Murphy, S. M. 1988. Caribou behavior and movements in the Kuparuk Oilfield: Implications for energetic and impact analysis. Pages 196–210 in R. D. Cameron, J. L. Davis, and L. M. McManus, editors. Proceedings of the Third North American Caribou Workshop. 4–6 November 1987, Chena Hot Springs, Alaska. Alaska Department of Fish and Game, Juneau.

Study Location/Herd:
- Alaska; North Slope; Kuparuk Oilfield; Central Arctic Herd

Dates of Study:
- Summer; 1981 and 1982

Pipeline Characteristics:
- Kuparuk Pipeline
- Elevated, minimum height 1.5 m above ground
- 5 study sites: pipe-road site, pipe site, river-road site, and 2 control sites
- Pipe-road site contained the Spine Road with traffic adjacent to the Kuparuk Pipeline; traffic 1 vehicle/4 min
- Pipe site contained only the Kuparuk Pipeline and an infrequently traveled work road used for occasional maintenance
- River-road site contained a road with traffic and no pipeline
- 2 control sites contained neither roads nor pipelines; data from control sites were combined

Study Design:
- Behavioral observations conducted from towers
- No set observation schedule; rather, caribou were observed whenever they were in the study area
- Groups were considered successful in crossing pipeline/road corridors if >50% of members crossed; in control sites, this crossing success refers to frequency of caribou crossings of the northern border of plot

Objectives:
- Review Curatolo and Murphy (1986) and Murphy and Curatolo (1987) on effects of pipelines and roads on caribou movements and behavior
- Discuss energetic implications of altered movement patterns and activity budgets

This annotation focuses primarily on second objective, because both papers reviewed in this study are annotated in this bibliography

Data Quantity:

- See individual annotations for Curatolo and Murphy (1986) and Murphy and Curatolo (1987)

Analytical Methods:

- Summarized results of Curatolo and Murphy (1986) and Murphy and Curatolo (1987)

Results:

- 66% of caribou entering control sites crossed northern boundaries (hypothetical pipeline), so 34% did not cross
- During insect-free periods and mosquito harassment, group crossing frequency (37% and 31% , respectively) at the pipe-road site was significantly less than expected, but no significant difference was found among sites when oestrid flies were present
- No significant reductions in crossing frequency at pipe site or river-road site
- When insects were absent, caribou in control plot spent 90% of time in activities involving energy intake and assimilation (feeding and lying); mosquito-harassed caribou reduced time spent feeding, and time spent lying decreased by nearly 50%, whereas standing, walking, and running increased significantly; oestrid fly-harassed caribou spent even less time feeding and more time standing
- Decreased energy intake and assimilation have greater effects on energy balance than do increases in energy expenditure
- Rate of movement in control sites was significantly different during each insect season; movement rates were greatest during mosquito harassment, followed by oestrid fly harassment, and were lowest during periods of no insect activity
- Except for time spent feeding, during periods without insect harassment there were significant differences among sites in daily activities; running was greatest in pipe-road site
- During periods without insect activity, rates of movement were not significantly different between pipe site and controls, but the mean rate in pipe-road site was >3.5 times greater than in either of the other 2 sites
- Time spent feeding was not affected by disturbance when insects were absent
- During mosquito harassment, time spent feeding and lying did not differ significantly between pipe site and control, but caribou in pipe-road site spent significantly less time feeding and significantly more time lying than did caribou at either pipe site or control
- Movement rates did not differ significantly among sites when mosquitoes were present
- Under oestrid fly harassment, caribou in pipe site had activity budget nearly identical to those in control site; caribou in pipe-road site spent significantly less time lying and more time running than did caribou at less-disturbed sites
- No significant differences were found in time spent feeding among study areas during oestrid fly harassment
- Movement rates during the presence of oestrid flies differed significantly among study sites, with fastest movement rates occurring in areas of more human disturbance
- In control sites, distribution of time spent lying by caribou did not differ significantly from expected distribution, whereas there was significant deviation in treatment sites
- At pipe site, 300 m appeared to be the threshold distance at which the clearest differences in behavior could be identified
- At pipe-road site, 600 m appeared to be the threshold distance, indicating the effect of traffic

Conclusions:

- Caribou were able to cross elevated pipelines, but were disrupted in crossing attempts by moving vehicles
- Separation of road with traffic from pipelines will enhance crossing success
- Very high rates of traffic (>1 vehicle/min), would likely create a barrier to caribou movements with or without an associated pipeline
- Mosquito harassment did not appear to have an additive or synergistic effect on caribou activity budgets

- Differences in activity budgets and movement rates among study sites were greatest during insect-free periods and, because insects and oilfield disturbance had similar effects on caribou behavior, data collected during insect-free periods may be best for evaluating effects of oilfield disturbance
- Insects had a greater impact on energy balance of caribou than did oilfield disturbance; time spent feeding was not significantly affected by oilfield disturbance when insects were absent
- Suggestions for future studies included quantifying the frequency and duration of Central Arctic Herd caribou encounters with oilfield development and quantifying the extent that habituation may play in reducing oilfield impacts on individual caribou

Peer Reviewed: Yes

Murphy, S. M., and J. A. Curatolo. 1984. Responses of caribou to ramps and pipelines in the west end of the Kuparuk Oil Field, Alaska, 1983. Final report prepared for ARCO Alaska, Inc., Anchorage, by Alaska Biological Research, Fairbanks. 41 pp.

Study Location/Herd:
- Alaska; North Slope; Kuparuk Oilfield; Ugnuravik River drainage; Central Arctic Herd

Dates of Study:
- Calving, postcalving, insect seasons; 30 June to 2 August 1983

Pipeline Characteristics:
- Elevated to minimum height of 5 ft; mean height at VSMs in study area was ~72 in. (6 ft)
- Pipeline parallel to and 30 ft from road with traffic
- Crossing structures in study area included 2 ramps, 0.3 mi apart, that spanned the pipeline and road
- Ramps 150 ft wide
- Each ramp was a 50-ft-long gravel pad extending perpendicularly 20–25 ft from each side of the pipeline/road corridor

Study Design:
- Behavioral observations conducted from 2 towers, whenever caribou were present in the 1.2-mi^2 study area
- Successful group crossing defined as >50% of group members crossing the pipeline; crossing success based on total individuals also presented

Objectives:
- Determine if ramps increased the crossing frequency of caribou encountering the Kuparuk Pipeline
- Determine the most effective ramp design for maximizing caribou crossings while minimizing cost and habitat alteration

Data Quantity:
- 34 field days
- 1,151 caribou, 82% of which were recorded on 3 days

Analytical Methods:
- Used chi-square tests to compare crossing frequency before and after pipeline construction
- Descriptive statistics of ramp use and pipeline height selection

Results:
- Cow-calf groups usually were larger than bull groups, with the largest group sizes observed when mosquitoes were present and smallest when oestrid flies were present
- Caribou groups harassed by mosquitoes moved faster than groups under insect-free conditions
- Very high traffic levels (1.3 and 2.4 vehicles/minute) reduced caribou crossing frequency
- Higher percentage of caribou groups crossed the Spine Road before pipeline construction than afterward
- 31% of groups that successfully crossed the pipeline/road corridor used ramps as crossing sites; all ramp crossings occurred when no insects were present
- Most pipeline/road crossings occurred when oestrid flies were present and caribou were attracted to the corridor for insect relief
- Caribou did not react strongly to pipeline and road when oestrid flies were present

- When no insects were present, caribou using ramps reacted less strongly than caribou that crossed under the pipeline
- Mean pipeline height crossed by caribou was 72.4 in., compared with mean height of 71.8 in. available in study area; small sample size (10 groups, 36 crossings) disallowed statistical testing

Conclusions:
- Due to a construction mistake, both ramps were built identically, so planned comparison between ramp designs could not be accomplished
- Rigorous quantitative evaluation of the effectiveness of ramps was hampered by small sample sizes, but qualitative evaluation suggested that caribou used ramps more often than would have occurred if selection of crossing sites were random
- Ramps did not maintain crossing frequencies similar to pre-pipeline levels
- Poor ramp design may have contributed to low crossing frequency; authors suggested ramps should be extended several hundred feet on both sides of the pipeline to intercept caribou paralleling the pipeline
- High traffic levels on the road were considered the most significant factor affecting crossing frequency; ramps may not be able to mitigate the impacts of traffic on caribou

Peer Reviewed: No

Murphy, S. M., and J. A. Curatolo. 1987. Activity budgets and movement rates of caribou encountering pipelines, roads, and traffic in northern Alaska. Canadian Journal of Zoology 65: 2483–2490.

Study Location/Herd:
- Alaska; North Slope; Kuparuk Oilfield; Central Arctic Herd

Dates of Study:
- Summer; calving; postcalving; insect period; 2 July to 5 August 1981; 4 June to 1 August 1982

Pipeline Characteristics:
- Kuparuk Pipeline
- Elevated, minimum height 1.5 m above ground
- 2 experimental (treatment) plots: pipe-road site and pipe site
- Pipe-road site encompassed the Spine Road with traffic adjacent to the Kuparuk Pipeline
- Pipe site encompassed the Kuparuk Pipeline and an adjacent, infrequently traveled road used for occasional maintenance

Study Design:
- Behavioral observations conducted from towers at 2 experimental (treatment) sites, pipe-road and pipe site, and 2 control (reference) sites located in relatively undisturbed habitat south of experimental sites (data from control sites were combined)
- No set observation schedule used; rather, caribou were observed whenever they entered the study area
- Groups were considered successful in crossing the pipeline if >50% of group crossed (see Curatolo and Murphy 1986 and Murphy and Curatolo 1987 for more detailed description of study design and methods)

Objectives:
- Assess how activity budgets and movement rates of caribou were affected by insects, pipelines, roads, and traffic
- Delineate zones of reaction adjacent to pipelines and roads
- Describe behavioral differences among different group sizes and types

Data Quantity:
- 35 days of observation during 1981
- 62 days of observation during 1982
- Observation hours mostly 08:00–20:00

Analytical Methods:
- Compiled time budgets for a pipeline site, a site with a pipeline and traffic, and control sites
- Compared time budgets using Kruskal-Wallis tests

- Compared proportion of caribou lying down in different distance zones with empirical distribution generated using data set and 99 simulations

Results:

- Caribou spent 90% of time feeding and lying when insects were absent and traveled at an average speed of 0.7 km/hr
- Caribou spent 61% of time feeding and lying when mosquitoes were present; walking and running composed 28% of activities; mean movement rate was 2.7 km/hr
- Standing was the dominant activity when oestrid flies were present, constituting 31% of activities, whereas feeding decreased to 47% of the daily activity budget; mean movement rate was 1.6 km/hr
- Amount of time spent in all activity categories (feed, lie, stand, walk, run) varied significantly between periods when insects were absent and when mosquitoes or oestrid flies were present
- Only time spent feeding and standing differed significantly between periods when mosquitoes were present and when oestrid flies were present
- Rates of movement differed significantly among all insect harassment categories
- Traffic rate at pipe-road site was 15 vehicles/hr, versus <1 vehicle/hr at the pipe site
- In absence of mosquitoes, percentage of time spent lying and standing were nearly equal in pipe site and control, but caribou in pipe-road site spent significantly less time lying and more time standing
- In absence of insects, time spent walking and running differed significantly among all sites, with both variables increasing under conditions of greater disturbance
- In absence of insects, caribou in pipe-road site spent 14% of their time running, versus 3% and 2% in pipe site and control, respectively
- Movement rates in the absence of insects did not differ significantly between pipe site (0.8 km/hr) and controls (0.7 km/hr)
- When mosquitoes were present, time spent feeding and lying did not differ significantly between control and pipe sites, but caribou in the pipe-road site spent significantly less time feeding and more time lying
- Movement rates when mosquitoes were present did not differ statistically among sites
- When oestrid flies were present, caribou activity budgets did not differ between pipe site and controls, but caribou in pipe-road site spent significantly less time lying and more time running
- Movement rates when oestrid flies were present differed statistically among sites
- When insects were absent in the controls, no significant differences were found between empirical and expected distributions of lying caribou, but there were significant differences in the pipe-road and pipe sites
- Disturbance threshold distance was estimated at 300 m from the pipeline in the pipe site and at 600 m from the pipeline/road corridor in the pipe-road site
- Three categories of disturbance were identified: low disturbance in control sites and pipe site (300–1,000 m from pipeline); moderate disturbance in pipe site (<300 m from pipeline) and pipe-road site (600–1,000 m from pipeline/road); and high disturbance in the pipe-road site (<600 m from pipeline/road)

Conclusions:

- Undisturbed caribou in control sites spent 90% of time performing activities associated with energy intake and assimilation, a figure similar to other studies
- When harassed by insects, caribou spent more time engaged in energetically costly activities and less time acquiring and assimilating energy
- Caribou have lowest net cost of locomotion for any terrestrial vertebrate studied to date, so reductions in energy intake have greater effects on energy balance than do increases in activities associated with energy expenditure
- Strongest disturbance effects on behavior occurred within 600 m of the pipeline/road corridor in the pipe-road site; outside of the 300 m zone of the pipe site, caribou behaved similarly to undisturbed caribou in control sites
- Insect harassment appeared to disrupt energy intake and assimilation by caribou more than did oilfield disturbances

- Standing was the predominant activity in all study areas when oestrid flies were present
- Oilfield disturbance did not further reduce feeding time of caribou harassed by oestrid flies
- Behavioral differences among group types and sizes primarily involved amount of time spent feeding and lying, as well as rates of movement
- Cow/calf-dominated groups and large groups of caribou were most sensitive to oilfield disturbance
- Large groups had relatively high rates of movement and low crossing success at linear structures
- Groups of >10 caribou rested less and traveled faster than smaller groups, even under low disturbance conditions, so greater propensity for movement may be a behavioral trait of larger groups, regardless of disturbance
- Time spent feeding by groups of >10 caribou was unaffected by disturbance, indicating little effect on energy intake
- Moving stimuli, such as traffic, were more disruptive to caribou energetics than were stationary objects like the pipeline
- Authors concluded that disturbance-induced behavioral changes and subsequent energetic stress would be minimal in a properly designed oilfield that incorporates mitigative measures to allow for free passage of caribou, and in which density of structures does not exceed levels at which caribou can avoid reactive zones most of the time

Peer Reviewed: Yes

Noel, L. E., M. J. Nemeth, and B. J. Streever. 2002. Caribou movement in riparian areas crossed by the Badami Pipeline, Arctic Coastal Plain, Alaska, summer 2001. Chapter 4 in M. A. Cronin, editor. Arctic Coastal Plain caribou distribution, summer 2001. Final report prepared for BP Exploration (Alaska) Inc., Anchorage, by LGL Alaska Research Associates, Inc., Anchorage.

Study Location/Herd:
- Alaska; North Slope; Prudhoe Bay; Central Arctic Herd

Dates of Study
- Summer (postcalving, insect season); 27 June to 16 August 2001

Pipeline Characteristics:
- Badami Pipeline
- Elevated, height mostly 1.5 m; 3 areas with elevations <1.5 m
- Pipeline dampeners hanging down 94 cm below pipeline were installed on 4 sections of pipe (<21% of total pipeline length)
- Pipeline length 40 km
- Crossing structures include buried pipelines at river crossings

Study Design:
- Behavioral observations based on time-lapse video-camera footage taking pictures at 6–8 second intervals
- Cameras were set up in pairs at riparian tundra without the pipeline, river channel areas without the pipeline, riparian tundra with elevated pipeline, and river channels with buried pipeline
- Groups differentiated by elapsed time of 15–30 seconds
- Behaviors were recorded according to group
- Weather data were gathered from remote weather stations and insect activity indices were estimated

Objectives:
- Document number, group size, composition, and direction of large mammal movements in riparian corridors with and without buried pipeline
- Document temporal and spatial movement patterns and their relationship to weather conditions
- Test influence of Badami Pipeline on deflecting caribou movements to buried river crossings and adjacent riparian tundra

Data Quantity:
- 8 cameras at 16 sites recorded for cumulative total of 382 days
- 1,976 caribou in 134 groups

Analytical Methods:

- Used ANOVA to compare number of caribou crossing per day in riverine and tundra sites with pipelines, without pipelines, and with buried pipelines
- Analyzed the variables area, pipeline, habitat (riverine or tundra), and pipeline by habitat interaction
- Used a nonparametric sign test to compare the number of caribou per day among camera pairs
- Did not test differences in number of groups crossing

Results:

- Mean group size was 14.7 caribou with 95% confidence interval of 6.88 caribou
- 47% of groups were single caribou, 33% were 2–10 caribou, 11% were 11–50 caribou, and 9% were >50 caribou
- 70% of caribou could not be classified by sex and age
- Classified caribou included 58% bulls, 21% cows, 20% calves, and 1% yearlings
- Mean duration of caribou near cameras was 2.5 minutes, with maximum of 29 minutes for group of 190
- Caribou were more likely to be feeding at pipeline sites than at sites without pipeline
- Grizzly bears, moose, and muskoxen also were observed on video recordings
- Largest numbers of caribou moved through study area during 16–23 July, accounting for 47% of group observations and 86% of individual caribou counted
- Highest number of caribou observed from 16:00 to 21:00; caribou movements appeared to increase during the day
- Caribou group size varied among different river sites
- Group behavior among sites was generally similar
- Mean daily temperature at river bar weather station (6.60 degrees C) was significantly higher than at tundra station (6.36 degrees C)
- At tundra station, mean daily temperature and wind speed were negatively correlated but highly variable
- Number of caribou per day was positively correlated with mean daily temperature on 20 days when direction of travel was primarily northward or southward, but was not correlated with wind speed
- On 10 days when primary direction of travel was northward, number of caribou per day was positively correlated with wind speed
- 3 different models were used to predict insect activity, which was predicted to peak between 17 and 27 July
- Mean caribou per day at sites with and without pipelines were similar
- Mean caribou per day was lowest at river channels with pipelines and highest at riparian tundra with pipelines
- No evidence that number of caribou per day differed among river sites
- Mean number of caribou per day varied most between habitat types, with fewest seen at river channels both with and without pipelines, but effect was not significant
- Caribou did not seem to be deflected toward buried pipe at river crossings
- No evidence that numbers of caribou per day differed between river channel sites with and without pipeline
- Although not significant, number of caribou per day at riparian tundra sites was greater at sites with pipeline than without

Conclusions:

- Caribou may be more likely to cross a river channel without buried pipeline and on tundra with elevated pipeline; perhaps artifact of small sample size
- Crossing differences may be due to habitat differences among sites
- Data did not suggest the Badami Pipeline was funneling caribou toward buried river crossings
- Caribou use buried pipeline river crossings and river channels without buried pipelines at similar rates

Peer Reviewed: No

Pullman, E. R., and B. E. Lawhead. 2002. Snow depth under elevated pipelines in western North Slope oilfields. Final report prepared for Phillips Alaska, Inc., Anchorage, by ABR, Inc., Fairbanks. 19 pp.

Study Location/Herd:
- Alaska; North Slope; Kuparuk; Alpine

Dates of Study:
- 26–30 March and 17–20 April 2001

Pipeline Characteristics:
- Three different areas of elevated pipeline with minimum design height 152 cm
- Tarn (DS-2L and -2N) pipeline was examined in E–W and N–S sections; 3 adjacent pipes mounted on a single pipe rack; diameter unspecified; VSMs spaced at 17 m intervals
- Alpine pipeline: 3 pipes with diameters 24-in., 18-in., 2-in.; mounted on single VSMs at 20-m intervals; on Colville River delta, pipeline on larger-diameter VSMs and at higher elevation than in area east of delta (latter area referred to as Alpine Corridor)

Study Design:
- Measured snow depth and ground clearance (pipeline height) at 10 stations spaced evenly across 5 VSM spans (referred to as a sampling segment); at each station, 3 snow-depth and 1 ground clearance measurements were taken, for a total of 30 and 10 measurements of snow-depth and ground clearance, respectively, for each sampling segment
- Measurements under pipelines were paired with transects of equal length 100 m from and parallel to each side of pipeline
- Landform determinations were made from previously mapped terrain units
- 140–152 cm was considered to be minimum ground clearance necessary to allow snowmachiners and caribou passage under the pipeline, respectively

Objectives:
- Measure minimum clearance between elevated pipelines and snow surface
- Determine influence of physical variables affecting snow depth under and adjacent to pipelines, such as terrain type and pipeline orientation in relation to prevailing wind directions

Data Quantity:
- 140 and 100 snow-depth measurements for Tarn pipeline (both N–S and E–W orientations) in March and April, respectively
- 30 and 60 snow-depth measurements for the Alpine Corridor in March and April, respectively
- 60 snow-depth measurements for Alpine Pipeline on the Colville River Delta in April; no March sampling due to inclement weather
- 70 and 50 ground-clearance measurements for Tarn Pipeline (both N–S and E–W sections) in March and April, respectively
- 30 and 60 ground-clearance measurements for Alpine Corridor in March and April, respectively

Analytical Methods:
- Measured snow depth (mean +/- SD) under pipelines and at upwind and downwind sites for 3 pipeline locations and different orientations
- Compared results using analysis of variance (ANOVA)

Results:

Snow depth in March:
- Snow depth along N–S Tarn pipeline averaged 33 cm in basins, 37 cm on terraces, and 63 cm in riverine terrain; upwind background depths were 44 cm in basins, 38 cm on terraces, and 31 cm in riverine terrain
- Snow depth along E–W Tarn pipeline averaged 35 cm in basins, 32 cm on terraces, and 94 cm in riverine terrain; upwind background depths were 21 cm in basins, 28 cm on terraces, and 35 cm in riverine terrain
- Snow depth in Alpine Corridor averaged 37 cm on terraces, 47 cm in riverine areas; upwind background depths were 38 cm on terraces and 49 cm in riverine areas

- Background depths along N–S Tarn pipeline were significantly greater in downwind transects than under the pipeline
- Results confounded by landscape factors such as the location of downwind transects, many of which were located near transition areas between basin and terrace landform types, areas that act as snow traps
- Ice road immediately adjacent to VSMs on west side of Tarn pipeline disrupted natural snow accumulation patterns
- Under E–W Tarn pipeline, snow depths were significantly greater than background levels in all terrain groups
- Under N–S Tarn pipeline, snow depths were less than background levels in basin areas and were not significantly different in other terrain groups

Snow depth in April:

- Snow depths were only slightly less than in March
- Snow depth along N–S Tarn pipeline averaged 30 cm in basins and 34 cm on terraces; upwind background depths were 39 cm in basins and 36 cm on terraces
- Snow depth along E–W Tarn pipeline averaged 36 cm in basins and 26 cm on terraces; upwind background depths were 27 cm in basins and 24 cm on terraces
- Snow depth in Alpine Corridor averaged 49 cm in basins, 31 cm on terraces; upwind background depths were 30 cm in basins and 41 cm on terraces
- Snow depth in Colville River Delta section averaged 23 cm in basins and 19 cm on terraces; upwind background depths were 25 cm in basins and 24 cm on terraces
- On terraces and in basins under E–W Tarn pipeline and in basins in Alpine Corridor, snow depths under pipelines were significantly greater than upwind background measures
- On terraces under N–S Tarn pipeline and in thaw basins in Alpine Corridor, snow depths under pipelines were less than upwind background levels
- Snow depth under the pipeline differed significantly among individual sampling segments along E–W Tarn pipeline and Alpine Corridor, compared with adjacent background samples
- Across all study areas, depth of snow under pipelines and in background segments varied significantly in April, being greatest under pipeline in Alpine Corridor (39.9 +/- 17.6 cm), intermediate in Tarn area (31.4 +/-12.1 cm), and least on Colville River Delta (21.1 +/-10.1)
- Across all study areas, snow depths did not differ significantly between Tarn sections and Alpine Corridor (30.2 cm +/-9.8 vs. 35.5 +/- 16 cm), but were significantly greater than on Colville River Delta (24.2 +/-10.1 cm)
- Pipelines oriented parallel to prevailing wind directions tended to have a plume of deeper snow within 20 m of pipelines

Ground clearance in March:

- E–W Tarn pipeline clearance averaged 158.4 cm, range 81–286 cm
- N–S Tarn pipeline clearance averaged 160.7 cm, range 119–193 cm
- Alpine Corridor pipeline clearance averaged 169.4 cm, range 148–218 cm

Ground clearance in April:

- E–W Tarn pipeline had average clearance of 145.7 cm, range 94–179 cm
- N–S Tarn pipeline clearance averaged 173.8 cm, range 81–286 cm
- Alpine Corridor pipeline clearance averaged 173.8 cm, range 118–289 cm
- Clearance on the Colville River Delta was high, often >3 m (limit of measuring equipment); minimum clearance was 190 cm
- Snow depth in April was negatively correlated with pipeline clearance
- In Tarn area in April, 70% of sampling segments measured had at least one occurrence of clearance <152 cm within each 100-m transect surveyed; mean clearance height was <152 cm in 40% of segments; however, 90% of those segments had at least one clearance height >152 cm
- In Alpine corridor, 83% of sampling segments had at least one occurrence of clearance <152 cm; 50% of segments surveyed had mean heights <152 cm

- No areas of low clearance were observed on Colville River Delta
- Continuous areas of low clearance occurred along Tarn Pipeline, where 20% of segments had clearances entirely <152 cm

Conclusions:

- Snow depth at 59% of March sampling segments and 55% of April sampling segments did not differ significantly between pipelines and upwind background levels
- In both periods, 25% of sites under pipelines accumulated more snow than upwind background samples
- Landform, pipeline orientation with respect to prevailing wind directions, and ground clearance under pipelines are local factors that can be used to predict where significant accumulations of snow under pipelines might occur
- Thaw basins under pipelines tended to have greater snow depths than background areas; snow is most likely to be trapped along lee side of basins
- Snow depth varied over relatively short distances, with the lowest accumulation on the Colville River Delta
- In areas where mean pipe clearance was <152 cm, snow was likely to accumulate to greater depths than background levels
- Snow depth tended to be greatest where pipelines traverse low-lying terrain such as thaw basins and riverine areas
- On Colville River Delta, where pipe height often exceeded 250 cm, there was no evidence of significant snow accumulation above background levels
- In certain types of terrain, the effective clearance for snowmachiners and caribou (defined as >152 cm) beneath elevated pipelines was compromised
- In most of the study sections, stretches of reduced clearance were rarely continuous and sufficient clearance >152 cm usually occurred nearby

Peer Reviewed: No

Reges, A. E., and J. A. Curatolo. 1985. Behavior of caribou encountering a simulated low-elevation pipeline. Final report prepared for ARCO Alaska, Inc., Anchorage, by Alaska Biological Research, Fairbanks. 17 pp.

Study Location/Herd:

- Alaska; North Slope; Kuparuk River floodplain; Central Arctic Herd

Dates of Study:

- Postcalving; insect season; 1–28 July 1984

Pipeline Characteristics:

- 2.3 km of simulated, elevated pipeline made out of wax-coated cardboard tubes (Sonotube)
- Diameter of simulated pipe 20 cm
- Elevated pipe was adjusted to 3 heights during study: 108 cm, 77 cm, 51 cm
- Also made a combination section by lowering a section of 77-cm-high pipe to 36 cm
- Distance between vertical supports not specified

Study Design:

- Behavioral observations conducted from towers, 24 hr/day

Objectives:

- Determine the maximum height of low-elevation pipeline that caribou will cross
- Determine if the frequency of crossings varies under the presence or absence of mosquitoes and oestrid flies

Data Quantity:

- 624 hours of observation (no observations 2 days)
- 7,178 individuals observed, including 868 cows, 485 calves, 443 yearlings, 4,259 bulls, and 1,123 unclassified

Analytical Methods:

- Chi-square tests were used to compare crossing success at simulated pipeline (set at various heights) and hypothetical pipelines (adjacent to pipeline simulation
- Tests conducted during different conditions of insect harassment

Results:

- Caribou crossed the simulated pipeline significantly less often at all heights compared with hypothetical pipeline delineated by stakes
- Caribou crossed over the simulated pipeline more frequently at lower heights; only 6 of 1,254 caribou crossed the pipe at 108-cm height
- Despite some significant differences, no consistent trends were found in the frequencies at which caribou crossed the 77 cm, 51 cm, and combination 77 cm-36 cm pipes during the presence of mosquitoes and oestrid flies
- Caribou crossed over the 36-cm section of the combined 77 cm-36 cm pipe more frequently than expected under all insect conditions
- In the absence of insects, 537 caribou crossed at one of the pipeline heights, out of 1,676 caribou that approached the simulated pipeline
- When mosquitoes were present, 353 caribou crossed, out of 1,058 that approached, a nonsignificant difference in crossing frequency
- When oestrid flies were present, 243 caribou crossed the pipeline, out of 550 caribou that approached, a significant increase in crossing frequency; most of these successful crossings were at the 36 cm high section of the 77 cm-36 cm combination pipe
- Caribou generally reacted to the pipeline when within 100 m and usually moved parallel to it within 20 m for some distance
- If caribou attempted to cross, they usually did so singly or a few at a time by jumping from a standing position
- Most caribou paralleled the simulated pipe until they reached a terminus and went around it

Conclusions:

- Pipe elevated to 108 cm seemed to be a complete barrier to caribou movement
- None of the lower pipeline presented as much of a barrier, although authors cautioned this relationship could change if pipe diameter were increased
- Caribou tended to follow the "path of least resistance"
- Caribou traveled close to the pipeline and seemed to look for crossing sites, so authors concluded that caribou may be able to learn to cross over single pipelines lower than 108 cm
- Ramps may be useful crossing structures at multiple parallel pipelines or if a greater-diameter pipe affects caribou crossing success

Peer Reviewed: No

Shideler, R. T. 1986. Impacts of human developments and land use on caribou: A literature review. Volume II. Impacts of oil and gas development on the Central Arctic Herd. Technical Report No. 86-3. Alaska Department of Fish and Game, Juneau. 128 pp.

Study Location/Herd:

- Alaska; Canada; Russia; North Slope; Central Arctic Herd; Taimyr wild reindeer herd

Dates of Study:

- Mostly summer studies; calving; postcalving; insect seasons

Pipeline Characteristics:

- Various studies are discussed in this review, but pipeline characteristics are not described in detail

Study Design:

- Literature review and annotated bibliography

Objectives:

- Review history of oil and gas development on the North Slope of Alaska

- Review features of caribou distribution, movements, abundance, and utilization of specific areas that may affect caribou interactions with oil development
- Discuss impacts of direct habitat loss, harassment by aircraft, vehicles, or humans, avoidance of development, disruption of movements, and increase in predators or human harvest

This annotation only discusses pipelines and potential effects on caribou movement

Data Quantity:

- Cited 120 references, of which 40 were annotated

Analytical Methods:

- Literature review

Results:

- Reindeer and caribou reactions to linear developments, including pipelines, are discussed in the Impacts section of the review
- Movements by Taimyr reindeer herd were disrupted by Norilsk-Messoyakha natural gas pipelines in Siberia (not summarized in this annotation, but see annotations for Hemming, undated; Klein, undated, 1980; Skrobov 1972 for more details)
- As of 1985, Taimyr herd did not migrate across Yenisei River valley as it did prior to pipeline construction; however, this herd continued to increase in size
- Case history of a railroad and road disrupting the migration of a Norwegian caribou herd was discussed (see annotation for Klein 1971)
- Studies showing avoidance of linear developments were discussed, focusing on Trans-Alaska Pipeline; Prudhoe Bay, Kuparuk, and Milne Point oilfields
- Author reviewed studies addressing the possibility of linear developments (pipelines, seismic lines, gravel roads, and highways) disrupting caribou movements
- This review focused heavily on studies such as Child 1973, Child and Lent 1973, Fancy 1982, Fancy 1983, Fancy et al 1981, Curatolo 1984, Curatolo and Murphy 1983, Curatolo et al 1982, Murphy 1984, Smith and Cameron 1985a and 1985b (all of which are annotated separately in this bibliography)
- Studies were summarized in categories focusing on roads only, pipelines only, and pipelines associated with roads with traffic

Conclusions:

- Identified general ranking of severity of human disturbance in terms of effects on crossing success by caribou, with least severe being an isolated road with little or no traffic and the most severe being a road with traffic adjacent to a pipeline
- Roads with traffic averaging 15 vehicles/hr were associated with lower crossing success during midsummer
- Season appears to affect crossing success, perhaps due to changes in group composition or presence of insects
- Type and intensity of insect harassment influences crossing success
- Suggestions for future study include relating paralleling behavior of caribou attempting to cross pipeline with energetic costs to individuals

Peer Reviewed: No

Skrobov, V. D. 1972. Man and the wild reindeer on Taimyr. Priroda 72[3]: 98-99.

Study Location/Herd:

- Russia; Siberia; Taimyr reindeer herd

Dates of Study:

- 1967–1970

Pipeline Characteristics:

- Norilsk to Messoyakha natural gas pipeline
- Elevated ~40 cm above ground; total height to top of pipe ~1 m

- Pipeline placed on wooden supports

Study Design:

- An account of behavioral observations

Objectives:

- Describe behavior and movement of wild reindeer near Norilsk pipeline

Data Quantity:

- General observations of spring and fall migration during 1969–1970

Analytical Methods:

- Behavioral observations

Results:

- Wild reindeer usually avoided city of Norilsk, but in 1967 thousands came through and attracted more than 6,000 domestic reindeer; these animals crossed the railroad, highway, and water pipeline, resulting in loss of many calves
- By spring of 1969, gas pipeline from Messoyakha to Norilsk was completed
- Large groups of reindeer accumulated on banks of Yenisei River near gas pipeline
- Heavy vehicle and train traffic prevented reindeer from crossing corridors
- Some crossed road, but were unable to cross pipeline and instead paralleled it from east to west until they found an area blown over with snow or where ravines were deep enough to cross under pipeline
- During one aerial survey in May, up to 20,000 reindeer were found milling around human-made barriers
- Traffic along railroad was reduced to night hours to facilitate movements by reindeer, but some herds, mostly bulls, wandered south of railroad in June
- Some reindeer remained south of pipeline and railroad for summer
- Poaching occurred involving reindeer groups that accumulated near structures
- Reindeer avoided migrating over roads and pipelines and near industrial facilities during fall 1969 and the following spring
- In fall 1970, some reindeer approached the gas pipeline near Dudinka, but then followed the banks of the Yenisei River along the same route used in 1969; small groups remained north of pipeline for winter

Conclusions:

- Reindeer were able to change their behavior to reach summer and winter pastures despite obstacles

Peer Reviewed: Yes

Smith, W. T., and R. D. Cameron. 1985a. Factors affecting pipeline crossing success of caribou. Pages 40–46 in A. M. Martell and D. E. Russell, editors. Caribou and Human Activity: Proceedings of the First North American Caribou Workshop. 28–29 September 1983, Whitehorse, Yukon. Canadian Wildlife Service Special Publication, Ottawa.

Study Location/Herd:

- Alaska; North Slope; Kuparuk Oilfield; Central Arctic Herd

Dates of Study:

- Late spring; early summer; 1981 to 1982

Pipeline Characteristics:

- Kuparuk Pipeline
- Elevated to minimum height of 1.5 m, increasing to >2 m at creek and river crossings
- 45-cm diameter
- VSMs spaced at 20-m intervals
- Depending on location, 1–2 flow lines paralleled the Kuparuk Pipeline

Study Design:

- Road surveys conducted by pickup truck twice daily along the West Sak Road (WSR; later called Spine Road)

- Road transect totaled 32 km, including 10 km of road only and 22 km of road paralleled by pipeline
- Groups were observed until termination of initial crossing episode (not defined further)
- Successful group crossing was considered to have occurred when 100% of group members crossed pipeline/road corridor
- Authors report on frequency of crossing attempts, but provide no definition of the term

Objectives:

- Discuss relative importance of factors affecting crossing success of caribou beneath elevated pipelines, including group size and composition, topography, insect activity, traffic levels, intensity of road or pipeline construction activities

Data Quantity:

- In 1981, observed 14,148 caribou in 1,120 groups during 86 surveys
- In 1982, observed 9,523 caribou in 776 groups during 95 surveys

Analytical Methods:

- Descriptive statistics; compared crossing success using chi-square tests

Results:

- 1981 mean calf percentage in study area (17.6%) was lower than that obtained during regional composition counts (27%)
- In 1981, most caribou were in groups >40 animals, with <5% of groups accounting for 54% of all caribou seen
- In 1982, group size again was large, with <8% of groups accounting for 65% of all caribou seen
- Crossing frequency of individuals decreased with increasing group size in 1982, but not in 1981; however, 1981 data included one group of 917 individuals that was successful in crossing after attempting to cross for 5–6 hr (see Smith and Cameron 1985b)
- Although fewer caribou groups were seen trying to cross WSR in 1982, percentage of successful groups was similar to 1981, but fewer individuals successfully crossed in 1981 than in 1982; differences in number of groups seen trying to cross may have been due to single group of 636 caribou in 1981
- Fewer total caribou were seen and fewer crossing attempts were recorded in 1982 during precalving and calving periods than during any other period in either year
- Many crossing attempts by cows with calves were seen during the mosquito season in both years, perhaps due to greater movement rates through the areas as caribou attempted to access relief habitat north of WSR, leading to more contact with the pipeline/road
- Average group size during the mosquito season was an order of magnitude greater than during oestrid fly period
- Significantly higher percentage of groups successfully crossed pipeline/road corridor during oestrid fly period than mosquito period, possibly related to smaller group sizes during oestrid fly harassment
- In 1982 both individuals and groups were significantly more successful in crossing the pipeline/road during oestrid fly harassment than during same period in 1981; low crossing success of individuals in 1981 possibly attributable to response of single group of 58 caribou
- 30.7% of caribou in 1981 were recorded during moderate or severe insect harassment, but accounted for 93.2% of crossing attempts
- 52.3% of caribou in 1982 were recorded during moderate or severe insect harassment, but accounted for 97.2% of crossing attempts

Conclusions:

- During oestrid fly activity, fewer caribou use habitats adjacent to WSR, but their ability to negotiate roads and pipelines increased
- Differences in experimental design and definitions of crossing success complicate comparisons among studies
- In this study, authors attempted to relocate caribou that did not initially cross pipeline/road, after completing their standard survey; since larger groups were easier to identify and relocate, this method might have biased results toward large groups, which had lower crossing success than smaller groups

- Crossing success based on groups may give different results than crossing success based on the total number of individuals in those groups; crossing success for an entire group may be zero (using the criterion of 100% crossing), but a proportion of individuals may cross
- Crossing success may be a social response based on time of year, such as during insect season when social bonds are more ephemeral, or a functional response to a barrier
- Crossing success rates at roads alone were significantly higher than at pipeline/road complexes
- Caribou in this study did cross buried pipe in areas of heavy traffic, likely due to design problems such as width <22 m and, in some, openings being partially obscured from view
- Differences in ramp design, along with ramps associated with varying levels of disturbance throughout a study area, makes it impossible to identify factors that enhance its selection and use
- Little is known about importance of width, steepness of approach slopes, funneling structures, and visibility of opening on ramp effectiveness, all of which might affect ramp use; varying amounts of traffic also may affect ramp use
- Specific crossing sites should be integrated into a regional plan to preserve movement corridors through oilfield complexes

Peer Reviewed: Yes

Smith, W. T., and R. D. Cameron. 1985b. Reactions of large groups of caribou to a pipeline corridor on the Arctic Coastal Plain of Alaska. Arctic 38: 53–57.

Study Location/Herd:
- Alaska; North Slope; Arctic Coastal Plain; Kuparuk Oilfield; Central Arctic Herd

Dates of Study:
- Summer; insect period; observations from 18 July 1981 and 13 July 1982

Pipeline Characteristics:
- Kuparuk Pipeline, elevated to minimum height of 152 cm
- Diameter 50 cm
- VSMs spaced at 20-m intervals
- Pipeline closely paralleled roads with different amounts of traffic
- Crossing structures included functional ramps (buried sections of pipe at road crossings)

Study Design:
- (See Smith and Cameron 1985a, Smith et al. 1994)

Objectives:
- Describe responses by two large, insect-harassed groups of caribou to a road/pipeline corridor between the Kuparuk and Prudhoe Bay oilfields, during the first and second summers after pipeline construction

Data Quantity:
- 12 and 8 hr of observation on groups of 917 and 655 caribou, respectively

Analytical Methods:
- Behavioral observations and descriptive statistics

Results:
- Of the group of 917 caribou observed on 18 July 1981, 46% crossed under elevated pipeline, without recrossing, in 26 attempts; 13% crossed over buried sections in 2 attempts; 22% paralleled the pipeline for at least 32 km without crossing
- Of the 515 caribou observed on 13 July 1982, 26% crossed under elevated pipeline without recrossing; 37% crossed over a buried section in one attempt; 37% separated from the main group and their crossing success could not be determined
- Overall, 60% and 64% of the group members crossed the pipeline during the authors' observations in the 1981 and 1982 encounters, respectively

Conclusions:
- Some caribou in large insect-harassed groups may exhibit difficulty in crossing or be prevented from crossing elevated pipelines

- Groups may fracture into smaller groups, potentially exposing individuals to greater degree of mosquito attack
- Caribou were more successful in crossing buried sections of pipeline, particularly those isolated from traffic, compared to elevated pipeline

Peer Reviewed: Yes

Smith, W. T., R. D. Cameron, and D. J. Reed. 1994. Distribution and movements of caribou in relation to roads and pipelines, Kuparuk Development Area, 1978–1990. Wildlife Technical Bulletin No. 12. Alaska Department of Fish and Game, Juneau. 54 pp.

Study Location/Herd:
- Alaska; North Slope; Kuparuk Oilfield; Central Arctic Herd

Dates of Study:
- Spring and summer; late May, June, July, early August; 1978 to 1990

Pipeline Characteristics:
- Kuparuk Pipeline (constructed winter 1980–1981) and feeder pipelines in Kuparuk Oilfield
- Elevated pipelines (152-cm minimum height), most paralleling roads

Study Design:
- Systematic road surveys conducted once or twice daily over standardized route by one observer in a light truck
- Caribou were observed approaching roads and/or pipelines until the termination of the initial crossing event, generally 5–20 min
- Crossing success not defined; in earlier reports, authors considered group crossings successful if 100% of group members crossed during observations
- Crossing attempts referred to, but criteria were not defined (e.g., using a specific approach distance)
- Traffic rate was recorded but not reported or analyzed in relation to crossing success of caribou

Objectives:
- Determine chronological changes in distribution, movement patterns, and composition of caribou within or near Kuparuk Development Area (KDA)
- Determine locations of pipeline and road crossings by caribou
- Characterize responses of caribou to human structures and disturbance

This annotation only summarizes the last two objectives as they relate to crossings of linear structures

Data Quantity:
- 13 years of seasonal data: precalving (10–25 May), calving/postcalving (1–30 June), midsummer (1 July–10 August)

Analytical Methods:
- Conducted road surveys along the Spine Road (referred to in their earlier reports as the West Sak Road) during 1978–1990 and the Oliktok Point Road during 1982–1990
- Recorded locations of caribou crossing roads, pipelines, and road/pipeline combinations
- Reported crossing success by year and group size

Results:

Crossings of newly constructed roads prior to Kuparuk Pipeline construction (1978–1980):
- Most crossings occurred during insect-induced movements, although relatively few caribou were observed during insect harassment
- Number of crossings increased annually
- Number of groups successfully crossing roads increased, but individual crossing success decreased
- Most crossings in any one year occurred in a single road segment near intersecting stream drainages located away from construction activities
- Only two groups of >100 caribou were observed trying to cross the road and both were unsuccessful

Period of initial construction (1981–1984) – Precalving (10–25 May):
- Numbers of caribou observed crossing road continued to increase, but represented only 1% of all caribou observed

- Crossing success of roads by individuals was low: 28.5% in 1982, 16.7% in 1983, 44.4% in 1984
- In 1983 and 1984, 50% and 30.8%, respectively, of individuals crossed pipeline/road corridors successfully

Period of initial construction (1981–1984) – Postcalving (2–30 June):

- Crossing success during all 3 years was high for groups (100%, 80%, 100%) and individuals (94%, 95%, and 100%), although in 1981 only 14 of 29 caribou in 2 groups were observed crossing road/pipeline

Period of initial construction (1981–1984) – Midsummer (1 July–7 August):

- Oliktok Point Road was added to survey coverage, increasing group and individual crossing success; percentage of maternal cows crossing was high
- Crossing success of groups approaching pipeline/road corridors was 80%
- Individual success was lower than group success because large groups >100 animals were more likely to be prevented from crossing
- Both group and individual crossing success tended to be lower for pipeline/road corridors than for either roads or pipelines alone

Period of advanced construction (1985–1990) – Precalving (11–24 May):

- Few caribou were seen attempting to cross pipelines or roads before calving
- In 1985, 5 of 7 groups (11 of 28 caribou) crossed successfully during observations
- In 1986, 5 individuals in a single group of 7 caribou crossed successfully during observations

Period of advanced construction (1985–1990) – Postcalving (2–20 June):

- Crossing rates of pipeline/road corridors were low during postcalving
- Large groups had difficulty crossing pipeline/road corridors
- Groups had greater crossing success than did individuals

Period of advanced construction (1985–1990) – Midsummer (1–6 August):

- Numbers of caribou observed crossing pipeline/road corridors increased until 1988
- Calf percentage of crossing groups was greater than or equal to annual estimated calf percentages for the region
- In 1986, numbers of individuals and groups, including those containing >100 caribou, successfully crossing pipeline/road corridors increased, but declined thereafter
- In 1990, crossing success of pipeline/road corridors reached highest levels

Conclusions:

Authors made recommendations to mitigate the effects of oilfield development on caribou and suggested future studies

- Continue to discourage development on calving grounds
- Maintain 3-km-wide zone of minimum surface development along the coast to accommodate mosquito-harassed caribou
- Discourage additional road construction within the two major crossing areas then used by caribou entering and exiting the KDA
- Minimize "network effect" of KDA by concentrating new support and processing facilities in areas already developed
- Reduce traffic through convoying of vehicles and busing of workers
- Promote development of technology for pipeline burial and encourage improved design and evaluation of elevated pipelines
- Give elevated pipelines greater clearance, separate roads from pipelines, and build crossing ramps of varying height and length
- Curtail road surveys during calving due to low sighting rates
- Continue midsummer surveys to determine distribution and group composition of caribou along road, monitor changes in distribution of road/pipeline crossings and crossing success, and obtain estimates of midsummer sex/age composition of the western segment of the Central Arctic Herd

Peer Reviewed: No

Thompson, D. C., K. H. McCourt, and R. D. Jakimchuk. 1978. An analysis of the concerns for the Porcupine Caribou Herd in regard to an elevated pipeline on the Yukon Coastal Plain. Report prepared for Dome Petroleum Ltd., by Renewable Resources Consulting Services Ltd. 88 pp.

Study Location/Herd:
- Canada; Yukon; Arctic Coastal Plain; Porcupine Herd

Dates of Study:
- Various studies prior to 1978

Pipeline Characteristics:
- No pipelines built at time of study, this review addressed possible effects of an elevated pipeline on caribou movements

Study Design:
- Literature review

Objectives:
- Review concerns regarding effects of development projects on caribou, based on effects documented in literature and expressed as concerns by participants in the Mackenzie Valley Pipeline Inquiry
- Synthesize information on effects into substantiated concerns for the construction of an elevated pipeline along the Yukon coast

Data Quantity:
- Literature review

Results:
- Only information relevant to movements and crossing success of caribou in relation to elevated pipelines is summarized in this annotation
- Sensitivity of caribou to construction and operation of an elevated pipeline was discussed in relation to sensory disturbances, direct mortality (i.e., vehicle collisions), habitat alteration, and interference with caribou movement patterns
- Caribou may avoid or parallel pipelines or avoid pipeline corridors
- Snowbanks >1.5 m in height prevented caribou from crossing plowed roads
- Some studies showed a degree of accommodation by caribou to pipelines (see Child 1973); one study of winter reactions of caribou to seismic lines found that caribou were deflected by new lines, but crossed older ones without hesitation
- Authors discussed observations of wild reindeer encountering a pipeline in Russia (see annotated references for Klein 1971 and Skrobov 1972 in this bibliography)

Concerns expressed at public inquiry:
- If caribou intersect pipeline at approach angles <45 degrees, their movements may be deflected
- Pipeline might cause disturbance on calving grounds and if a shift were to occur, caribou might suffer increased predation by wolves
- Presence of pipeline may disrupt movements and lead to separation of calves and cows or slower rates of movement
- Many witnesses expressed concern over impacts of pipeline next to a road with traffic and impacts associated with hunting from these roads
- Most expert witnesses rejected the idea of a road across the Yukon coastal plain
- Limiting pipeline construction during calving may limit disturbance
- Mitigation measures may include limiting public access to roads associated with pipeline development

Conclusions:
- Placement of pipeline as close as possible to coast would reduce interactions with caribou on calving grounds and migration routes
- Access roads should be placed parallel to pipeline and be restricted to right of way as much as possible (note that this recommendation was made before Kuparuk studies revealed negative effects of roads with traffic immediately adjacent to pipelines; e.g., see Curatolo and Murphy 1986)

- Roads should be planned in consultation with biologists who are familiar with distribution and movements of caribou in area
- Length of access roads should be kept to minimum
- Ancillary installations should be located away from key areas of caribou range
- Pipelines should be elevated a minimum of 7–8 ft above ground level to allow passage of caribou; not known how much of pipeline should have crossings at this height
- VSMs should be placed at a maximum distance apart
- When stringing pipe, pipe should be placed at angle to allow passage of caribou
- Snow fences located parallel to road should not interfere with caribou movements
- No pipeline facility should be used as a base for hunting
- If pipeline were to be abandoned at some point, all structures should be removed and disturbed tundra should be rehabilitated

Peer Reviewed: No

Whitten, K. R., and R. D. Cameron. 1986. Groups versus individuals as sample units in the determination of caribou distribution. Pages 325–329 in A. Gunn, F.L. Miller, and S. Skjenneberg, editors. Proceedings of the Fourth International Reindeer/Caribou Symposium. 22–25 August 1985, Whitehorse, Yukon Territory. Nordic Council for Reindeer Research, Harstad, Norway: Rangifer, Special Issue No. 1.

Study Location/Herd:
- Alaska; North Slope; Central Arctic Herd

Dates of Study:
- Winter, spring; calving; postcalving; August; pre-rut; rut

Pipeline Characteristics:
- Critique of selected previous studies

Objectives:
- Demonstrate how failure to consider variation in group size and composition led to erroneous conclusions regarding differential habitat use by male and female caribou

Data Quantity:
- Not specified; focused on critiquing two studies (by Carruthers et al. 1984 along TAPS [not the same citation annotated in this bibliography], and by Curatolo 1985 in Kuparuk Oilfield [not the same citation annotated in this bibliography])

Analytical Methods:
- Used selected data from Carruthers et al. (1984) to reassess their conclusions based on total number of individual caribou in groups instead of number of groups
- Calculated percentage of individuals in riparian areas; did not address problems arising from lack of independence in statistical tests using individuals.

Results:
- Authors compare two studies quantifying habitat use by male and female caribou
- First study of habitat preference analyzed data based on whether or not groups were male- or female-dominated, based on which gender comprised >70% of the group
- Second study assigned group gender in a similar fashion, using >67% as the classification percentage; that study also analyzed habitat selection data based on individual caribou locations
- Both studies found that a higher percentage of male groups was found in riparian habitat compared to female groups
- Data from groups can only be extrapolated to populations as a whole if individuals are distributed similarly to groups
- Because female groups tended to be larger than male groups, female caribou in riparian areas may still outnumber males, even though a smaller proportion of female-based groups were found in riparian areas compared to male-based groups

- Based on analysis of individual locations, second study found that caribou consistently preferred riparian habitats, both along Trans-Alaska Pipeline (TAPS) and the surrounding area
- Percentage of calves along TAPS was lower than surrounding region
- Except during calving, calves were less abundant within or near riparian habitat along TAPS
- Except during August and pre-rut, calves were less abundant in nonriparian habitat along TAPS
- No clear evidence from second study, based on individual locations, that females with calves used riparian habitat differently from other caribou; rather, all caribou preferred riparian habitat, with cow/calf pairs avoiding all habitat along TAPS
- Authors claim first study based on group locations did not take into account human disturbance that occurs along the Kuparuk river drainage

Conclusions:

- Authors assert that data based on groups are not appropriate for describing population distribution or habitat preferences of caribou (the statistical need for independence of observations was not acknowledged)
- Extrapolations based on data analyzed by group yielded different results than data based on individuals composing groups
- Because caribou groups vary in size and composition, and members of the same sex/age class may occur in more than one group type, analyses based on groups alone will not be representative of the population
- Number of individual caribou, not number of groups, should serve as basis for most studies of distribution

Peer Reviewed: Yes

Wolfe, S. A., B. Griffith, and C. A. Gray Wolfe. 2000. Response of reindeer and caribou to human activities. Polar Research 19: 63–73.

Study Location/Herd:

- Alaska; Norway; Russia; Canada; Nelchina Herd; Central Arctic Herd; woodland caribou; wild reindeer

Dates of Study:

- Various, not specified

Pipeline Characteristics:

- Trans-Alaska Pipeline
- Kuparuk Pipeline

Study Design:

- Literature review

Objectives:

- Review literature investigating the responses of reindeer and caribou to human activities
- Human activities included aircraft, railways, highways, pipelines, recreational activities, and forestry practices

This annotation focuses only on reactions to linear structures (roads, railways, pipelines).

Data Quantity:

- 86 studies, including published reports, journals, theses, and conference proceedings

Analytical Methods:

- Literature review

Results:

- Elevated road berms that pose visual barriers were most strongly avoided by caribou in fall and winter
- Insect harassment, particularly by oestrid flies, increased the frequency with which caribou of all sex and age classes crossed roads and other linear infrastructure
- Roads with no or light traffic did not deter caribou from crossing and had little effect on use of traditional migration routes, distribution, or energetic costs

- While migrations have continued across railways or roads in Canada, Newfoundland, and Alaska, they ceased in Norway after construction of a railway adjacent to a highway
- Publications reviewed specific to pipeline interactions included Child 1973, Caruthers and Jakimchuk 1987, Curatolo 1983, Curatolo and Murphy 1986, Eide et al. 1986, Fancy 1983, Hanson 1981, Murphy 1988, Murphy and Curatolo 1987, and Smith et al. 1994, all of which are annotated elsewhere in this bibliography; no new information was presented
- Authors reviewed studies detailing the distribution of caribou near infrastructure, but those studies were not specific to caribou crossing success of linear structures and so are not summarized here

Conclusions:

Authors listed mitigation measures to facilitate crossings of pipelines by caribou, as suggested by other authors (see studies listed above). They also suggested mitigative measures to minimize disturbance caused by other infrastructure and aircraft which are not discussed below

- Involve biologists in project design
- Minimize traffic and prohibit unnecessary access to oilfields in critical habitats and during critical seasons
- Avoid exploration and construction during calving and postcalving
- Minimize network effect of road developments
- Elevate pipelines 1.5 m or higher above ground level and bury pipelines where feasible, especially near known caribou crossing areas
- Separate elevated pipelines from roads with traffic by >150 m

Authors discuss effects of disturbance and factors that might affect the ability to detect these effects

- Population effects of disturbance on caribou are less clear, but reduced density of animals near infrastructure suggests that individual avoidance may accumulate at the population level
- Animals may be displaced into less desirable habitat, but studies have not demonstrated such effects of displacement
- Estimation of cumulative effects of disturbance is necessary to estimate net effects of disturbance
- For effects to be detectable, cumulative effects must be of consistent direction and exceed natural variability within or among herds; however, disturbance may increase variability in distribution or population performance rather than alter average measures such as means
- Effects of disturbance may be affected by annual or seasonal variation in environmental conditions
- Herds should not be expected to show same sensitivity to reactions as herds occupying low-quality or more variable ranges; herds exposed to multiple disturbance types in multiple portions of their range may be less resilient to disturbance
- Estimates of proportions of individuals exposed to disturbance are lacking, making it inappropriate to project modeled estimates of energetic costs at the individual level to the population level
- More empirical and modeling work needs to be done before effects of human disturbance on caribou can be assessed fully
- The most neglected elements of study include identifying mechanisms of cumulative population response, estimating exposure of individuals and populations, and modeling population responses to disturbance

Peer Reviewed: Yes