APPENDIX A

REVIEW OF STUDIES CONCERNING EFFECTS OF OIL FIELD DEVELOPMENT ON CARIBOU AND POTENTIAL MITIGATION MEASURES

Introduction

We first reviewed available data concerning the distribution, growth, and reproduction of the Central Arctic Herd (CAH) and compared these parameters with herds (i.e., Porcupine Caribou Herd [PCH], Teshekpuk Lake Herd [TCH], and Western Arctic Herd [WAH]) not exposed to oil field development to gain insight on whether caribou had been affected by oil field development at the herd level. We also evaluated whether the herd concept was useful for evaluating the impacts of oil field development.

We then reviewed potential effects of oil fields on caribou in the absence of mitigation and drew general conclusions about mitigation measures. After examining individual studies, we attempted to identify patterns and congruities. Such an approach was particularly necessary with regard to field studies in complex natural systems where possibilities for strong inferential arguments are limited (Eberhardt and Thomas 1991:54). Strong, substantiated conclusions ultimately depend on agreement of numerous individual results (Tukey 1960, Strong 1982).

We prioritized our review as follows: Highest priority was given to crossing studies because these most directly addressed the effectiveness of specific mitigation measures. Second, we focused on the Kuparuk and Milne Point oil fields and the western portion of the Prudhoe Bay field. These were more recently developed than the main Prudhoe field and more closely resemble future oil fields (Robertson 1989). In addition, these areas have been used historically by calving and post–calving caribou.

In a review of this nature, precise usage of terms is critical. To aid the reader we have included a list of selected terms and definitions (Appendix B). Some of these definitions also appear in the body of the text where appropriate. There are other terms for which we could not supply uniform definitions. This was because either usage varied considerably among the studies reviewed or the term was poorly defined. In these cases, we comment on specific usage at the appropriate point in the text.

Because our task involved a study of mitigation, we needed at the outset a working definition. We adopted that of Krulitz (1979:19 et seq.), based upon National Environmental Policy Act rules, that mitigation includes "avoiding, minimizing, rectifying, reducing or compensating for project effects on natural resources". In our review, we found no mention of efforts to compensate for potential effects to caribou. Thus, we have emphasized acts or measures which avoid or reduce (minimize) any potentially adverse effects on caribou. Such a definition emphasizes ecological effects as opposed to social effects (Beanlands and Duinker 1983:44).

We refer to caribou that occur in and around the Prudhoe Bay region and that have been subject of study in the various oil fields as the CAH. On a short time scale, there is currently a high degree of predictability involved in use of calving areas, in that most of the caribou observed east and west of the Sagavanirktok River in the oil fields of the Prudhoe Bay area in any given year can be expected to return to the same general area in the subsequent year (Cameron et al. 1986).

Unless specified otherwise, all references to "effects" refer to behavioral responses of individuals and groups of caribou and not to herds or population–level phenomena. Effects on movement and behavior are of interest because such effects could have an effect on population dynamics and status in the absence of sufficient and appropriate mitigation.

Infrastructure and human·activities in oil fields could possibly lead to detrimental effects on caribou populations by increased predation, increased accidental mortality, reduced forage availability, reduced time spent feeding, or increased energy expenditures (Table A–1). Perhaps equally important, increases in human population during operation and following decommission of oil fields can result in settlements which result in habitat displacement, increased harassment, and increased hunting pressure. Mitigation in Prudhoe Bay oil fields has been designed and employed under the assumption that one or more of the above factors could have such effects. We assess the potential relative importance of each of these factors in the next sections.

Table A-1. Plausible effects of oil field development on individual and groups of caribou in arctic Alaska, and mitigation options potentially alleviating the effects.

Potential impacts	Impact mechanism(s)	Development action responsible	Relevant current or potential mitigation
Exacerbation of predation	• Cows shift their distribution during calving to areas where predator densities are higher.	• Infrastructure and/or activities that block access to traditional calving areas.	• Elevated pipes • Ramps over pipes • Pipe–road separation • Control of traffic to alleviate barrier effects.
	• Predators increase in abundance in oil fields.	• Predator protection policies or predator food subsidies in oil fields. • Alternate prey species may increase due to artificial habitats or feeding.	• Regulations governing disposal of solid waste that might attract predators. • Prohibit feeding of predators and prey species.
	• Predation is facilitated by roads and other oil field infrastructures.	• Road maintenance and snow removal in winter provides predator travelways and stalking cover.	• Predator control.
Increase in accidental deaths	• Oil field vehicles collide with caribou.	• Roads with traffic.	• Regulations governing traffic speed and road safety. • Restricted access.
Reduction in quality/quantity of forage available	• Forage is destroyed or altered.	• Gravel fill used for facilities support, oil spills, gravel mine development. • Dust from traffic.	• Consolidation of facilities to reduce total gravel cover. • Rehabilitation of abandoned gravel sites and other disturbed areas. • Dust control.
	• Forage is made inaccessible to caribou.	• Infrastructure and/or activities block access to foraging sites.	• Consolidation of facilities. • Elevated pipes. • Ramps over pipes. • Pipe–road separation. • Traffic control to alleviate barrier effects.

Table A–1. (continued)

Potential impacts	Impact mechanism(s)	Development action responsible	Relevant current or potential mitigation
Reduction in time caribou spend feeding	• Caribou are disturbed near roads with heavy traffic and thus feed less.	• Movement of vehicles on major roads.	• Consolidation of facilities to reduce total length of roads with heavy traffic.
	• Caribou spend more time moving and less time feeding when navigating oil field infrastructure.	• Infrastructure or activities that hinder normal passage.	• Consolidation of facilities. • Elevated pipes. • Ramps over pipes. • Pipe–road separation. • Traffic control to alleviate barrier effects.
Increase in energy expended by caribou	• Caribou are disturbed by nearby traffic or other activities.	• Movement of vehicles on major roads.	• Consolidation of facilities to reduce total length of roads with heavy traffic.
	• Caribou cannot reach normally used insect–relief areas.	• Infrastructure or activities that hinder normal passage.	• Consolidation of facilities. • Elevated pipes. • Ramps over pipes. • Pipe–road separation. • Traffic control to alleviate barrier effects.
Increased human access after development	• Increased hunting • Increased traffic • New settlements		• Regulate hunting. • Close roads or impose traffic restrictions. • Remove roads.

The relationship between oil field development and predation is of concern because caribou calves are known to be vulnerable to predators (Bergerud 1978:86, Whitten et al. 1992a), and there is the possibility of oil field development in caribou calving areas.

Individual Level Effects

Exacerbation of Predation

Oil field development can affect predation on caribou by shifting caribou distributions away from development into areas of greater predator density (Whitten et al. 1989:12), artificially elevating predator densities near development (Roby 1978:97; R. Shideler and J. Hectel, ADF&G, pers. comm.), or helping predators catch caribou (Roby 1978:103). The first of these phenomena is the only one considered potentially significant, as indicated by impact assessment (Clough et al. 1987) and research efforts (Whitten et al. 1989). Consequently, we focused on this issue. The basis of this concern is that: (1) neonates are more vulnerable to predators than other age classes (Bergerud 1978:86, Young et al. 1990, Whitten et al. 1992a), (2) calving areas are characterized by relatively low densities of predators in comparison with adjacent areas (Bergerud 1988, Heard and Williams 1991), and (3) existing and potential oil fields overlap traditional calving grounds (Smith and Cameron 1990:54, Fancy et al. 1990:8).

The oil field development in Arctic Alaska which has overlapped a concentrated calving ground is that of the Kuparuk and Milne Point oil fields. These oil fields encompass half of the CAH calving area. In spite of this overlap, it continues to be used for calving (Carruthers et al. 1984:53, Smith and Cameron 1990:51), although patterns of use by cows with young calves may have changed (Dau and Cameron 1986a, b). Changes in mortality rates due to predation have not been reported; but predator densities have been and remain low (Carruthers et al. 1984:121, Cameron et al. 1988:5, Appendix A). Presumably, few early deaths would be caused by predation regardless of local changes in calving distribution.

The PCH calves on the Arctic Coastal Plain in northeastern Alaska. It probably offers the best opportunity to assess potential effects because the potential for oil field development on part of the historic calving ground (the so-called 1002

Area) is high (Clough et al. 1987), and predator populations on the calving grounds are low but relatively high in adjacent areas (McCabe 1989, 1990, Young et al. 1990).

There are three ways in which caribou avoid or lower predation on calves. One is synchronized parturition and the aggregation of animals so predators are "swamped" by available prey and only kill a small percentage of vulnerable calves. Second, cows may calve in areas of melted snow where calves are cryptic and less susceptible to predation than when snow cover is complete. Third, cows can move away from areas with high densities of predators (avoidance strategy).

A predator–swamping strategy is effective when herds are large. Large herds can produce more calves than can be preyed upon in a short period of time. For large caribou herds, such as the George River herd (Messier et al. 1988), this strategy may limit predation on neonates.

With small herds, the predator swamping strategy is less effective and avoidance strategies become more important. Small caribou herds, attended by predators at calving, tend to disperse rather than aggregate to calve (Bergerud et al. 1984a, Brown et al. 1986). Even when avoidance is the principal strategy, the other strategies are also used (Whitten et al. 1988:88, Eastland et al. 1989:827).

During one of three years, high proportions (75%) of PCH pregnant cows calved within the 1002 Area (Pollard and Roseneau 1992). It has been hypothesized that a portion of the coastal plain (southeast portion of 1002 Area) that has been used for concentrated calving during some years (i.e. a "traditional" area) provides less predation risk than adjacent areas used less consistently ("peripheral" areas) (Whitten et al. 1987, Weiler et al. 1989, Whitten and Fancy 1990, Young et al. 1990, Whitten et al. 1992a). First–month mortality rates of PCH calves were estimated for 1983–1985 and 1987–1989 by Whitten and Fancy (1990) and Whitten et al. (1992a). Total mortality of calves was consistent among years despite differences in spatial distribution of calving (Eastland et al. 1989:824) and the proportion of cows that calved in the 1002 Area. When mortalities for each year were adjusted to exclude those <48 h after birth, median mortality rates were higher in 1987 and 1988 (19.4%, Kruskal–Wallis test, $P=0.046$) when more calving occurred outside the 1002 Area, than in 1983–1985 and 1989 (9.5%) when most calving occurred within the 1002 Area (Whitten et al. 1992a:30).

Whitten et al. (1992b) determined that sites where collared calves died in the 1002 Area were farther south than sites where calves survived during June. This difference was attributed to higher predator densities in the southern areas (Whitten et al. 1992b). On this basis, they predicted that displacement of calving to southerly "peripheral" areas would expose calves to more predators and, thus, increase mortality.

In conclusion, small to moderate shifts in calving distribution may cause measurable increases in total predation. Clearly, no such effects have occurred with regard to the CAH which have been displaced by 0.6–1.2 miles (1–2 km). However, major displacement in the PCH might increase predation.

Increase in Accidental Deaths

Accidental deaths, mainly from vehicle–caribou collisions, could cause caribou mortality in developed areas. However, existing traffic restrictions associated with the Prudhoe Bay development appear to have limited the number of caribou killed and injured annually to very few. Similar restrictions in future oil field developments will be sufficient to keep this type of mortality at a low level and not influence the demography of large herds entering oil fields. In any case, mitigation to alleviate an unexpectedly high accidental death rate could be applied on short notice in the form of additional traffic control regulations.

Reduction in Forage Quality or Quantity

Nutritional intake by caribou affects herd recruitment and mortality through its effects on body condition and reproduction. Reproductive rate is influenced by average age and condition of females at first breeding, and the proportion of years thereafter that an average female conceives. Conception may also be dependent on nutrition (Cameron et al. 1992:67). Survival of neonates fluctuates with nutritional condition of their dams in late–pregnancy (Reimers et al. 1980:781, Rognmo et al. 1983:16), while survival of calves to the end of their first winter is thought to be dependent on nutritional intake in the previous months (White 1983:382).

Quantity of available forage may be reduced by oil field development in three ways (Table A–1). First, forage can be destroyed or degraded by covering with gravel and by flooding upslope from the gravel. Second, forage can become inaccessible because facilities and activities (roads, pipes, traffic) form barriers to caribou movement. Third, potential forage may be lost due to burial by road dust. This latter factor is thought to have significant effects only on lichens and mosses (Walker and Everett 1987:479), which are not likely to be significant components of the total forage base used by caribou in arctic oil fields.

Clearly, some forage in any oil field development will be permanently covered and inaccessible during the life of the field. Whether these forage losses affect caribou populations that use the oil fields in summer depends on two factors: how much forage is made unavailable and the carrying capacity of summer range. Five percent of vegetation in an oil field is the likely maximum that can be expected to be covered by roads and structures in future oil fields (Truett and Kertell 1992). In fact, the maximum in future oil fields may be considerably less than that lost in the Prudhoe Bay oil field (Robertson 1989) (see section entitled, The Influence of Habituation and Learning of this Appendix).

Forage can be made inaccessible, at least temporarily, if barriers such as pipes and roads prevent caribou from reaching an area. It has been hypothesized that some perinatal cows have avoided oil field development areas (Cameron and Whitten 1980; Whitten and Cameron 1985:35; Smith and Cameron 1990:48; Cameron et al. 1992) although pre–development data were not available (Jakimchuk et al. 1987:540). The available evidence for disturbance and avoidance effects is reviewed later (see section entitled, Roads and Pipelines as Barriers to Caribou: Crossing Studies.)

Any tendency for cows with calves to avoid sites of human activity apparently declines sharply when mosquito abundance increases (Murphy and Curatolo 1987:2489, Lawhead 1988:9). Commencement of insect season (early July) occurs one month following the calving peak (Murphy and Curatolo 1987:2488, Lawhead 1988:10–11).

Available data suggest that caribou avoidance occurs within 0.6 to 1.2 miles (1 km) of roads. Depending on the spacing of infrastructure, the majority of forage within oil fields remains accessible to all age groups as long as linear facilities do not block movements (Murphy and Curatolo 1987:2483, 2489; Smith and Cameron 1990:47).

Cameron (1992) speculated that displacement of maternal females and calves from preferred areas may adversely affect foraging success and, therefore, growth and fattening; which, in turn, may reduce subsequent reproductive performance. This hypothesis was based upon the premise that condition at breeding and during winter influence conception/parturition rate, calving date, calf birth weight, and calf survival. Their preliminary results suggested that condition does affect reproduction. To determine the effects of oil field development on caribou productivity, they compared calving caribou west of the Sagavanirktok River (exposed to oil field development) with those calving east of the river (not exposed to oil field development). For a valid comparison, their analyses assumed that caribou occurring east of the river never came in contact with oil field development, the two groups never exchanged individuals, and that quality and quantity of summer and winter ranges were similar. These assumptions should be investigated. For example, Fancy and Whitten (1991:18) and Christiansen et al. (1990:77) indicated that biomass and digestibility of *Eriophorum vaginatum* in PCH calving areas was apparently higher in the 1002 Area than in peripheral areas to the south and east (though the total biomass of forage was not greater). Caribou productivity parameters between the two areas were not significantly different ($P<0.2$ and $P<0.4$); however, they speculated that there was a trend for lower productivity for caribou in contact with oil field development. They stated that inadequate sample sizes and a need to subclassify radio-collared females by reproductive status hampered their research program.

An important point is that summer range may or may not influence caribou productivity as much as winter range. Variation in snow conditions and food availability during winter may have greater effects on caribou population levels and productivity (through effects on calf survival) than variation in summer forage (Fuller and Keith 1981:201, Gates et al. 1986:220; also see review by Truett et al. 1989:69-84). Therefore, winter forage scarcity could prevent caribou populations from reaching the summer range carrying capacity. The importance of summer range to growth and welfare of caribou populations is poorly understood (WMI 1991:43), and winter range of the CAH has not been well–studied.

<u>Reduction in Feeding Time</u>

The amount of time caribou spend foraging was high compared with other ruminants which are less selective in their diets (Trudell and White 1981:79).

Increases in energy expended by CAH caribou as a result of oil field development may or may not have an effect on herd demography. Zones in which effects are measurable occupy a small percentage of existing oil fields (Murphy and Curatolo 1987:2489). Increased energy expenditures are associated with increased time or rate of movement; and, for caribou, the energy costs for locomotion are very low (Fancy and White 1987:123, 124). Energy loss attributable to oil field development is small in comparison to that caused by insect harassment in the same areas (Murphy and Curatolo 1987:2489). Also, insect harassment affects much greater proportions of the herd than does oil field activity. Cumulative effects on herd demography of the above-described factors are unknown.

No additive or synergistic effects between insect harassment and oil field activities are apparent (Murphy 1988:205). In fact, oil field infrastructure may provide relief from oestrid fly harassment (Wright 1980:172, Murphy and Curatolo 1987:2489).

Mitigation Priorities

Oil field development in caribou range could increase predation or accidental deaths, reduce energy (forage) intake, or increase energy expenditures. For existing oil fields, these potential effects may have occurred had no modifications in design or operations been made. However, existing mitigation measures currently in use at current oil fields, such as elevated pipelines, ramps, regulation of vehicle and human traffic, and separation of pipelines from roads, appear to have reduced accidental mortalities and allowed caribou to pass through oil fields and use adjacent forage. Because of differences in herd size, group size, duration of time on summer range, range size and quality, and growth rates of the PCH, potential effects and mitigation needs may be different for development in the 1002 Area. These potential effects need to be addressed in future research. Testing and refinement of measures to allow caribou to pass through oil fields appears to be the most promising measure for ensuring minimum effects from development.

Our conclusions concerning mitigation for future oil fields are as follows:

1. Restrictions on vehicular traffic appear adequate for reducing accidental mortalities to caribou. If problems arise in the future, vehicle schedules can be modified.

2. Mitigation to reduce the amount of forage covered by infrastructure is unlikely to provide measurable benefits to caribou populations because very small proportions of the surface area within oil fields are covered, and future fields may cover less.

3. Mitigation to alleviate the effects of oil field activities on the amount of time caribou spend feeding, according to one study, is unlikely to measurably affect caribou populations.

4. Mitigation to ensure free passage of caribou across linear facilities (pipelines, roads) is highest priority.

5. Disturbance and displacement studies should continue to quantify disturbance due to oil field activities. Potential impacts such as reduced access to caribou use areas due to proximity to structures and oil field activities also need to be evaluated and potentially mitigated.

Review Considerations

Types of Studies

We reviewed and synthesized relevant studies conducted within the Prudhoe Bay area and along the Trans–Alaska Pipeline System since 1970. Studies were divided into three general categories. The first category consisted of "crossing studies", which focused on movements of caribou in relation to oil fields acting as barriers that impede, deflect, or prevent movements of caribou. These studies also dealt with the extent to which various features or mitigation measures have helped to reduce the potential barrier effect. The second category, "disturbance studies", compared patterns of behavior of caribou in oil fields to behavior exhibited by caribou in areas not subjected to development. The general hypothesis was that proximity to oil fields would alter caribou behavior. This assumed that caribou behavior patterns serve as indicators of some influence or stress. The third category consisted of studies of habituation.

An underlying assumption of the studies was that unrestricted movement of caribou was the most desirable state of affairs, and that any measure that significantly reduced the human influence on these movements was a successful mitigation measure. Mitigation effectiveness has been frequently measured by determining the probability that individuals or groups of caribou will cross over or under that feature. Few of the reports, however, explicitly stated hypotheses regarding these effects. Only general hypotheses are described or implied. Lack of clearly stated, testable hypotheses was a frequent weakness in impact assessment studies (Beanlands and Duinker 1983:58, WMI 1991).

Many studies failed to provide a statistical model (Green 1979:9) that explicitly stated the functional relationship between the dependent and independent variables. Thus, the applicability of the specific findings to the general situation may be limited. Where possible, we attempted to state implied hypotheses. Many studies inferred effect on the basis of spatial pattern without pre-impact observation. Ideal study design should include both baseline (before-impact data) and spatial controls (Green 1979:72). An ideal study design would have involved collection of baseline pre-development data and prediction or determination of effects based on models or actual data, determination of necessary mitigation measures, development and implementation of mitigation plan, and testing the effectiveness of the mitigation measures (Rappoport 1979:3). Only Child (1973, 1974), Child and Lent (1973), and Reges and Curatolo (1985), simulated or deliberately manipulated features or events to test caribou responses. Curatolo and Reges (1986) also blocked ramps for two days to compare crossing success with and without access to ramps. Advantages of experimental studies in impact assessment are well known (Beanlands and Duinker 1983:58 et seq.).

Measurement Units for Analysis of Mitigation Effectiveness and Caribou Distribution

Although the "caribou group" has been used as a unit of measurement and analysis, most authors have not defined it. Two definitions were found. A group is "...two or more animals that function spatially, temporally and behaviorally as a unit" (Murphy and Curatolo 1984:7). Carruthers et al. (1984:32) defined groups to be "clusters of individual caribou separated by less than 165 ft (50 m) and/or engaged in similar behavior". Some authors included single animals as "groups".

Different interpretations of the distribution patterns of female caribou in the Prudhoe Bay region have occurred based upon the use of groups versus individuals as the unit of measurement. Carruthers et al. (1984) and Whitten and Cameron (1986) reached different conclusions regarding the distribution of female caribou in relation to riparian habitat versus avoidance of the Trans-Alaska Pipeline.

Curatolo and Murphy (1986:219) reported crossings of groups rather than individuals because groups generally behaved as cohesive units: "A caribou group was arbitrarily considered to have crossed a pipeline successfully when >50% of the group crossed". The latter definition of a successful group crossing implies that groups are **not** "cohesive" in their behavior. Therefore, use of groups as units of measurement creates problems of interpretation and may limit extrapolation of results to other situations.

One weakness of use of groups as units is that they are variable in size; a group of two individuals is weighted equally with groups ≥100. Crossing success rate of "cow–calf groups" is not the same as the success rates of cows and calves (Whitten and Cameron 1986).

Smith and Cameron (1985b) cited Miller et al. (1972) and Bergerud (1974) as evidence for the importance of social interactions and groups during migration and calving. Functional importance of groups as an anti–predator mechanism has been suggested. The aggregation of females, yearlings and young calves was believed by some to have developed as a strategy to reduce wolf predation in young neonates (Bergerud 1978, Curatolo 1985); aggregation also tended to insulate caribou in the center of the group from severe insect harassment (Dau 1986). Helle and Aspi (1983) established importance of groups as mechanisms for reducing insect harassment, but dynamics and movements of groups were fluid. Groups were constantly splitting, merging and reforming under natural conditions. Splitting as a result of encountering oil field infrastructure could have an impact if it caused increased stress or energy expenditure.

"Crossing events" have also been used as units of measure for crossing success (Murphy and Curatolo 1984). A "crossing event" occurred when ≥1 animal crossed (Murphy and Curatolo 1984). The latter provided more data about dynamics of crossing than use of groups only, but were also subject to limitation during analysis.

Child (1973) hypothesized that cows and calves might respond differently to oil fields than other caribou. Because of the importance of calf survival to caribou population status, most studies have attempted to examine potential effects on maternal cows.

Although "group type" has been frequently defined, there has not been consistency in usage. Initially, a cow–calf group was defined as ≥50% cows, calves and yearlings (Murphy and Curatolo 1984, Curatolo and Murphy 1986, and Murphy and Curatolo 1987). Curatolo and Reges (1986) defined "cow:calf–dominated" groups as >55% cows with calves (yearlings not mentioned). Lawhead and Murphy (1988) and Lawhead (1990) defined cow–calf groups as >66% cows and calves.

Groups in which maternal cows constitute <50% of the individuals reacted differently under alarm or disturbance than a "nursery band" (Pruitt 1960:28) composed largely of maternal cows. Cows with young calves in mixed groups respond more radically to alarm or disturbance stimuli than other sex–age classes and may leave the group (de Vos 1960:258, Lent 1964:116).

Group Size and Cohesiveness

Interpretation of crossing success needs to be qualified based on cohesiveness of groups. Groups were relatively cohesive during crossing studies of the Endicott Access Road. Only 5 of 48 groups which did not cross had >10% of the animals crossing and no groups had 30 to 50% crossing. Of 51 successful group crossings, ≥50% crossed and there were only five groups in which <90% crossed. Group size averaged 43 with a median of three. Lawhead (1990:90) reported group cohesion was highest (93–99% of individuals) during northbound crossings when mosquito harassment occurred and during southbound movements when insects were absent (96–97% of individuals). No comparative data were presented for directional movements under other insect conditions.

Larger caribou groups appeared less cohesive than small groups, but were highly dynamic and complex. For example, Johnson and Lawhead (1989:33) described a group consisting initially of 1000 caribou that grew to 2100 and then to 3384 individuals by merger with two other groups. This merged group then split twice during crossing attempts over the course of the day. First, it split into a group of 755 (22%) which did not cross, and about 2629 which did cross. The group of 2629 later split into a group of 290 (12%) which did not cross, and 2339 which did cross.

Small groups also had complex dynamics. Johnson and Lawhead (1989:30–31) observed 40 animals for approximately nine hours on 7 July 1981. The group lost individuals on three occasions, in the course of two partially successful crossing attempts and five deflections, and gained individuals on two occasions. During the day the group varied in size from 30 (all bulls) to 76, and contained 68 individuals, including cows and calves, at the end of the observation period.

These observations were made during periods of mosquito harassment, a time when group behavior may be especially dynamic. Group size was a function of various behavioral and environmental variables. Group size increased as a result of mosquito harassment (Dau 1986:99); and, in the CAH, groups >1000 animals were observed during these periods. The effects of group size and cohesiveness cannot be separated from the effects of insect harassment. In general, large groups acted less cohesively regardless of the level of insect harassment. Conversely, there were descriptions of massive and abrupt crossings of road–pipeline corridors by large groups (Pollard et al. 1992b) similar to those at river crossings (Lent 1964:138).

This discussion illustrates problems inherent in attempting to describe and quantify the behavioral responses of caribou to anthropogenic stimuli. Measures of group response and group cohesiveness are dependent upon methodology and criteria for describing groups.

<u>Summary of Review Considerations</u>

Three types of studies have been used to evaluate effects of oil field development on individuals and groups of caribou: crossings, disturbances, and habituation studies. Evaluation of the studies was difficult and hampered by lack of testable *a priori* hypotheses and use of similar methodology and definitions. Measurements of effects on caribou crossings have used group size, individuals, or both, but definitions have varied by study. Some authors believed evaluation of crossings by individuals was more meaningful than use of group crossings because sex and age can be accurately identified. Survival value of group membership versus individuals has not been established. Large groups appeared less cohesive than small groups. Crossings of perinatal and maternal cows appeared potentially more important from a population perspective than crossings by other sex–age categories. Insect harassment can significantly alter group size. Few studies have been conducted during pre–calving through the peak of calving.

Roads and Pipelines as Barriers to Caribou: Crossing Studies

The principle objective of caribou mitigation measures in north Alaskan oil fields was to minimize impacts of oil fields on caribou. Efforts have focused on lessening barrier effects of pipelines and roads; the primary approach has been to alter pipeline design and configuration. This section describes mitigation practices that have been applied and reviews relevant studies to evaluate the effectiveness of each measure.

Design Characteristics of Crossing Structures

Structures designed to facilitate caribou crossing pipeline corridors have varied in the Prudhoe Bay area and elsewhere. Design details can influence the effectiveness of crossing structures and may account for differences in results among studies. For example, ramps may vary in width, height, and distance of extension beyond pipe. Relatively few studies have provided descriptions or graphic representations of physical characteristics of ramps and pipeline configurations. Ramps evaluated by Murphy (1984:Fig. 3), Lawhead and Murphy (1988), Lawhead and Smith (1990) and Lawhead (1990) are graphically depicted in Figs. A–1 and A–2. They are probably typical of some recent design configurations for smaller diameter pipelines in terms of spacing of pipe from the road bed, profile, average ramp width, and "visual window". Windows are created by gradually lowering the elevation of the pipeline rather than using an abrupt "bend" as was frequently done in the past. Apparently, this design was intended to provide a view of terrain beyond the ramp. Examples of how elevated pipelines are buried at road crossings are provided in Figs. A–3 and A–4. Buried sections are used by caribou for crossing, but no data exist regarding use of these configurations. Location of structures illustrated in Figs. A–1 through A–4 are given on Fig. A–5. Configuration of the Trans–Alaska Pipeline right–of–way and elevated pipe is presented in Fig. A–6.

The configurations presented are examples of ramp and pipeline designs. No exhaustive catalogue exists. Johnson and Lawhead (1989) reported the occurrence of up to 19 multiple elevated pipelines along portions of the Spine Road in the Kuparuk oil field. Variations of pipe–roadbed spacing configurations are discussed.

Elevated Pipelines in Arctic Oil Fields as Mitigation Measures

Elevated pipelines have been the most frequently used and studied mitigation measure. Many environmental and design variables could influence crossing attempts at elevated pipelines but only a few have been systematically studied.

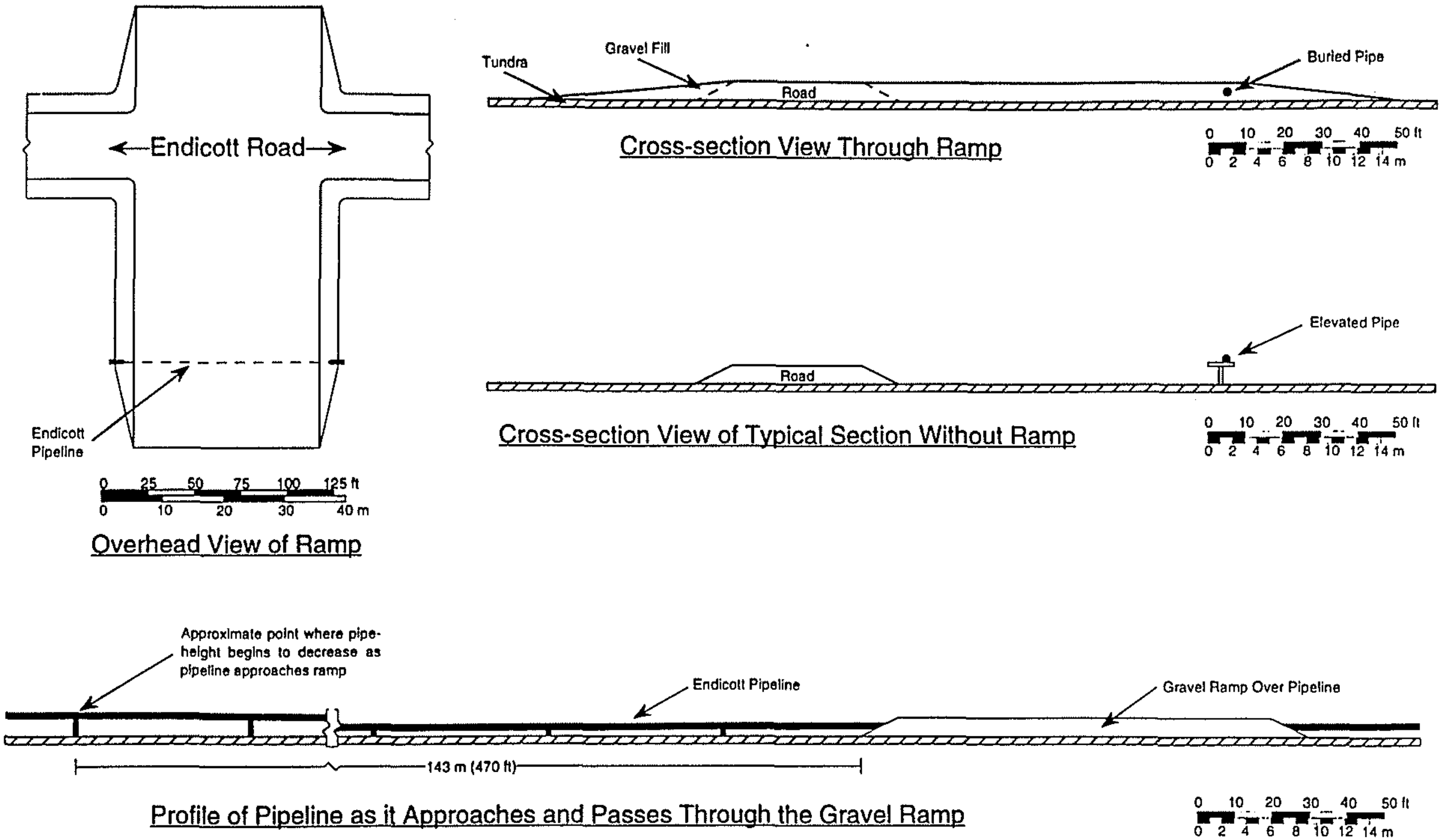


Fig. A–1. Overhead view of a gravel ramp (section of buried pipeline designed to facilitate caribou passage), cross-section views of the ramp and a typical section of elevated pipeline along the Endicott road, and a profile-view of the pipeline as it approaches and passes through the gravel ramp. The diagrams depict the western-most ramp along the road/pipeline corridor, part of a site (Plot 1) where caribou crossing data were collected during the years 1987-1990 (Lawhead and Smith 1990, Lawhead 1990).

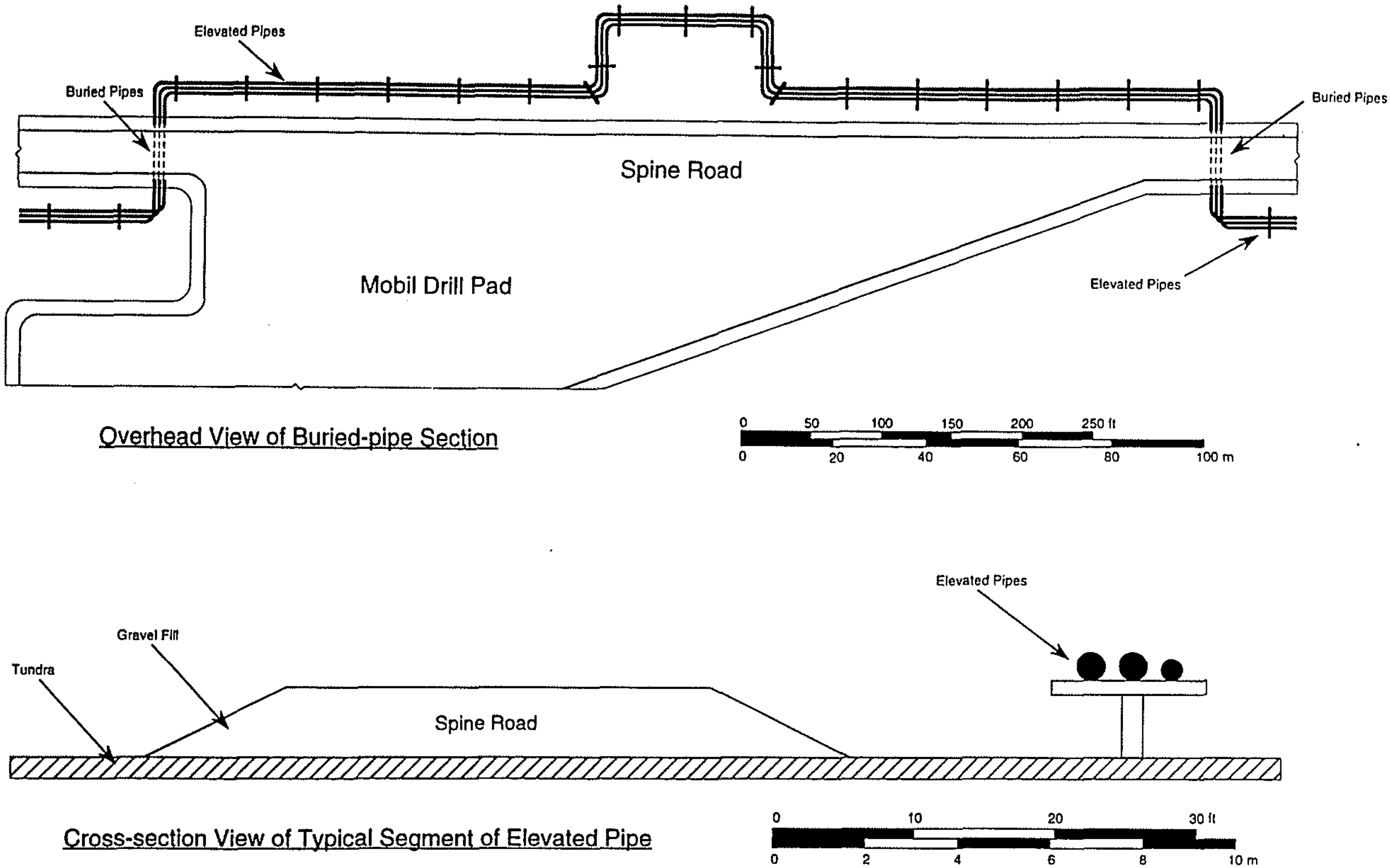
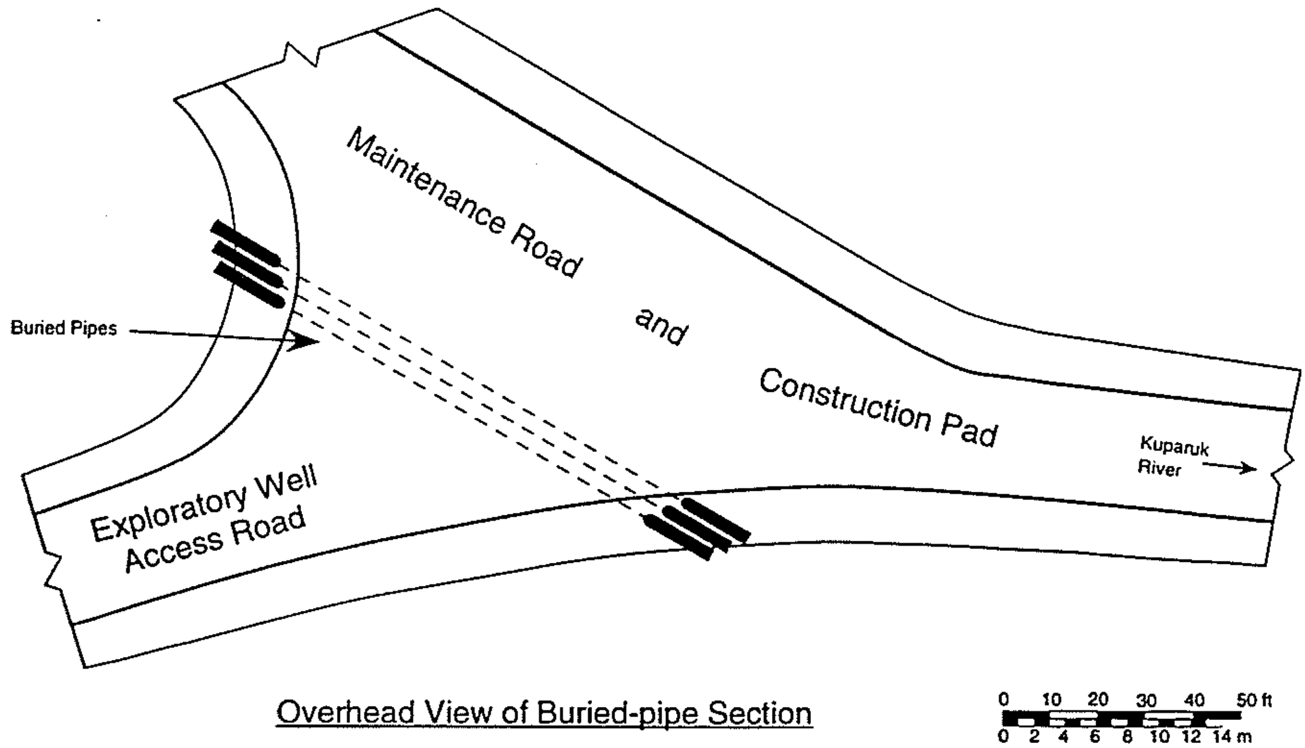
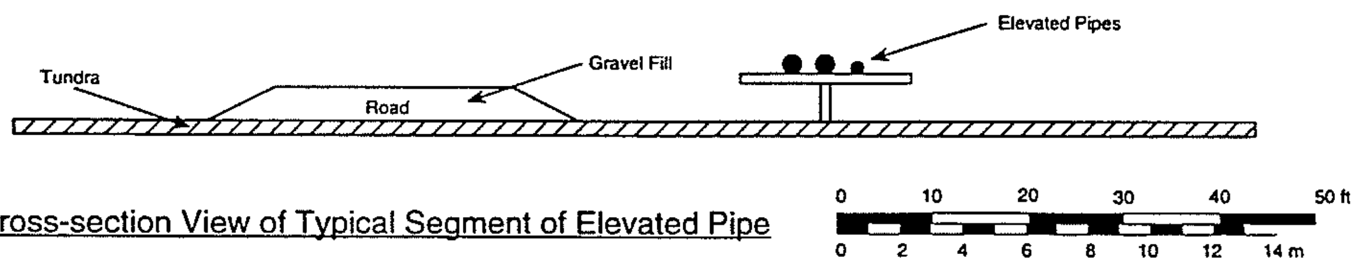


Fig. A–2. Overhead view of the buried-pipe section and a cross-section view of a typical segment of elevated pipes parallel to a road in the western portion of the Prudhoe Bay oil field. The diagrams depict part of a study site ("Pipe-road Site") of Curatolo and Murphy (1986). Site location is shown in Fig. A–5.



Overhead View of Buried-pipe Section



Cross-section View of Typical Segment of Elevated Pipe

Fig. A–3. Overhead view of the buried-pipe section and a cross-section view of a typical segment of elevated pipe parallel to a road in the western portion of the Prudhoe Bay oil field. The diagrams depict part of a study site ("Pipe Site") of Curatolo and Murphy (1986). Location of site is shown in Fig. A–5.

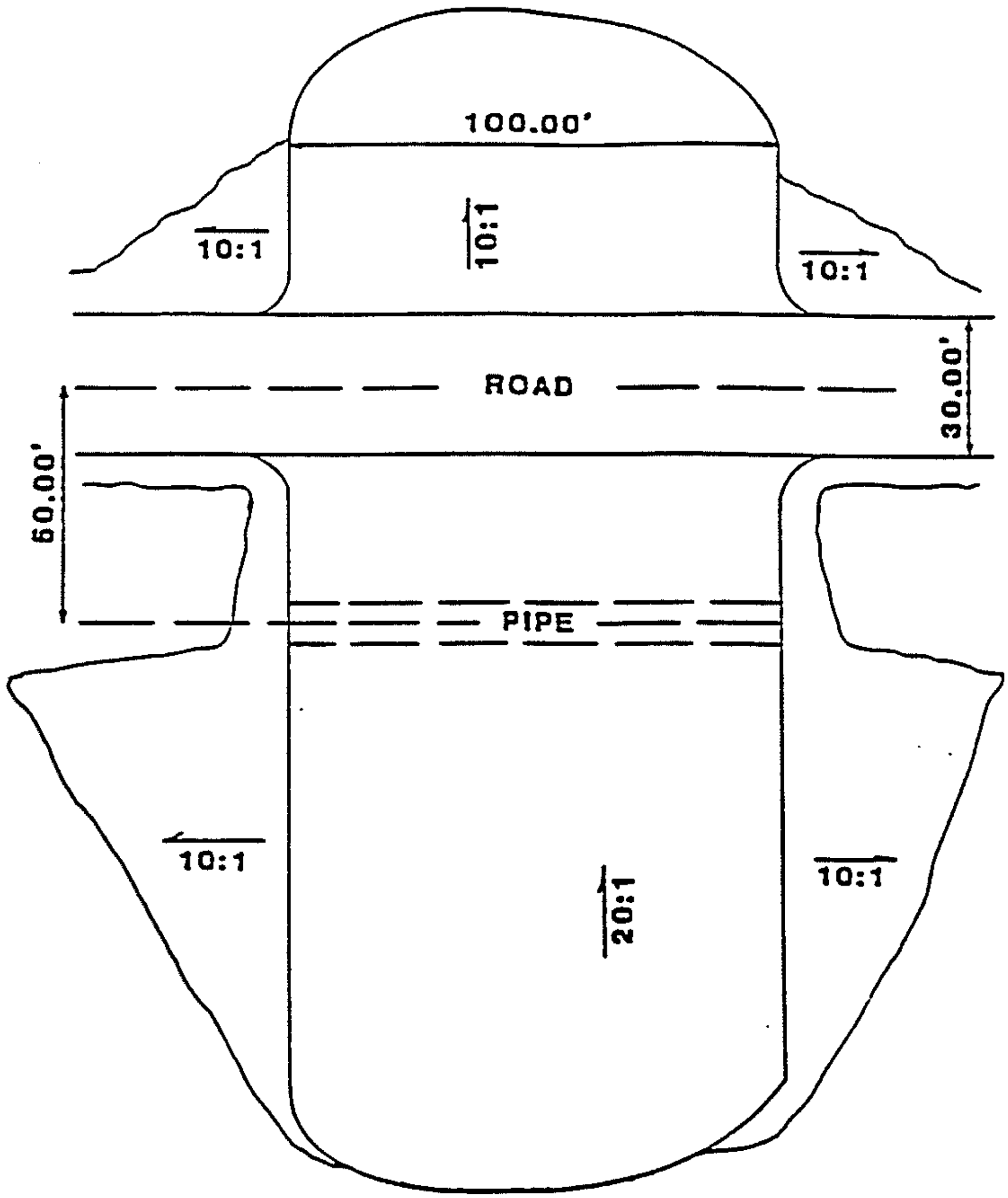


Fig. A–4. Approximate dimensions of ramp in the Kuparuk oil field. From Murphy (1984:Fig. 3). Location of ramp is shown in Fig. A–5.

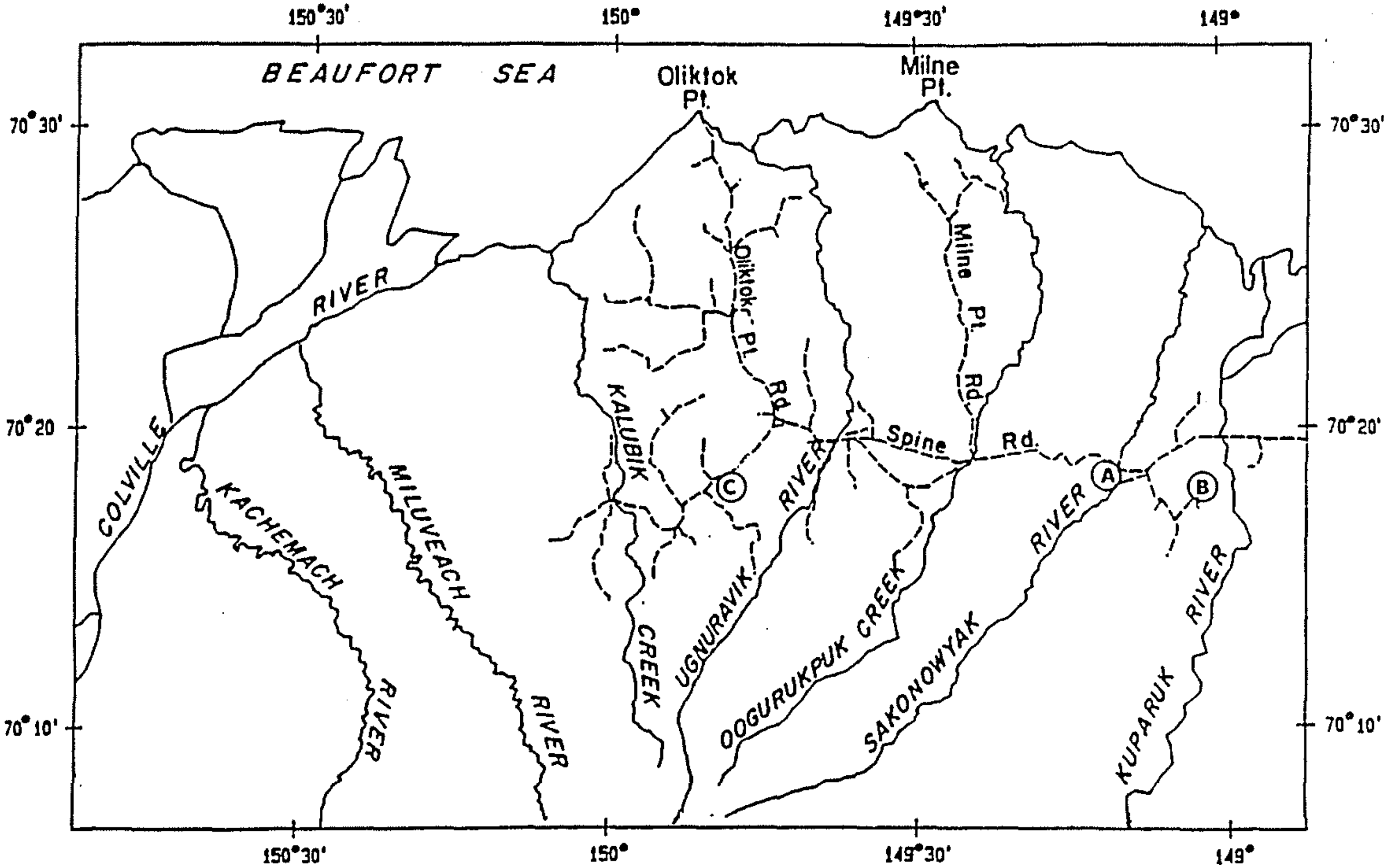


Fig. A-5. Area of Milne Point, Kuparuk, and western Prudhoe Bay oil fields. (A) Location of site depicted in Fig. A-2. (B) Location of site depicted in Fig. A-3. (C) Location of site depicted in Fig. A-4.

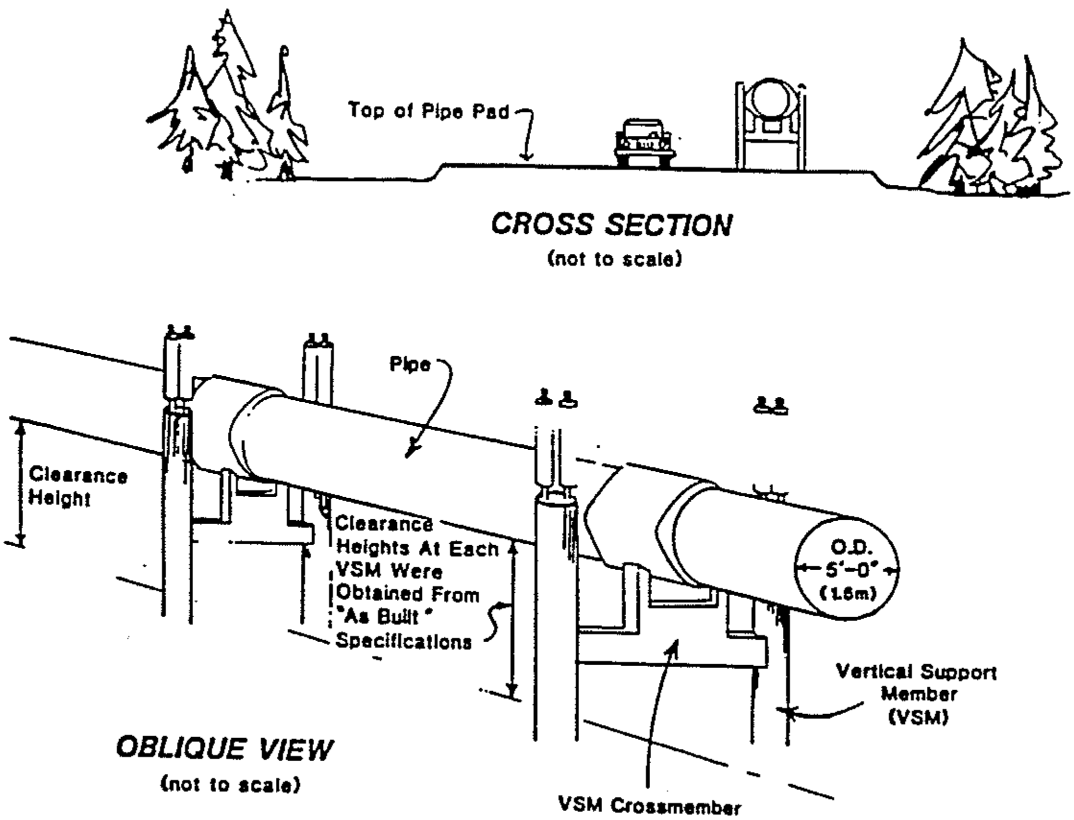


Fig. A–6. Configuration of Trans–Alaska Pipeline in area of Nelchina Caribou herd crossing studies. From Eide et al. (1986:Fig. 2).

Originally, it was thought that caribou would not pass under elevated pipe. Initial evaluations on simulated pipeline structures by Child (1973) were not encouraging. Only 5.4% of the caribou encountering his experimental structures went under the simulated pipe. All groups were > 50 individuals.

Reasons for low crossing success were presented by Smith and Cameron (1985a:43 et seq.) and Shideler (1986). Animals that successfully crossed used ramps, which comprised only 1.7% of the 2 mile (3.1 km) long structure. Because the structure was relatively short, many animals went around it. Another reason was that the test structures were new to the caribou and habituation and learning had not occurred. Also, burlap (used to simulate pipe by providing visual barriers) flapped in the wind and may have frightened animals away.

Curatolo and Murphy (1986:220) provided the best study design for evaluation of crossings by using control sites in conjunction with defined plot boundaries for identifying crossing attempts. Use of "controls" made this study close to ideal, although explicit *a priori* hypotheses were not given. Of 190 groups (2742 individuals) observed over three years, only 66% of the groups (61% of individuals) successfully crossed over imaginary lines at the northern boundary of their control plots.

Relationships among insect conditions, direction of movement of caribou, and characteristics of crossing sites were also examined (Curatolo and Murphy 1986:220). Five test sites and one "control site" (actually combined data from two control sites) were used. Forty-four comparisons between crossing success rates on control plots versus five test plots under a variety of insect conditions were compared by chi-square analyses. Fourteen of 44 comparisons were statistically significant ($P<0.05$). Where pipelines were not associated with roads having moderate or heavy levels of traffic, elevated pipelines with ≥5 ft (1.5 m) clearance did not significantly deflect caribou movements. A similar conclusion was reached for pipelines without roads.

We tested three hypotheses using the data provided by Curatolo and Murphy (1986):

Hypothesis 1: There were no differences in caribou crossing success rates during insect harassment between areas with pipelines only (Site 1-experimental), pipelines and roads with moderate to heavy levels of traffic (Site 2–experimental plot), and areas without pipelines and roads (control plot). The hypothesis was based on the expectation that the greatest motivation for caribou movement northward toward coastal insect relief habitat occurs under conditions of mosquito harassment. If the hypothesis was false, statistically significant differences would occur between crossing success rates on control plots versus those on experimental plots with pipelines and roads with moderate to heavy traffic levels (sites 1 and 2 of Curatolo and Murphy 1986).

Hypothesis 2: Caribou crossing success rates while moving southward following insect harassment were not different than crossing rates during movements northward during insect harassment on areas with pipelines only (Site 1–experimental), or pipelines and roads with moderate to heavy levels of traffic (Site 2–experimental), or no pipelines and roads (control plot). If the above hypothesis was false, movement rates across experimental plots would be lower than on control plots. This hypothesis reflected our understanding that caribou in such circumstances would show an intermediate level of motivation for movement. Movements to the south were presumably associated with searches for better forage lying farther inland (Smith 1991).

Hypothesis 3: There were no differences in caribou crossing success rates during northward movements under low insect harassment between areas without roads and pipelines (control) and areas with pipelines only (Site 1–experimental plot) and pipelines with roads with moderate to heavy levels of traffic (Site 2–experimental plot). Given a lack of strong motivation for northward movements, caribou were expected to frequently stop or change direction without completing crossings of control or experimental plots. Based on this, we predicted that differences between crossing success rates at control sites and those at experimental sites would not be significant.

To test Hypothesis No. 1, we pooled frequencies of elevated pipeline crossing successes reported by Curatolo and Murphy (1986:Table 1) to correspond with specific test conditions. Levels of crossing success on the control and pipeline only plots were high and not significantly different ($P>0.05$), while crossing success was significantly lower ($P<0.05$) on the pipeline–road plots versus the control plots (Fig. A–7). Therefore, we rejected Hypothesis No. 1. We concluded that pipelines with

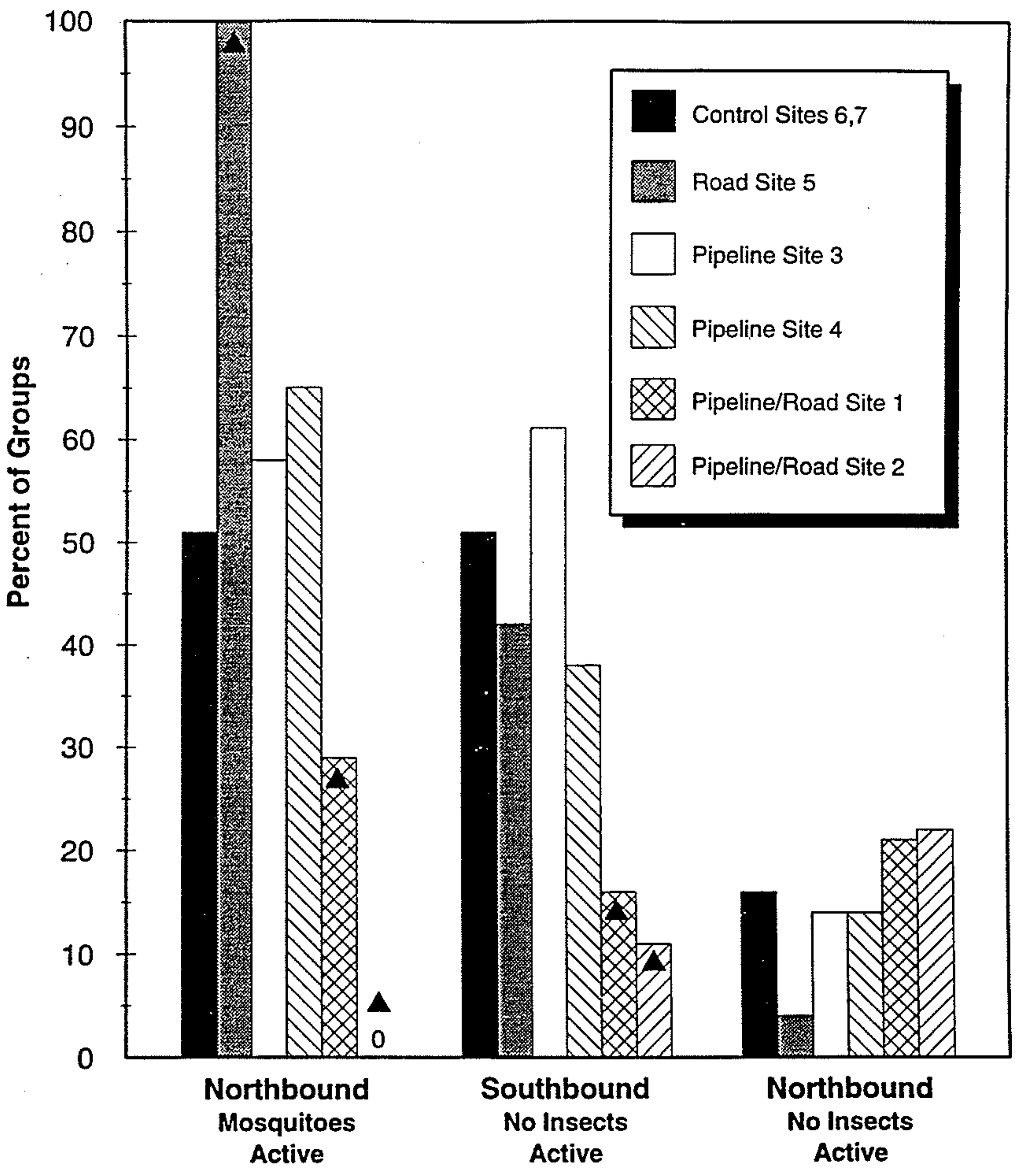


Fig. A-7. Crossing success of caribou groups at study sites in Kuparuk and Western Prudhoe Bay oil fields under three conditions. Adapted from Curatolo and Murphy (1986). ▲ Difference from control statistically significant ($P < 0.05$).

We concluded that neither elevated pipelines nor roads alone posed significant barriers to the movements of groups of caribou, but that pipelines with roads that have moderate to high levels of traffic did pose a barrier to caribou movements. Although ideal pipeline height in relation to caribou crossing success has not been systematically studied, pipelines elevated at least 5 ft (1.5 m) appeared to be effective mitigation measures, except that significant reductions in crossing success occurred when elevated pipelines were in proximity to roads with moderate to heavy levels of traffic (15 or more vehicles/hour). The above conclusions do not apply where multiple numbers (>10) of elevated pipelines occur in a corridor. Although caribou appear to prefer pipelines elevated >5 ft (1.5 m) above the terrain, pipelines elevated to 5 ft (1.5 m) appeared to allow relatively free passage of caribou.

The Height of Elevation of Pipeline above the Terrain as a Variable in Mitigation

Early studies of caribou crossing rates at pipelines did not consider pipe widths or pipes of varying heights. Heights evaluated by Child (1973) were 5 ft (1.5 m) and 8 ft (2.4 m). These included simulations of both the 48 in (122 cm)–diameter Trans–Alaska Pipeline and a 24 in (61 cm)–diameter culvert pipe used to simulate a feeder pipe system. Pipes <3.3 ft (1 m) in height were not evaluated except by anecdotal information (Shideler 1986:61).

Curatolo and Murphy (1986:221) investigated influence of pipe height on crossing success. They compared mean height of elevated pipeline under which caribou crossed with the mean height of sections available for crossing. Although a null hypothesis was not explicitly stated, it was as follows: $\mathbf{H_0}$: There was no difference in the frequency of caribou crossing under pipes 5 ft (1.5 m) and pipes >5 ft (1.5 m) above the terrain.

They examined three sites from one to three years for a total of five tests in the Kuparuk oil field (Fig. A–8). Only one test was significant ($P<0.05$). Thus, the null hypothesis was not rejected. However, topographic drops in landscape may have funnelled caribou to higher–clearance crossing sites. There were no crossings in sections with less than 5 ft (1.5 m) clearance at this site (Fig. A–8).

Lawhead and Murphy (1988), Lawhead and Smith (1990), Lawhead (1990), and B. Lawhead (pers. comm.) also studied effects of pipeline height along the Endicott Access Road. Their pooled data suggested a preference for crossing under pipelines

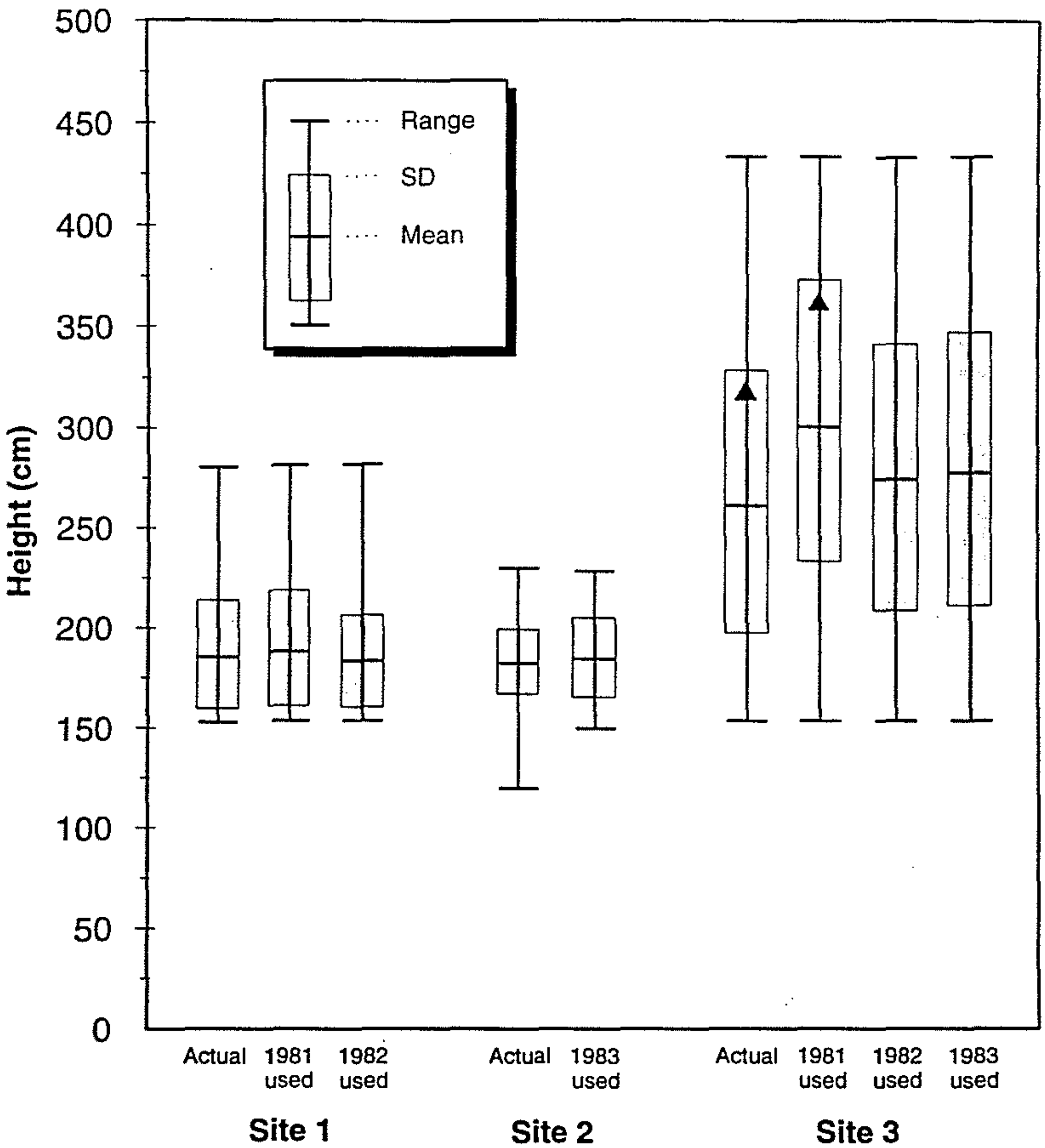


Fig. A-8. Mean heights of elevated pipeline available for crossing compared with mean heights of pipeline selected by caribou for crossing, as measured by crossing events. Based on Curatolo and Murphy 1986:222.
▲ Significant difference (P < .05) with Mann-Whitney test.

elevated 59.1–98.0 in (150–249 cm) and reduced use with pipes elevated <39.4 in (100 cm) (Fig. A–9).

We reanalyzed their data and tested the following hypothesis: $\mathbf{H_0}$: caribou crossing success between pipeline elevated >5 ft (1.5 m) versus those <5 ft (1.5 m) were similar. Significant differences occurred in relation to expected values if caribou groups crossed sections in proportion to the availability of each height class. Therefore, we rejected the null hypothesis that no selection occurred and that crossing location was not affected by pipeline elevation ($\chi^2 = 23.73$, df = 4, P<.001). Subdivision of the chi–square analysis (Zar 1984) suggested pipes <59 in (150 cm) in height were used less than expected by chance ($\chi^2 = 10.02$, df=1, P<.005). We also tested differences in pipeline elevation 59.1–78.3 in (150-199 cm) versus those >78.7 in (200 cm). There was significant selection for the higher pipelines ($\chi^2 = 4.25$, df=1, P<0.05) suggesting preference for the elevated pipelines.

Snow drifting can reduce the available clearance under pipes available for use by caribou in spring (Smith and Cameron 1985b:40, Eide et al. 1986:207). In one case, extreme snow drifting actually created a ramp that was used by reindeer for crossing a simulated pipeline on the Seward Peninsula (Child and Lent 1973).

Mitigation efforts to provide for passage of caribou without use of ramps have focused on elevating pipes sufficiently so that caribou will pass freely under them. A potential alternative for small diameter pipes would be to place them close to the ground so that caribou would pass freely over them. Reges and Curatolo (1985) studied simulated single pipelines of 8 in (20 cm) diameter and tested heights ranging from 14 in to 43 in (36 cm to 108 cm) from ground to top of pipe. Pipelines elevated 43 in (108 cm) formed a nearly total barrier. Thirty–three percent of caribou that attempted to cross pipes elevated <30 in (77 cm) actually crossed. The remainder subsequently moved parallel to the structures and passed around one end of the simulation. When confronted with a simulated pipeline having sections elevated to 30 in (77 cm) and other sections elevated to 14 in (36 cm), caribou showed strong preference for crossing at the lower height. Caribou were less likely to cross a study area with a simulated low elevation pipe than a control area without such a pipe, regardless of pipe height or insect conditions (Reges and Curatolo 1985:17).

Caribou that successfully crossed the low pipeline often moved parallel for varying distances and jumped over from a standing position. Reges and Curatolo

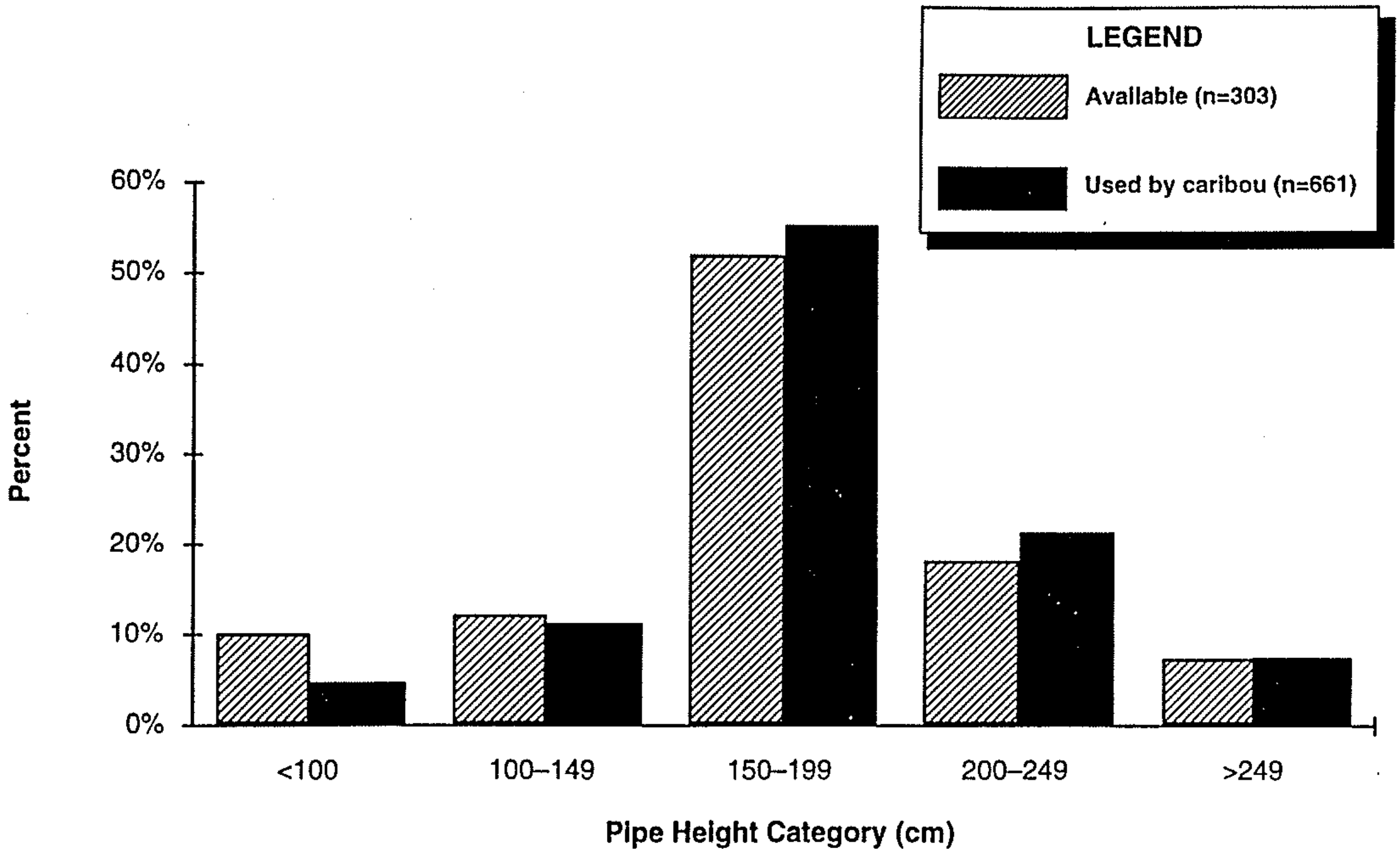


Fig. A–9. Pipeline height categories used for crossings by caribou in relation to availability. Data are combined for three study plots in Endicott development area over four years. Based on Lawhead and Murphy 1988, Lawhead and Smith 1990, and Lawhead 1990 and B. Lawhead (pers. comm.).

(1985:v) concluded, "Based on the caribou's behavioral response and infrequent displays of fear, we believe that caribou may learn, in time, to cross low elevation pipelines." Relative success of calves or cows was provided. They indicated that increases in pipe diameter or use of multiple pipes would probably decrease the proportion of successful crossings and necessitate the use of ramps.

Curatolo and Reges (1986:12) suggested that caribou which spent part of their annual cycle in forested areas would be more familiar with low elevation obstructions and, thus, more likely to cross such pipe simulations than were CAH caribou. Miller et al. (1972) reported that caribou on spring migration through Canadian boreal forest readily jumped over obstacles of 59.1 in (150 cm) height.

<u>Gravel Ramps—Buried Pipelines</u>

Child (1973, 1974) reported that caribou preferred ramps as crossing sites, in comparison to underpasses. Ramps composed 22% of the distance studied, but received 76% of the crossings. Curatolo and Murphy (1986:223) compared ramp crossings with elevated pipelines in the Kuparuk oil field. Ramps were preferred for crossing based upon a comparison of the observed versus expected number of crossing events by each mode (Table A–2). Murphy (1984) came to a similar conclusion. Similar preferences for ramps as crossing sites were demonstrated during the Endicott Access Road studies (Table A–3) (B. Lawhead, pers. comm.).

Results of these studies suggested a preference for ramps as crossing sites. However, their conclusion did not always apply. Murphy (1984) described an example based on work of Robus (1983) of a recommended site for a ramp that received little use. Lawhead and Murphy (1988), Lawhead (1990) and Lawhead and Smith (1990) evaluated ramps by determining amount of time caribou spent in study plots prior to a successful crossing. They assumed more time spent in plots indicated more reluctance to cross. The time spent by northbound caribou in plots containing ramps and not containing ramps were not different. Because these caribou were seeking insect relief habitat, they had strong motivation to cross all structures.

Murphy (1984) indicated that larger groups (presumably >50 individuals) had stronger preferences for use of ramps than small groups. Effective use of ramps by large groups in the Prudhoe Bay oil field was also documented by Pollard et al. (1992b). However, Lawhead (1990:80) concluded that ramps in Endicott study areas

Table A-2. A comparison between the number of ramp crossings and the number of elevated pipeline crossings by caribou groups observed in three different locations along the Kuparuk Pipeline. From Curatolo and Murphy (1986:223).

Site	Ramp Width	Year	Ramp Crossings[1]		Elevated pipeline crossings	
			Observed	Expected	Observed	Expected
Pipeline/Road Site 1	50 m	1981–1982	10 (6%)[2]	1.07	170	178.93
Pipeline/Road Site 2	30 m	1983	5 (12%)	0.85	36	40.15
Pipeline Site 3	20 m	1981–1983	65 (9%)	5.27	667	726.73

[1]A "crossing" consisted of one or more Caribou crossing under a pipeline between two adjacent vertical support members (VSM) or over a ramp in a more or less cohesive manner. Thus, one Caribou group can account for one or more crossings.

[2]Percent of total crossing events. In total, the 3 ramps comprised 2% of available pipeline length within study sites.

Table A–3. Tests of null hypothesis that caribou use ramps and elevated pipelines as crossing sites in proportion to their availability as measured by linear distance in study plots[1].

		Ramp Crossings (%)[2]	Elevated Pipeline Crossings (%)	Goodness of fit (G)	Significance[3]
1987	Groups	17 (21)	64 (79)	44.53	P<0.001
	Individuals	106 (18)	482 (82)	613.22	P<0.001
1988	Groups	17 (20)	66 (80)	49.25	P<0.001
	Individuals	168 (5)	3,459 (95)	80.11	P<0.001
1989	Groups	7 (11)	54 (89)	10.63	P<0.001
	Individuals	10 (8)	121 (92)	9.39	P<0.005

[1]Data and test statistics from Lawhead and Murphy (1988), Lawhead and Smith (1990) and Lawhead (1990), based on study plots on Endicott Access Rd.

[2]Proportion expected to cross on ramps was 2.15% of groups or individuals based on proportion occupied by ramps of linear distance of pipeline in plots.

[3]Reject H_O based on comparison of observed versus expected values.

were used only by groups ≤50 individuals. Large groups (>100 individuals) approached or crossed lips of ramps without using them. Movements of groups in this area were at acute angles to the road corridor. Insect–harassed groups did not need to cross the corridor to reach relief habitat.

Johnson and Lawhead (1989:44) provided a different perspective on ramp use by following the behavior of individual groups in the Kuparuk oil field. Their observations (Table A–4) supported the view that ramps were not particularly effective for large groups and that the behavior of groups was not necessarily cohesive. Larger groups tended to split, using both ramps and elevated pipe to cross. They observed overall ramps were used very little.

Overall, the effectiveness of ramps as crossing structures for large caribou groups appeared equivocal and worthy of further study. There are documented events of rapid crossings by large groups and also times when ramps were not used, though available.

Few data exist that relate ramp design to effectiveness. During the early stage of Trans–Alaska Pipeline studies, Cameron and Whitten (1978:22) reported that caribou selected ($P<0.05$) haul road crossing sites where the mean ramp height was 4.7 ft (1.43 m) ($N=33$) compared to available mean height of 5.6 ft (1.70 m) suggesting that lower height ramps with more gradual slopes receive more use than higher ones. Murphy (1984) and Lawhead (1990:80) reported that ramp effectiveness as caribou crossing sites was reduced in their areas because ramps were occupied by parked vehicles.

Our general conclusion with regard to ramps is that caribou may or may not show a preference for their use in relation to availability. Factors causing this preference cannot be identified. It has not been established that ramps facilitate crossings in comparison to elevated pipelines by reducing time required to cross or by reducing degree or frequency of deflections. Ramps in areas with unelevated pipelines, such as some of the first areas developed in the Prudhoe Bay oil field, are certainly useful as the only way over such pipelines. Their use in areas of known caribou movement is warranted when existing pipes are a barrier (Pollard and Ballard 1993).

Table A–4. Use of ramps during 10 successful group crossings in Kuparuk oil field. Based on Johnson and Lawhead (1989:44).

Insect conditions	Group size	Total % crossing	% crossing ramps
Insect free	2	100	100
Insect free	10	100	100
Insect free	12	75	8
Insect free	43	47	33
Insect free	3,384	69	2
Mosquito harassment	1,815	99	3
Fly harassment	2	100	100
Fly harassment	2	100	100
Fly + mosquito	89	100	44
Fly + mosquito	560	100	6

Crossings during the Pre–calving and Calving Periods

We noted earlier the scarcity of studies during the perinatal period. There were few observations and no adequate data sets that tested the effectiveness of mitigation structures in facilitating corridor crossings by caribou during the calving and immediate pre–calving periods.

However, movements of CAH caribou during the pre–calving and early calving periods must take place across corridors into the Kuparuk and Milne Point oil fields because caribou were observed there. During annual aerial surveys at peak of calving (Dau and Cameron 1986b), numbers of neonatal calves observed have varied from 85 in 1980 to 900 in 1984 (R. Cameron, pers. comm.). Further evidence of crossing was reported by Pollard et al. (1992b).

The Effect of Group Size on Crossing Success

Influence of group size on crossing success and the effectiveness of mitigation measures is complex. Caribou groups >100 in the Prudhoe Bay area often occur during mosquito harassment. Large groups are rare during other times of the year. Consequently, it is difficult to separate effects of insect harassment versus group size on crossing behavior. Child (1973) concluded that large groups were less successful in using crossing structures than were small groups. None of 15 groups >51 individuals crossed pipeline simulations, while 27 of 97 groups containing ≤50 crossed using either ramps or underpasses. He reported only events when 100% of a group crossed.

Curatolo and Murphy (1986:221) reported a tendency for groups ≥100 to be less successful than smaller groups in crossing road–pipeline corridors at two sites, but the difference was not statistically significant. They concluded that large groups spent more time adjacent to a pipeline prior to crossing it and that such delays increased the potential for encounters with and responses to traffic on adjacent roads. That is, they believed that the synergistic effect of road and pipeline acting together produced a barrier that was more pronounced for large groups than for small groups.

Smith and Cameron (1985a, 1985b:45), using the criterion that 50% of individuals crossed, reported that none of four groups >100 individuals observed at road/pipeline complexes in the Kuparuk oil field successfully crossed. They provided further detailed examples of the splitting of large groups and described the failure of one insect–harassed group of 636 individuals to cross the West Sak Road. Smith and Cameron (1985b:44) reported that three groups >100 individuals observed by Fancy (1983) detoured around his experimental area without crossing a road or pipe. In comparison, 70.7% of 99 groups <100 individuals crossed at least one such structure.

Johnson and Lawhead (1989:39) observed extremely high crossing success rates for large groups under mosquito harassment, but they also noted that such groups made frequent deflections. However, they only considered a crossing as successful when groups closely approached the pipeline. Lawhead (1990:88) was unable to observe consistent effects of group size on crossing success in the Endicott Development area. He concluded that, when caribou were harassed by both mosquitoes and oestrid flies, very large mixed–sex groups formed that experienced low crossing success and usually deflected or moved back from the corridor (Lawhead 1990:100). The behavior of these groups was very similar to that of the large groups described by Child (1973).

Interpretation of the above studies again rested in part on whether one uses groups or individuals as units for measuring crossing success. However, large groups occurred relatively infrequently. In general, studies indicated lower crossing success rates by groups ≥100 individuals. However, no single data set or statistical test provided a strong inference that groups of caribou were less successful in crossing elevated pipelines or road–pipeline corridors than small groups. We conclude that caribou groups containing >100 individuals may experience lower success in crossing than will smaller groups, especially with road–pipeline corridors with heavy traffic, but further studies are warranted.

Mitigation for Trans–Alaska Pipeline Crossings

Eide et al. (1986) and Carruthers and Jakimchuk (1987) investigated caribou crossings of the Trans–Alaska Pipeline by migrating Nelchina Herd Caribou during periods of snowcover, based on analysis of tracks. The Nelchina Herd historically had crossed the adjacent Richardson Highway for many years prior to pipeline construction. Portions of the pipeline lie immediately adjacent to the highway, while others are separated by a few kilometers. Highway crossings and interactions or cumulative effects of pipeline and highway were not mentioned.

Conclusions regarding elevation of the pipeline as a mitigation measure for facilitating crossings were similar to those derived from oil field studies. Caribou crossings were less than expected for pipes ≤ 6.9 ft (2.1 m) high. This differed from the 5 ft (1.5 m) high pipeline in CAH studies. The difference may have been due to larger pipe diameter in the Nelchina study (Fig. A–4) which presented a different visual stimulus. Also, relating deep snow in the Nelchina study would tend to make the visual gap between the bottom of the pipe and the top of the snow surface smaller than the "as built" specifications. Carruthers and Jakimchuk (1987) mentioned that snow depths averaged 20.5 in (52 cm) in one section of their study area. Eide et al. (1986) observed that the results of their studies might have been different if they had included a winter of very deep snowcover.

The mitigation feature of "sagbends", that is, short (<60 ft or 18.3 m) buried sections of pipe, is a measure comparable to the ramps of the arctic oil field. These were not used more than would be expected by chance. This finding could have been due to the relative scarcity of these structures and an abundance of other acceptable crossing sites. In addition, refrigerator units extending vertically from the buried pipe may have affected caribou behavior. Caribou did not move parallel to the pipe until encountering one of these features. There was no strong evidence to justify their further use for caribou mitigation.

Relatively long sections of buried pipe were heavily used in the Nelchina study. However, this was largely due to the location of these sections within the principal migration routes of the herd.

We conclude that, with long buried sections and extensive sections of elevated pipeline (>6.9 ft, 2.1 m), the Trans–Alaska Pipeline does not constitute a significant barrier to caribou migration.

<u>Vehicular Traffic</u>

Effectiveness of ramps and elevated pipelines as mitigation measures may be reduced where such structures occur in proximity to roads with heavy levels of traffic. Under some conditions, roads alone with heavy levels of traffic (~ 60 vehicles/hr) may act as partial barriers (Murphy 1988:200).

Vehicle traffic has two potential effects in addition to blocking caribou movements: (1) it may disturb animals and alter normal behavior patterns and energy intake or expenditure; and (2) caribou may avoid such roads and not have access to available habitat.

Roby (1978:134) suggested that a negative correlation between amount of traffic and the distance of caribou from the haul road (now Dalton Highway) was due to a partial barrier effect. Lawhead (1990:93) referred to this as the "fence effect". Roby (1978) observed that such caribou showed a high frequency of disturbance responses. However, he also suggested (Roby 1978:138) that habituation played a role in this phenomenon.

No study has specifically tested the effectiveness of traffic regulation as a mitigation measure. There has been no experimental work to simulate vehicular disturbance or levels of vehicular activity in the range of the CAH. Experiments such as those conducted with trucks on caribou (Horejsi 1981), snowmachines on reindeer (Tyler 1991) and aircraft on caribou and muskoxen (Miller and Gunn 1979, 1980; Gunn and Miller 1980) may be applicable.

Quantitative information on relative traffic rates is necessary to interpret behavioral studies and to extrapolate to potential future situations. Levels or rates of traffic have been examined in only a few studies (Table A–5). However, as Lawhead (1990:28) pointed out, the manner in which many of the traffic rates have been calculated may not be appropriate for comparison with caribou behavior. He calculated short term rates (over periods of 20 min) because these would best approximate the period a caribou was exposed to traffic after entering a study plot and before attempting a crossing. Most other investigators calculated average rates based on longer periods of sampling. Roby (1978) apparently calculated such traffic rates to test correlations between measures of caribou behavior and levels of traffic on the Dalton Highway (see below) but the actual values were not presented. Roby (1978:149) observed groups of bulls in winter feeding and ruminating as close as 230 ft (70 m) to the haul road "...while heavy construction vehicles were passing at a rate of 1/min".

Traffic rates of five vehicles/hr or less were considered insignificant to caribou, except that pregnant females near parturition appeared to respond to these traffic levels (Table A–5). Rates of 5 to 15 vehicles/hr were considered typical of trunk roads leading to several pads or to smaller camp facilities. In the Endicott

Table A–5. Data on traffic rates on roads in arctic oil fields.

Source	Rate (veh./hr)	Road	Remarks
Curatolo & Murphy (1986)	15.4	Spine Rd.	Trunk road (Site 1, Figs. A–4 and A–7)
($\overline{X}$ 3 years data)	31.5	W. Ext., Spine Rd.	Construction activity. Attribute low crossing success to high traffic level. (Site 2, Fig. A–7)
Curatolo and Reges (1986)			
1984 data	9.3 (2–17)*	W. ext. Spine Rd.	During construction
1985 data	20.5 (3–100)*	W. ext. Spine Rd.	Study Area #3. Strong traffic effect on crossing success.
1985	14	Oliktok Rd.	
Dau and Cameron (1986a)			
June 1983 & 84	<10/day	Milne Pt. Rd.	
June 1982	10–100/day		
June 1985	>200/day		
Lawhead (1988)			
1987 00:00–06:00	8.5	Endicott Rd.	Many gravel trucks.
1987 06:00–12:00	22	Endicott Rd.	Maximum per 10 min period=10 vehicles.
1987 12:00–18:00	21	Endicott Rd.	
1987 18:00–24:00	16	Endicott Rd.	
Lawhead (1990)			
1989	5.8 $\overline{X}$, (13 max.†)	Endicott Rd.	Maximum per 10 min period=9 vehicles
06:00–18:00	10.1 (4.4–26.9)*	Endicott Rd.	
00:00–06:00	0.9	Endicott Rd.	
Murphy (1984)			
1983	32	Spine Rd.	16 small & 16 large vehicles/hr
1984	55	Spine Rd.	37 small & 18 large vehicles/hr
1984	6	2D Rd.	Drill site service rd.
1984	5	2X Rd.	Drill site service rd.

*Range of mean values recorded.
†Mean hourly rate on days with construction activity.

Road studies, >30 vehicles/hr were considered a high level of traffic, occurring mostly during construction.

Lawhead and Murphy (1988) concluded that large caribou groups experienced reduced crossing success in response to traffic levels >15 vehicles/hr. Subsequent Endicott Road studies (Lawhead 1990, Lawhead and Smith 1990), however, did not confirm a clear relationship between crossing success and traffic rate. No study provided statistical tests of the relationships.

Murphy (1988:200) indicated when traffic exceeded 60 vehicles/hr, a road alone (without an adjacent pipeline) was probably sufficient to create a barrier effect, but no data were provided to support this contention.

Separation of Roads and Pipelines

Curatolo and Murphy (1986), concluded that crossing frequency of caribou under elevated pipelines was lowest where such pipelines were parallel to roads with moderate to heavy levels of traffic. They believed that this synergistic effect arose principally because of a delay or hesitation period of several minutes between the time when a typical group of caribou approached a pipeline and the time when that group crossed under it. If they were disturbed by traffic on the adjacent road during this time interval, the caribou frequently retreated before crossing under the pipeline. Hesitation periods were less evident with regard to caribou crossing only a road; and, for this reason, roads alone did not constitute significant barriers except possibly when traffic rates approached 60 vehicles/hr. Therefore, Curatolo and Murphy (1986) hypothesized that crossing success would be facilitated by separation of road and pipelines, providing opportunities for caribou to cross corridors in two stages. They noted that when road and pipeline were well separated caribou often fed between these two stages.

Curatolo and Reges (1986) tested the effectiveness of road–pipeline separations as potential mitigation measures by comparing frequency of successful crossings along sections of corridor where separations were less than 300 ft (91 m) with sections where separation distances were 300–600 ft (91–182 m) and >600 ft (182 m). These distance intervals were chosen because most disturbance occurred <300 ft (91 m) and very little disturbance occurred >600 ft (182 m). They assumed such separation distances would extend a minimum of 1/4 mile (0.4 km).

Three implicit hypotheses were tested by Curatolo and Reges (1986):

$H_o^{(1)}$=Number of caribou crossing corridors where pipeline/road was <300 ft (91 m) were the same as the number of expected crossings based on the proportion of the total corridor length.

$H_o^{(2)}$=Number of caribou crossings at pipeline/road separations >300 ft (91 m) but <600 ft (182 m) were equal to the expected numbers based on the proportion of the corridor length.

$H_o^{(3)}$=Number of caribou crossings at pipeline/road separations >600 ft (182 m) were equal to expected numbers based on proportion of the corridor.

Each null hypothesis was further categorized based on rates of road traffic (>5 but <15 vehicles/hr, >15 vehicles/hr) and insect conditions (no insects, flies, all insect conditions). Crossings by class of caribou could not be tested.

The null hypothesis for distances <300 ft (91 m) was rejected for all traffic levels and all insect conditions (Table A–6). Expected number of individuals that would have crossed with insect harassment was 2430, while the observed number was 1493 (Curatolo and Reges 1986:26). These results provided evidence of a synergistic barrier effect where roads and pipelines were separated by less than 100 m.

The null hypothesis was also rejected for 300 ft (91 m) to 600 ft (182 m) separation, except when oestrid flies were present (Table A–6).

The null hypothesis for separations >600 ft (182 m) was also rejected. Evidence presented earlier regarding responses to disturbing stimuli did not provide a basis for the hypothesis that separations >600 ft (182 m) would have a beneficial effect. Because disturbance events were rare at distances over 600 ft (182 m), any beneficial effect from this degree of separation would be extremely small and other environmental variables probably confounded the results.

In this analysis the tests stressed numbers of individuals. This approach was consistent with the general conclusion that measures of individual success were biologically meaningful. In this case, the number of individuals was particularly meaningful as a measure of the effect because the synergistic barrier effect of road

Table A–6. Summary of results of pipeline/road separation study by Curatolo & Reges (1986).

Crossing Success Measured by Number of Individuals

Distance of Separation	Vehicles 5–15/hr No insects	Flies	All conditions	Vehicles >15/hr No insects	Flies	All conditions
<300'	R(L)	R(L)	R(L)	R(L)	R[a]	R(L)
300–600'	R(M)	R(M)[a]	R(M)[a]	R(M)	R(L)[a]	R(M)[a]
>600'	R(L)[b]	A(M)	R(L)[b]	R(L)[a]	R(M)	R(L)[a]

A=Accept null hypothesis.
R=Reject null hypothesis (α<.05).
L=Observed less than expected.
M=Observed more than expected.

[a]But accepted by measure of number of crossing events.
[b]Reject, but **more than expected** for number of crossing events.

traffic and adjacent pipeline was expected to be most pronounced on large groups. Curatolo and Murphy (1986:221) also reached this conclusion: "Large groups take more time to cross a pipeline than small groups and this delay increases the potential for encounters with traffic. Thus, traffic along a pipeline may contribute to the lower crossing success we observed".

The results of Curatolo and Reges (1986) were tests of preference. They demonstrated only that caribou were less likely to cross corridors where the separation of road and elevated pipeline was <328 ft (100 m). Based on their results, Curatolo and Reges (1986:34) recommended that pipelines and roads should be separated by a distance of at least 400 ft (130 m) along roads with moderate to heavy levels of traffic.

We conclude that separation of the roads and pipelines by at least 500 ft (152.4 m) will substantially increase the effectiveness of elevated pipeline sections as crossing structures. This recommendation should take into consideration such factors as topography, soil structure and texture, and other physical factors which may require less or greater separation of pipelines and roads.

Disturbance Studies

Zones of Influence

Any effort to assess the effects of oil field activities on caribou should include estimates of the distances at which such activities may influence caribou behavior.

Roby (1978) was the first to delineate zones for his study of the Dalton Highway. He measured activity budget differences, inter–individual spacing, and rate and magnitude of alarm reactions (also referred to as avoidance reactions). He concluded (Roby 1978:140) that "An approximate 'critical distance' from the haul road, in terms of caribou activity budgets, was 984 ft (300 m) for groups with calves in summer and 656 ft (200 m) for bull groups in summer and all groups during winter". His conclusion with regard to groups with calves in summer was based on a significant (P=0.025) decrease in the amount of time spent lying down. Behavior of groups with calves was highly affected between 328–656 ft (100–200 m) as indicated by several measures of behavior in comparison to those beyond 1312 ft (400 m). Results <328 ft (100 m) zone were inconclusive because of small sample size of groups with calves observed in this zone.

Roby (1978:25) also estimated degree of disturbance to groups within each distance zone by use of a derived index called "mean level of alarm reaction" on a scale from 0 (no visible reaction) to 4 ("movement away from the stimulus at a run"). The results were consistent with results obtained from activity budget data. There was a marked difference in summer between levels of alarm reaction for groups with calves compared with all other groups. Mean alarm levels (high alarm) for groups with calves declined to 984 ft (300 m) and then declined at a lower rate to 2953 ft (900 m). However, Thomson (1973) found that the effect of alarm reactions on overall behavior patterns to be very short lived in most cases, while Skogland and Grøvan (1988) reported a difference in duration of disturbed behavior between groups of well fed and poorly nourished reindeer.

Roby (1978) also reported inter–individual distances because they have been shown to decrease under conditions of alarm or disturbance. He hypothesized that such distances would be less among individuals in groups near the road. Lowest mean inter–individual distances occurred within 984 ft (300 m) of the haul road for both age classes of caribou groups but no statistical tests were performed.

Johnson and Lawhead (1989:50) observed 291 "disturbance events" when insect levels were low along the road system in the Kuparuk oil field between 11 June and 10 August 1988. They measured distances between reacting caribou and presumed sources of disturbance, most of which were vehicles. Of the disturbing stimuli, 96% were within 984 ft (300 m) and 82% were within 328 ft (100 m) of the caribou showing the reaction. Lawhead (1990) and Lawhead and Smith (1990) presented similar results. When caribou were under conditions of insect harassment, overt reactions to disturbance generally occurred at much shorter distances.

Lawhead and Murphy (1988) and Lawhead (1990) reported similar results as Roby (1978) under all insect conditions on the Endicott Access Road. Under widely different traffic conditions, the proportion of disturbance events occurring within the 328 ft (100 m) zone was stable, i.e., 79%, 82% and 89%. Traffic levels altered the frequency of such responses more than the zone in which the disturbance occurred. All three of the studies indicated consistency in the proportion of disturbance events attributed to moving vehicles; 77% in the Kuparuk oil field, and 78% and 77% on the Endicott Road in 1987 and 1989, respectively.

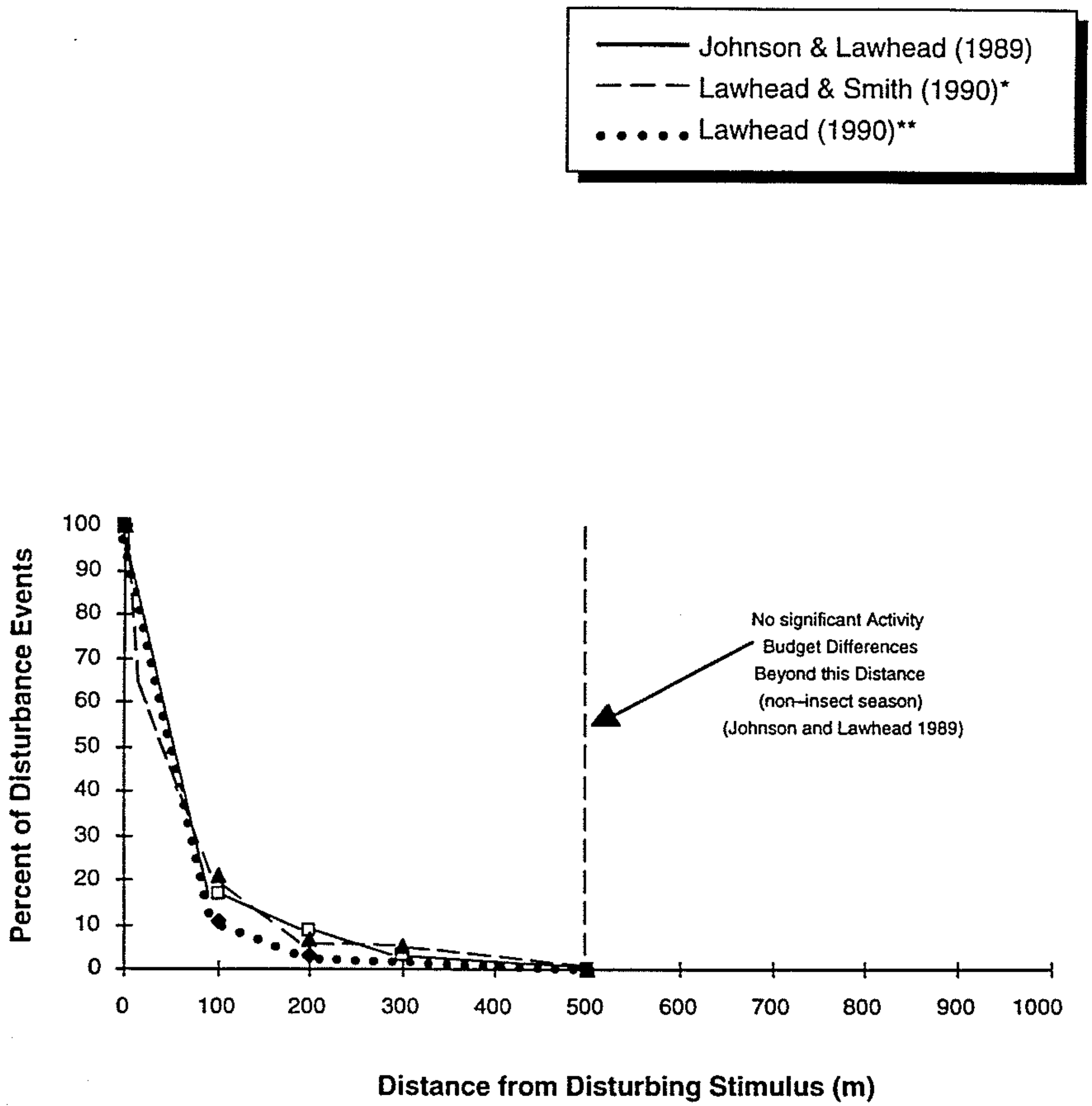
Johnson and Lawhead (1989:64) also compared activity budgets under various conditions and at various distance intervals from roads. During insect–free periods, the proportion of time spent lying was significantly greater for caribou beyond 1640 ft (500 m). However, no significant differences in activity budgets could be detected for caribou within 328 ft (100 m), an anomalous result remarkably similar to that of Roby (1978).

Murphy and Curatolo (1987) compared activity budgets and other behavioral attributes in experimental and control areas. Caribou harassed by mosquitoes moved greater distances and spent more time running (also confirmed in Johnson and Lawhead 1989:66). Thus, the effects of human disturbance were masked under these conditions.

During relatively insect–free periods, Murphy and Curatolo (1987) determined that for the pipe–road site (traffic level ~15 vehicles/hr) time spent lying was significantly less out to 1,969 ft (600 m) from the road (Fig. A–10). The slope of the observed threshold line is important, because both expected and observed distributions must start at the 0% intercept and end at the 100% point (Fig. A–11). Breaking points in the curves allow identification of threshold distances. A breaking point of 1969 ft (600 m) was evident with moderate levels of traffic. Breaking point on the pipe site was approximately at 984 ft (300 m). They concluded that caribou in the pipe–road site were reacting to traffic out to 1969 ft (600 m) from the road.

Murphy and Curatolo (1987) used 984 ft (300 m) at the pipe site and 1969 ft (600 m) at the pipe–road site to derive implicit hypotheses for further testing. They also compared rates of movement by caribou within and beyond these distances. Caribou in zones nearest to both corridors exhibited significantly ($P<0.05$) greater rates of movement, while rates in the more distant zones were not significantly ($P>0.05$) different from the control. Proportion of time spent lying was significantly different ($P<0.05$), while time spent feeding was not significantly affected.

Murphy and Curatolo (1987) concluded that caribou in the closest (0 to 984 ft [0 to 300 m]) zone of the pipe site with traffic <5/hr and those in the 1972–3281 ft (601–1000 m) zone of the pipe–road site with heavy traffic were subject to moderate but significantly greater levels of disturbance than those in the control areas.



*Traffic >15/hr during 18% of observation periods. N=115
** Traffic >15/hr during 61% of observation periods. N=229

Fig. A–10. "Zones of influence" as measured by percent of disturbance reactions that occurred beyond the designated distances from the disturbing stimulus.

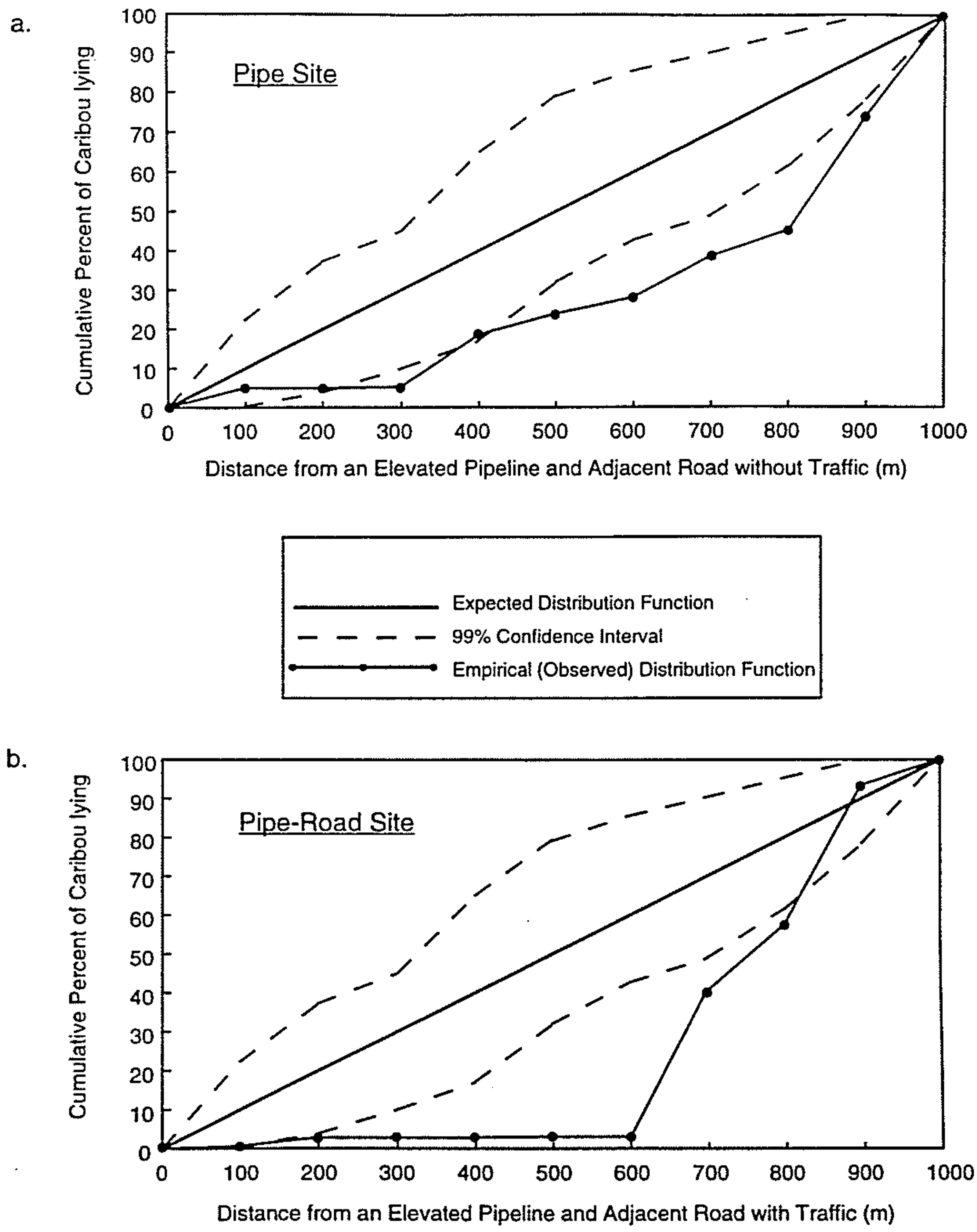


Fig. A-11. "Zones of influence" as measured by empirical (observed) distribution functions for caribou lying down in study sites with a pipeline and adjacent road without (a) and with (b) traffic (adapted from Murphy and Curatolo 1987). Data are for times when insects were absent in the study sites.

Under conditions of moderate to heavy traffic during relatively insect–free, post–calving, summer periods, 95%–99% of all responses to human disturbance occurred <984 ft (300 m) from the sources. Effects on activity budgets were detectable to 984 ft (300 m) with low levels of traffic and out to 1969 ft (600 m) with heavier traffic in summer. Effects on the rates of movement of groups were also evident under these traffic and distance conditions. The Dalton Highway, with undetermined levels of traffic, also affected summer activity budgets of groups with calves to 984 ft (300 m). Thus, several independent findings identified the 984 ft (300 m) distance as a general zone of influence. Murphy and Curatolo (1987) and Johnson and Lawhead (1989) strongly indicated that the zone of influence may have extended out to 1640–1969 ft (500–600 m) under heavier traffic conditions. Simpson (1987) similarly concluded that the avoidance distance shown by mountain caribou in response to snowmachines on their winter ranges was 1640 ft (500 m).

One data set indicated how traffic levels in oil field roads compared with those anticipated in environmental effect analyses. Lawhead (1990:89) reported that traffic rates on the Endicott Access Road declined in 1989 in comparison to the two previous years. In that year, there were only four days in July when traffic levels were at or below the operational rate of four vehicles per hour predicted in the EIS for the Endicott Development Project (USACE 1984). According to the conclusions cited above, such a low rate would result in traffic disturbance effects being generally restricted to the 984 ft (300 m) zone.

Murphy and Curatolo (1984:20) indicated the level of traffic reduction achieved through vehicle restrictions. During the period 30 June to 6 July 1983, 45 vehicles per hour traveled the Spine Road of the Kuparuk oil field. After initiation of vehicle restrictions, traffic flow was reduced to 25 vehicles per hour. Hours of observation, sample sizes or variances were not reported. Overall reduction was achieved by reduction in numbers of large vehicles (26/hr to 10/hr). Murphy and Curatolo (1984:21) implied that such reduction levels were insufficient to reduce effects of traffic on caribou crossing success.

<u>Avoidance of Roads and Corridors</u>

One possible effect of disturbance is avoidance. Caribou may avoid the disturbance directly, or by a learning process, they avoid areas with previously encountered stimuli.

Cameron and Whitten (1979), Cameron et al. (1979, 1992) and Cameron and Whitten (1980) concluded that caribou cows with calves avoided areas <0.9 mi (1.5 km) on either side of the arctic slope portion of the Trans–Alaska Pipeline haul road. This conclusion was based on a comparison of the proportion of calves observed from the road with those seen during aerial surveys over a broader study area that encompassed the road and pipeline. The area of aerial surveys served in essence as a huge "control area", providing a basis for comparisons with the observations made in the "experimental area" along the corridor.

One study reported on the distribution of caribou both before and after construction of an oil field road. Dau and Cameron (1986a) reported on the densities of caribou observed during annual aerial surveys conducted after the peak of the calving season within 3.7 mi (6 km) of either side of the present Milne Point Road. Surveys were conducted prior to and after construction of the road. They divided the Milne Point Road study area into 40 quadrants of 136 acres (1036 ha) each and calculated the number of caribou observed in each quadrant. They concluded that the median percent of caribou declined significantly in seven quadrants through which the road passed, from 8.5% (out of 2806 observed) in 1978–1981 to 2% (out of 5424 observed) in 1982–1985 (Mann Whitney, P=0.03). The seven quadrants, comprising 17.5% of the study area, contained 17% of calves in the pre-construction years but less than 1% (6 calves) in the later years.

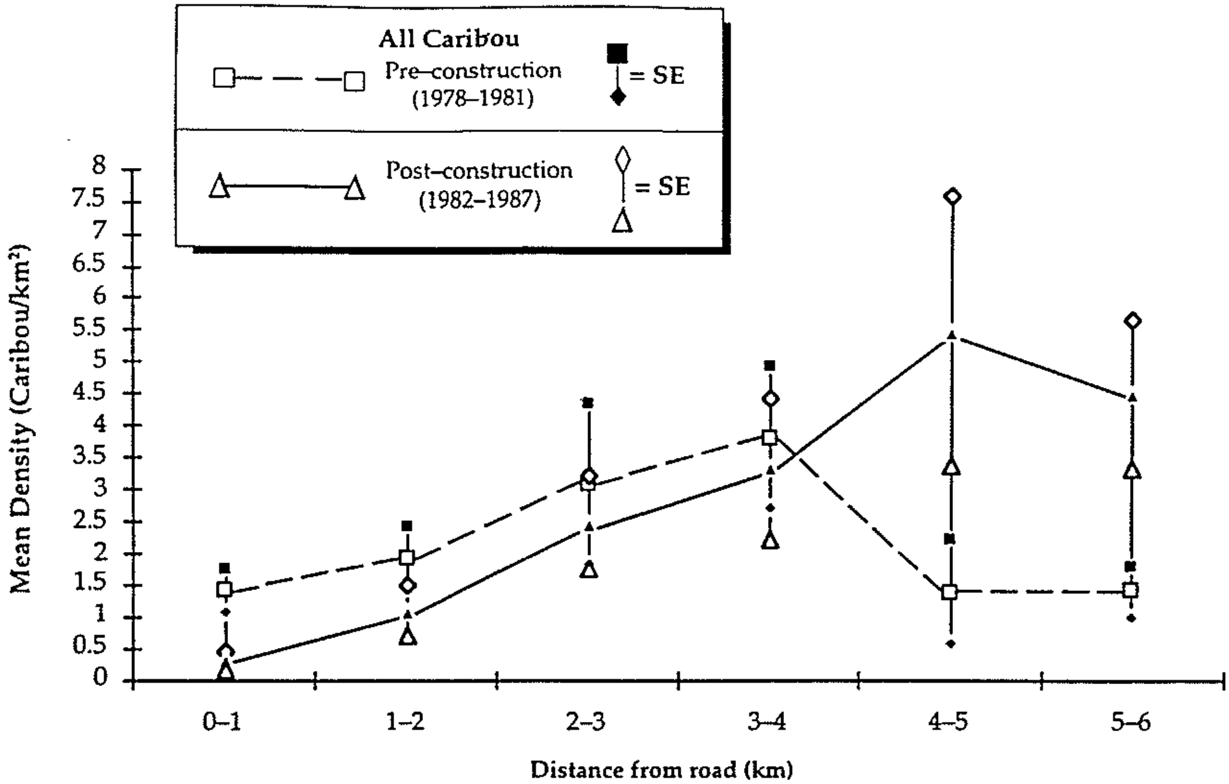
Densities of animals were calculated by 0.6 mi (1 km) intervals out to a 3.7 mi (6 km) distance from the road. They concluded that density of maternal caribou was positively correlated with distance from roads, whereas no such relationship existed with the road route prior to construction. That is, the null hypothesis of no change in the relationship between distance and density was rejected. Density of groups ≥25% calves exhibited a similar positive relationship with distance after construction but not before. Groups <25% calves exhibited no such significant relationship in either period. Surveys were conducted between 10-14 June. Thus, almost all calves in the population would have been born and the average age of calves would have been approximately one week. This was a period when rates of movement and degree of motivation to cross roads or structures were presumed to be relatively low.

Dau and Cameron (1986a:99) speculated that the effects they observed in the Milne Point road system could cause partial displacement of maternal caribou from calving grounds with extensive, dense networks of roads. They concluded that there was no evidence of habituation occurring among such maternal caribou. However, Lawhead (1988:9) noted that pregnant cows continued to use the "dust-effect" zone, feeding on vegetation that greened-up early adjacent to roads in the Kuparuk oil field, even during the calving period.

Densities of caribou and calves as reported by Dau and Cameron (1986b) are depicted in Fig. A-12. Cameron et al. (1992) presented additional data for years 1986 and 1987, as well as new statistical tests and interpretations of the above findings (Table A-7). The data in Table A-7 were provided by R. Cameron and D. Reed at our request and were summarized in Cameron et al. (1992). It was clear that the percentage of calves or all caribou within the 0-0.6 mi (0-1 km) interval was lower in the years after the road was built than before. Cameron et al. (1992) concluded there was a significant decline in mean density of both caribou calves (P=0.05) and total caribou (P=0.04) in the 0 to 0.6 mi (0 to 1 km) zone in the post-construction (1981-1987) period. They further stated that not only did the mean relative abundance of caribou decrease by two-thirds in the first 1.2 mi (2 km) away from the road, but it nearly tripled in the zones 2.5 to 3.7 mi (4 to 6 km) from the road. During the 10 year period encompassed by their surveys, the number of caribou in the CAH increased from approximately 5000 to 15000. A change of this magnitude could result in shifts in both absolute and relative patterns of habitat selection within areas generally used for calving. However, the marked decline in mean densities in the first 0.6 mi (1 km) zone was all the more striking in view of the fact that overall densities were increasing in the post-construction period.

In order to explore an alternate hypothesis, that a general shift in habitat selection may have caused the post-construction distribution, we examined densities of calves separately for each side of the Milne Point Road. Post-construction densities of calves was roughly symmetrical within the first 1.2 mi (2 km) on either side of the road (Fig. A-13). This pattern lends strength to the argument that the overall densities of calves within these distance intervals were the result of relative avoidance of the road and not artifacts of other environmental changes.

We concluded that a strong avoidance effect out to 0.6 mi (1 km) along the Milne Pt. Road during low to moderate traffic levels by maternal caribou was evident during a short period (probably two to three weeks) near the peak of the



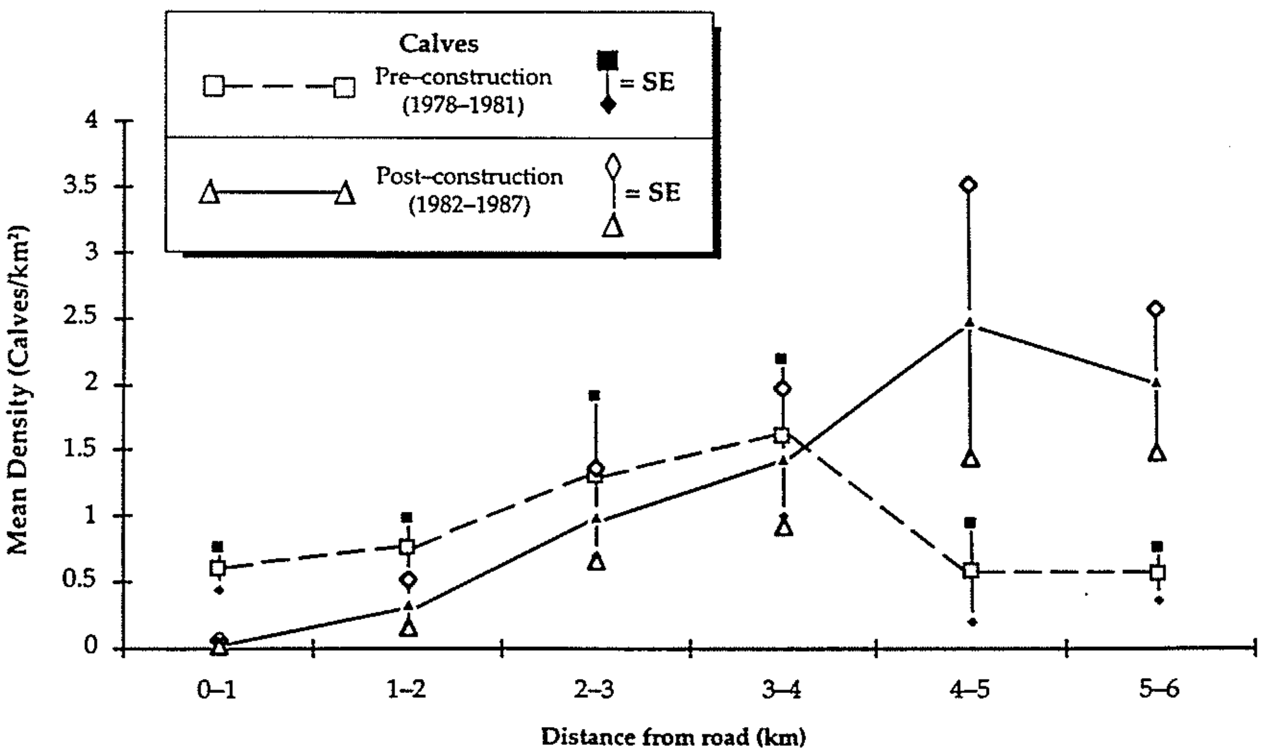


Fig. A–12. Density of all caribou and calves observed in mid–June within each of six distance intervals from the Milne Pt. Road system (from Cameron et al. 1992).

Table A-7. Number, density, and % of yearly total of caribou within each of six distance intervals from the Milne Point Road, 1978-87*. Values above dashed lines for both groups are pre-construction; values below dashed line are post-construction.

		DISTANCE INTERVAL (km) 0-1			1-2			2-3			3-4			4-5			5-6			
Sample Unit	Year	Density (no./km2)	No. of Caribou	% of Total	Density (no./km2)	No. of Caribou	% of Total	Density (no./km2)	No. of Caribou	% of Total	Density (no./km2)	No. of Caribou	% of Total	Density (no./km2)	No. of Caribou	% of Total	Density (no./km2)	No. of Caribou	% of Total	Total No. Caribou
All caribou	1978	1.94	113	23.3	3.37	163	33.6	0.67	27	5.6	3.11	111	22.9	1.80	58	12.0	0.45	13	2.7	484
	1979	0.81	47	7.3	1.70	82	12.7	4.26	172	26.6	4.96	177	27.3	3.53	114	17.6	1.94	56	8.6	648
	1980	0.79	46	19.8	1.16	56	24.1	1.34	54	23.4	1.06	38	16.3	0.22	7	3.1	1.08	31	13.4	232
	1981	2.08	121	16.8	1.49	72	10.0	6.04	244	33.9	6.16	220	30.5	0.00	0	0.0	2.19	63	8.8	719
	1982	0.24	14	4.6	0.37	18	5.9	1.46	59	19.4	2.30	82	26.9	1.24	40	13.2	3.19	92	30.1	305
	1983	0.34	20	2.6	3.04	147	19.1	2.55	103	13.4	4.17	149	19.3	5.57	180	23.4	5.97	172	22.3	770
	1984	0.91	53	4.2	0.60	29	2.3	2.90	117	9.3	8.18	292	23.2	15.54	502	39.9	9.24	266	21.1	1259
	1985	0.28	16	3.1	1.01	49	9.2	5.74	232	43.6	0.45	16	3.0	5.23	169	31.8	1.74	50	9.4	532
	1986	0.00	0	0.0	0.93	45	9.9	1.53	62	13.6	3.39	121	26.6	2.51	81	17.8	5.07	146	32.1	455
	1987	0.10	6	2.2	0.64	31	11.6	0.67	27	10.2	1.54	55	20.7	2.82	91	34.3	1.94	56	21.0	266
Calves	1978	0.84	49	26.1	1.41	68	36.5	0.10	4	2.2	1.20	43	22.9	0.62	20	10.7	0.10	3	1.5	187
	1979	0.38	22	7.9	0.66	32	11.3	1.83	74	26.3	2.16	77	27.4	1.64	53	18.9	0.80	23	8.2	281
	1980	0.26	15	21.1	0.37	18	24.9	0.54	22	30.5	0.14	5	7.0	0.03	1	1.4	0.38	11	15.2	72
	1981	0.91	53	16.3	0.58	28	8.6	2.77	112	34.5	2.91	104	32.0	0.00	0	0.0	0.97	28	8.6	324
	1982	0.07	4	3.6	0.04	2	1.7	0.47	19	16.9	1.01	36	32.1	0.50	16	14.4	1.22	35	31.3	112
	1983	0.00	0	0.0	1.20	58	17.7	1.04	42	12.8	1.88	67	20.4	2.48	80	24.4	2.81	81	24.6	328
	1984	0.14	8	1.5	0.17	8	1.5	1.14	46	8.2	3.81	136	24.3	7.46	241	43.1	4.17	120	21.4	559
	1985	0.03	2	0.8	0.31	15	6.7	2.60	105	47.0	0.14	5	2.2	2.29	74	33.1	0.80	23	10.3	224
	1986	0.00	0	0.0	0.06	3	1.8	0.57	23	14.4	1.12	40	25.0	0.90	29	18.2	2.26	65	40.6	160
	1987	0.00	0	0.0	0.25	12	10.5	0.22	9	7.7	0.73	26	22.7	1.30	42	36.6	0.90	26	22.5	115
Stratum area (km2)		58.05			48.26			40.44			35.65			32.31			28.76			

* R. Cameron, unpubl. data; from Cameron, R.D., D.J. Reed, J.R. Dau, and W.T. Smith. 1992. Resdistribution of calving caribou in response to oil field development on the Arctic Slope of Alaska. Arctic 45:In press.

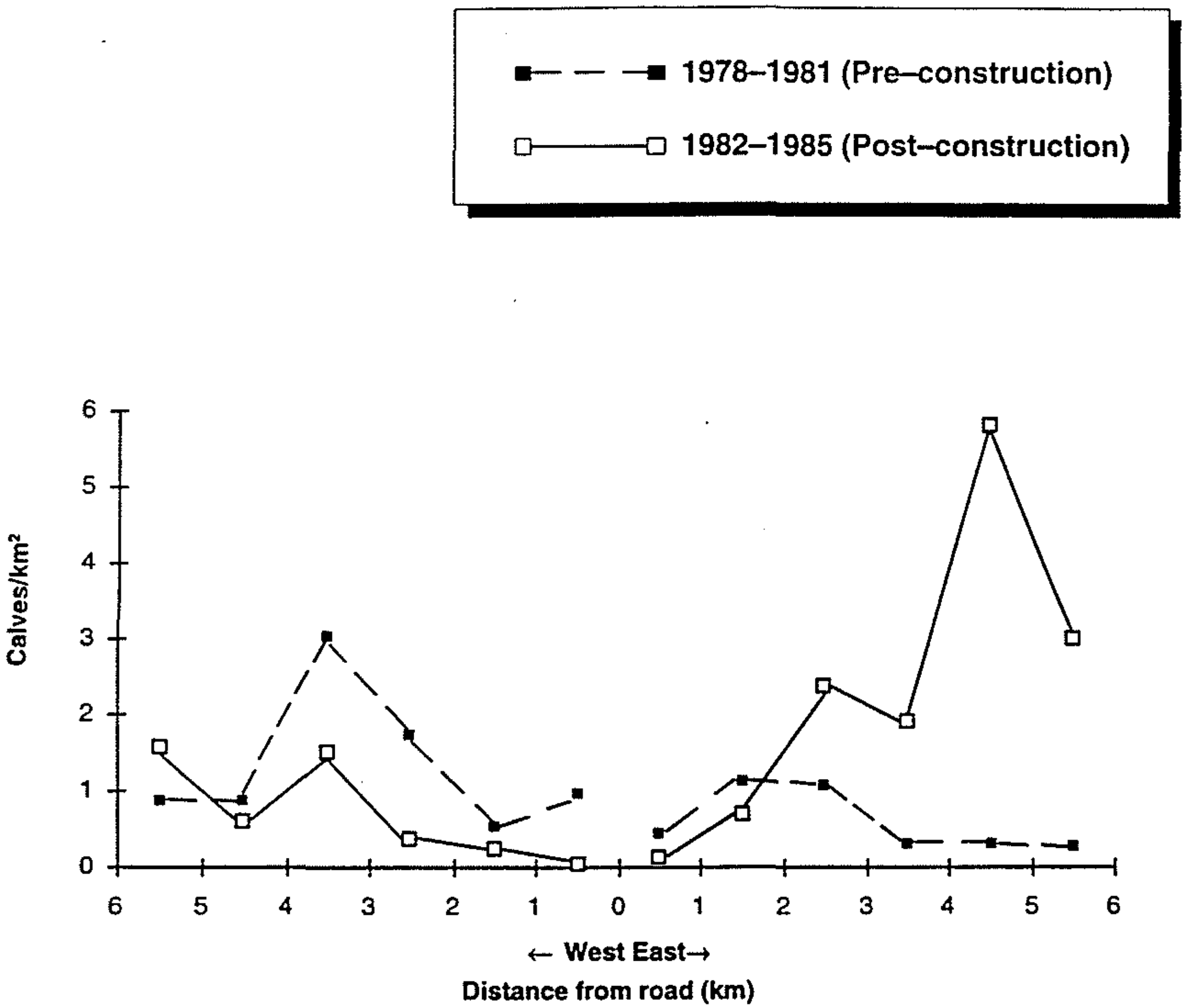


Fig. A–13. Mean density of calves observed in mid–June within six 1–km distance intervals east and west of Milne Pt. Road. Adapted from data reported in Dau and Cameron (1986b) as recalculated by D. Reed (pers. comm).

calving season (Dau and Cameron 1986a:95). Evidence for density effect between 0.6 to 1.2 mi (1 to 2 km) remained equivocal. Evidence that an increase in density occurred during the post–construction period within the 3.1–3.7 mi (5–6 km) range was statistically significant.

Cameron et al. (1985:6) concluded that cows were avoiding the haul road March through April as parturition was approached. However, the results of Dau and Cameron (1986b) during May and June did not confirm such an avoidance response. De Vos (1960), Lent (1964, 1966) and Bergerud (1974) all described the acute sensitivity of cows with neonatal calves to anthropogenic stimuli. None of these authors reported any special sensitivity of pregnant females or females unaccompanied by calves. In summary, evidence to date does not suggest heightened sensitivity or avoidance response by pregnant females, except possibly as they commence parturition.

We performed a spatial analysis of the developed area of the Kuparuk River and Milne Point oil field units using the 0.6 mi (1 km) zone of Cameron et al. (1992). The study area extended from near Kalubik Creek on the west to approximately 0.6 mi (1 km) east of the Milne Point Road System. Using map files within our ARC/INFO Geographic Information System (Pollard et al. 1992a, b) we calculated the proportions of the above area that fall within hypothesized zones of influence around roads and other infrastructure features. We estimated that 50% of the described area fell within such a zone of influence extending outward from the primary road system (roads in active use). Obviously, many primary roads received less use than the Milne Point Road but others received substantially more. The estimate of 50% represented a worst case scenario.

To develop a comparative scenario, we calculated the extent of potential zone of influence extending outward from the primary road system to a distance of 984 ft (300 m). The 984 ft (300 m) distance was chosen because during the post–calving and summer periods the great majority of observed disturbance events fall within this zone. The total proportion of the study area falling within this zone amounted to approximately 16%, leaving approximately 84% in the undisturbed zone. This represented an approximation of the area within which caribou would be exposed to disturbance and not an area in which habitat use, *per se*, would be altered.

Summary and Conclusions: Crossing and Disturbance Studies

Mitigation measures which have been used to allow caribou passage through oil fields and transportation corridors have included ramps, sagbends, relatively long sections of buried pipeline, and elevated pipelines. Success of these measures have been evaluated in a number of studies by measuring crossing success of individuals and groups. No assessments have been made for effects on the CAH in general.

Studies of individual and groups of caribou suggested that single pipelines elevated >5 ft (1.5 meters) adjacent to roads with low levels of traffic did not pose barriers to caribou movements. Ramps were not necessary when pipelines were elevated, but may be preferred over elevated pipelines in some cases. Relatively long sections of buried pipe also allowed free passage of caribou. Sagbends were not selected and appeared unnecessary as a mitigation measure. Elevated pipelines adjacent to roads with moderate to heavy levels of traffic resulted in many unsuccessful crossing attempts by caribou. Caribou groups >100 individuals may have had lower crossing success than smaller groups (i.e., <100). Crossing success of perinatal and cow–calf groups during calving have not been evaluated. Effects of multiple elevated pipelines have also not been satisfactorily evaluated.

The potential effects of vehicle traffic include blocking caribou movements and disturbance to animals with possible effects on energy balance. Several studies suggest that there is a general zone of influence which exists out to 984 ft (300 m) from roads and road–pipe complexes. Within this zone, disturbance reactions by caribou are most pronounced. Where heavy traffic levels occur, the zone may extend out to 1969 ft (600 m). Cows with calves appear to be more sensitive to disturbance than other segments of the herd, especially during calving. Cows with calves avoid roads with moderate levels of traffic out to 0.6 mi (1 km) for about 2–3 weeks.

Roads and road–pipeline combinations may significantly affect caribou crossing success rates and cause delays in movements. The relationships between survival value and delays in crossing and lower crossing rates have not been established. Roads without pipelines experiencing heavy vehicle traffic up to 60/hr may pose barriers to caribou movements, but further study is needed. Pipeline–road combinations appear to have a synergistic effect on impeding caribou movements. Separation of pipelines from roads by at least 500 ft (152.4 m) significantly minimizes disturbance to caribou and appears to be an effective mitigation measure for improvement of crossing success. Caribou calf densities were lower within 0.6 to 1.2 mi (1 to 2 km) of the Milne Point Road for about a 3–week period.

The Influence of Habituation and Learning

We discuss how learning and habituation may alter responses of caribou to stimuli associated with oil fields. Caribou can learn over time to accommodate to some of man's activities and structures (Miller et al. 1972, Villmo 1975:8, Roby 1978:134, Davis et al. 1985, Valkenburg and Davis 1985). The purpose of this section is to describe the extent to which caribou can adjust to man's activities, the conditions promoting ready adjustment, and the implications for design and operation of arctic oil fields in caribou habitat.

Several terms require definition. A stimulus is any environmental variable that provokes response from an animal. Habituation is the waning of an animal's response with repeated exposure to a stimulus (Shalter 1984:351). Sensitization is the opposite of habituation, that is, the increasing of response level with repeated exposure. Flight distance is the closest an animal can be approached before fleeing (Altmann 1958). An alarm reaction is any observable response indicating aversion or fear. Alarm or alerting distance is the distance to which a stimulus elicits an alarm reaction.

Animals that have evolved as prey of other animals develop behaviors to avoid being killed (Shalter 1984:350). Large prey mammals generally respond to man with generalized predator–avoidance behaviors, and most human–caused disturbances to large animals come about because people or their machines or structures are viewed as potential predators (Geist 1971a:416, Bergerud 1974:579, Hirth and McCullough 1977:32) or as circumstances signaling predation risk (Miller et al. 1972:199, Singer 1978:595).

Prey animals have limited innate ability to discriminate among harmful and harmless stimuli. Some birds seem able to recognize shapes or flight patterns of raptorial predators without having had prior experience. Some mammals seem to respond instinctively to odors of some potential predators (Muller–Schwarze 1972, Geist 1978:290). The cues in these cases seem to be a few basic characteristics of classes of predators (Shalter 1984:352).

In general, young prey animals discriminate poorly between harmful and harmless situations, but possess an innate disposition to respond to a wide variety of aversive stimuli. Because there are so many stimuli impinging daily on an organism, life would be impossible unless prey animals rapidly stopped responding to harmless ones. Through learning and habituation, they narrow the array to which they respond (Shalter 1984:353–356).

Cues for Learning

Animals use several types of sensory cues to identify potential predators. The main cues are visual (moving or stationary objects that contrast with backgrounds), auditory (distinctive sounds), and olfactory (strong or pungent odors). Prey individuals learn to interpret these cues to identify danger and to habituate to harmless situations.

Large mammals, and indeed most animals with vision, respond strongly to motion. Ungulates, such as caribou, that evolved in relatively open country with cursorial predators interpret moving objects as potentially dangerous (Altmann 1958:208, Bergerud 1974:579). Motion (along with scent) appears to be a major flight releaser in caribou (Bergerud 1974:579, Roby 1978:153).

One would expect a direct approach by a moving object to be perceived as a greater threat than a tangential or right–angle movement, and this has been documented for chamois (Cederna and Lovari 1985:219) and caribou (Horejsi 1981:180–185, Tyler 1991:189). Pruitt (1960) described how caribou will often ignore a wolf moving nearby, but will respond with alarm when one stalks directly toward them with lowered head. He believed a man with a fur parka hood ruff could resemble this visual pattern. Because large approaching objects present such a basic threat (Geist 1978:290), approaches by humans or vehicles are often the most difficult of circumstances to which animals can habituate (Geist 1971a:416, Bergerud 1974:580, Hutchins and Geist 1987:140). Rate of movement also affects prey response; adverse responses to the sudden increase in apparent size of an object (denoting a rapid approach) (i.e., "looming") are probably innate to some extent (Geist 1978:290).

Caribou and other mammals have difficulty detecting motionless predators (and other objects) that do not contrast sharply with background (Bergerud 1974:579, Curio 1976:136). But caribou in open landscapes often detect and visibly respond to elevated anomalies, possibly because of the potential for such structures to conceal predators (Curatolo and Murphy 1986:223). The perceptible discrepancy between the feature and the surrounding landscape seems to be the cause for response (Geist 1978:291). Northern natives have for centuries used columns of rock or sod placed in rows to deflect migrating caribou (Kelsall 1968:213) and reindeer (Skogland and Molmen 1980) toward corrals or hunters. Nevertheless, these fixed stimuli are usually reinforced by interspersing people (motion and auditory stimuli) among them (Stefansson 1921, Ingstad 1954). Caribou encountering elevated linear structures such as pipelines and roads tend to alter their course of travel such that they parallel the structure for some distance before crossing (Curatolo and Murphy 1986:223). However, the disruptive effect of these kinds of objects appears small in comparison with that of moving objects (Murphy and Curatolo 1987:2489), and caribou routinely pass close beside, under, or over such objects as pipes, elevated roadways, and poles, even when passage is physically difficult (Miller et al. 1972, Curatolo and Murphy 1986:223).

Unless they were accompanied by other stimuli, noises of unusual type or amplitude often elicit only low–level or short–term responses from animals (Busnel 1978). A short–lived startle response to sudden noises was common, following the "discrepancy principle" discussed above. Sonic booms caused only moderate responses in penned reindeer (Espmark 1972). Likewise, mink and several other species of penned animals such as wild ravens did not respond or responded only briefly to sonic booms (Cottereau 1978:68, 69). Simulated compressor–station noise caused PCH caribou to avoid the area within about 328 ft (0.1 km) of the simulator (McCourt et al. 1974).

Among wild ungulates, responses to unusual noises are typically short–lived unless the animal associates the noise with some other stimulus (Geist 1978:291). Mountain sheep and mountain goats tended to respond to sudden very loud noises by fleeing to the sanctuary of cliffs, presumably an innate response to avoid avalanches and rock falls (Geist 1978:291). Motor noises, common in populated or industrialized areas, may cause variable responses depending on an animals' previous experiences with similar sounds. If the sound of a chain saw has been associated with food brought to ground, animals will search out the source (Geist 1978:291, Bergerud et al. 1984b:19). Sensitization may occur if the stimulus is threatening (Hill 1985); for example, if ungulates learn to associate the sound of a snowmobile with pursuit, the animals subsequently will respond with excitation and flight (Geist 1978:291, Simpson 1987). In contrast, habituation generally occurs to harmless sounds. Geist (1978:291) reported that moose in a hunted population completely ignore the power saw and axe noises of men cutting a trail as close as 164 ft (50 m) away. White–tailed deer quickly learn to ignore sounds such as automobiles, tractors, and whistles that are not accompanied by unpleasant experiences (Halls 1978:53).

Similarly to most animals, caribou and reindeer appear to soon ignore noises unless the noises are associated with other stimuli. For example, Bergerud (1974:579) studied caribou that wintered near a major highway and railway in Newfoundland, observing that the sounds of trains, cars, chain saws, and dynamite produced no visible reaction. Reindeer encountering a newly–constructed power line that generated considerable noise seemed at first reluctant to pass under the line, but later exhibited less response (Villmo 1975:8). Caribou are known to be attracted by chain saw noises associated with the felling of trees that makes arboreal lichens available (Klein 1971, Geist 1978:292, Bergerud et al. 1984b:19). On the other hand, Simpson (1987:7) observed large flight distances of woodland caribou in response to snowmobile noise; apparently the caribou associated the noise with other stimuli such as motion. Rigorous studies of caribou responses to noise are non–existent; most studies are anecdotal and do not adequately consider the potential effects of other stimuli (Jakimchuk 1980:20).

The sense of smell is keen in most ungulates, and olfaction plays a prominent role in their interactions with their environment (Leuthold 1977:94). North American ungulates use odor detection of conspecifics to enhance intraspecific communication, as exemplified in white–tailed deer (Halls 1978:52, 53), mule deer (Geist 1981:176), and elk (Geist 1982:262). Many ungulates (Eisenberg and Kleiman 1972:1–32, Leuthold 1977:95), including caribou (Lent 1966:728), probably interpret odor signals of conspecifics to alert them of danger; and most, including such distantly–related species as black–tailed deer (Muller–Schwarze 1972), bighorn sheep

(Hansen 1980:115), and collared peccary (Day undated:28), respond strongly to odors of potential predators including humans. Despite the well-known importance of olfaction in detecting and avoiding danger, its function to these ends has been poorly researched, perhaps because of the relative inaccessibility of olfactory signals to human observers (Leuthold 1977:94).

The extent to which caribou use olfaction to detect and avoid potential danger is poorly understood. Bergerud (1974:579) and Calef (1981:154) believed caribou use scent more than sight or sound to confirm danger and to trigger appropriate responses. Roby (1978:98) reported caribou to move downwind of pursuing wolves to "eliminate the chance of another undetected approach" and Lent (1964) described how caribou frequently circle downwind of a human before fleeing. Simpson (1987) concluded that the scent of humans snowmobiling nearby was a major alarm stimulus to mountain caribou in British Columbia. Scent appears to be one of two main flight releasers in female caribou with young (the other is movement) (Roby 1978:153, Klein 1980:524). Disadvantages of using scent alone for predator avoidance are that scent may offer relatively few clues to the proximity of danger (Bergerud 1974:579) and upwind approaches of predators cannot be detected.

Thus, despite the potential importance of olfaction in signaling danger from human activities, virtually no quantitative data exist describing responses to olfactory stimuli and habituation thereto. There seems to be an implicit assumption among many researchers that visual or auditory stimuli are the primary mechanisms triggering alarm in such cases. Because this assumption may be invalid, the effects of odor must be kept in mind as a potential tempering mechanism for habituation.

Influences of Heredity and Experience

The main factors that influence habituation are: (1) the genetic makeup of the individual; and (2) the previous experience of the individual and its social group. Assessing how each of these has affected the ability of caribou and related species to accommodate to harmless situations can provide insight for making an oil field a more benign environment for caribou.

The genetic "program" of an animal is responsible for so-called instinctive or innate responses. As suggested earlier, caribou and other ungulate species instinctively respond in alarm to large, rapidly approaching (looming) objects and to some stationary landscape anomalies, and some may respond to odor types or to specific sounds (Muller–Schwarze 1972, Bergerud 1974:579, Geist 1978:290, 291). Thus, young animals exhibit innate alarm reactions at some unfamiliar objects, odors, or noises (Geist 1971a:417, Muller–Schwarze 1972), especially when the level of stimulus or stimulus contrast is great (Lent 1964:175). On the other hand, neonates may show inappropriate responses to moderate levels of stimulation as when newborn fawns or caribou calves follow humans or dogs.

Females appear to have innate differences from males in their sensitivity to stimuli. Adult females of caribou (Bergerud 1974:559; Roby 1978:101, 153) and reindeer (Geist 1971a:418, citing Zigunov 1961), and other ungulates (Altmann 1958:207, Leuthold 1977:80, Cederna and Lovari 1985:221) appear more predisposed to flight and other alarm reactions than do males. This difference begins very early in life, but appears most pronounced during and after parturition. The increased sensitivity of parturient females during the perinatal period and early life of the young seems common among ungulates (Leuthold 1977:80) and is well–known in caribou (Lent 1966:728, Kelsall 1968:185, Bergerud 1974:579, Klein 1980:524, Gunn and Miller 1980:507).

Some mammal species and populations are genetically predisposed to habituate less readily than others to human activities (Hutchins and Geist 1987:140). The fact that some species have been domesticated and others have not suggests this is the case, although Geist (1971a:414) and Parker and Graham (1971:399) suggest that many more species are genetically susceptible to domestication. Populations of *Rangifer tarandus* have lived for centuries as man's domesticate (Luick 1980:686) and presumably have a predisposition for habituation, although Klein (1980:524) and Thomson (1980) speculated that innate behavioral tendencies might vary among *Rangifer* populations, suggesting that reindeer could be more susceptible to domestication than caribou.

Experience, not heredity, is the most important factor molding the details of an individual's repertoire of responses. For example, many newborn ungulates will tend to follow any large, moving animal, even a human, and must learn to fear predators (Lent 1966:751, Schaller 1972:19). There is a period of accelerated learning in the early life of mammals during which the individual explores its environment and develops aversions to sights, sounds, and odors associated with unpleasantness. Important to our interests, the animal also habituates during this period to common but neutral stimuli (Geist 1971a:417). Response patterns developed at this early stage can be changed later in life, only with greater difficulty.

The learning of response patterns in social animals such as caribou is facilitated or conditioned by group behavior. Young animals condition many of their responses by imitating larger companions (Geist 1971a:417) which, in turn, have copied response patterns in their youth from older individuals.

In addition to this traditional aspect of learning in social animals, alarm responses of animals to threatening stimuli seem often to be dampened as group size increases (Parker and Graham 1971:399; Shalter 1984:366). Thus elk, moose, and mule deer in groups reportedly show a lower flight tendency than solitary individuals (Altmann 1958:208); white–tailed deer (Hirth and McCullough 1977, quoting Newhouse 1973) and sable antelope and wildebeest (Estes 1974) show less excitability or wariness as group size increases. The same tendency has been observed by Lent (1964:165 et seq.), Kelsall (1968:44), Roby (1978:114) and Calef (1981:94) in caribou. Baskin (1975:261–262) stated that in wild reindeer the "defense" reflex (flight response) diminished as herd size increased to about 400 to 500 animals, changing little as size increased thereafter.

Some observations seem to contrast with this pattern. Bergerud (1974:559) reported the same general trend in caribou, but noted that alert and flushing distances of single caribou with calves in Newfoundland were less than those of small cow–calf groups. This is apparently just a case of several pairs of eyes being better than one. Klein (1980:524) concluded that larger groups of caribou were more likely to avoid obstructions. However, he was apparently referring not so much to avoidance (fear) *per se*, but to the probability of negotiating structures.

Associations that animals make between particular stimuli and important life experiences strongly condition their future responses to these stimuli. For example, ungulate populations that are being hunted typically exhibit extreme wariness and long flight distances from vehicular traffic and humans on foot (Altmann 1958:208; Deane and Feely 1974:885; Dorrance et al. 1975:569; Morgantini and Hudson 1979:136; Hutchins and Geist 1987:140). On the other hand, frequent harmless contact between humans and ungulates leads to great reductions in the ungulates' alarm reactions to humans and vehicles, often to the extent that the animals come to have extremely short flight distances or may not flee at all (Geist 1971a:414, Krämer 1971:167, Parker and Graham 1971:398, Hutchins and Geist 1987:140).

Even when a stimulus has been associated with harmful consequences, frequent presentation thereafter of the same stimulus without harm can often reduce alarm. Animals hunted during restricted periods become less wary of humans as time passes beyond the hunting season and experience with harmless contact accumulates (Parker and Graham 1971:398, Deane and Feely 1974:885, Morgantini and Hudson 1979:136, MacArthur et al. 1982).

Temporal and Spatial Dimensions

Clearly, many wild animals, including caribou, have the potential to habituate to a wide range of visual, auditory, and olfactory stimuli associated with human activities. This habituation occurs only if the stimuli are associated with harmless consequences. Two other aspects of stimuli that strongly influence the speed and extent of habituation are their occurrence in time and space.

A specific stimulus usually generates the greatest response in animals the first time it is encountered because of the apparently innate fear of novelty (Bronson 1968:350, Curio 1976:103, Shalter 1984:351). Response appears to decline more rapidly the more frequently the stimulus is encountered, i.e., "familiarity breeds neglect, rarity engenders reaction" (Shalter 1984:351). Experience with a variety of large mammals in Africa has shown that they habituate more quickly and fully to the presence and activities of people when the non–alarming contact is frequent (Parker and Graham 1971:398, Deane and Feely 1974:885). Caribou in Alaska exposed more frequently to aircraft overflights (Valkenburg and Davis 1985) and to higher levels of vehicular traffic (Roby 1978:134) exhibited weaker alarm responses to these stimuli than did caribou that had experienced less frequent exposure. The same pattern was noted in reindeer exposed to high and low levels of snowmobile traffic in Svalbard (Tyler 1991:183).

Many species seem to be acutely aware of the spatial positions of stimuli encountered (Shalter 1984:363). A familiar stimulus appearing at a new location often evokes a response greater than that displayed in the setting which had become familiar. Angel fish habituated quickly to a moving shadow on one side of a test chamber, but showed renewed avoidance when the location of the shadow was changed (Schleidt et al. 1983). Jungle fowl displayed renewed responsiveness to warning calls broadcast at a new location after habituation to them had occurred at the original position (Shalter 1984:365). Ducks and geese which had habituated to dogs at one shore of a lake proved not to be habituated to them at the opposite shore (Shalter 1984:363, quoting Curio 1963).

The spatial specificity of habituation has been poorly studied in ungulates, but Geist (1971a:417) maintains that ungulates have a strong spatial orientation within their individual ranges and associate localities with previous experiences there. It is known that wild ungulates often avoid localities where unpleasant disturbances were experienced (Geist 1971a:417, 1978:289). Hunted populations of white-tailed deer (Dorrance et al. 1975) and caribou (Smith 1988) apparently avoided areas where they had experienced snowmobile traffic. Caribou females have been hypothesized to select calving grounds where past encounters with predators have been few (Bergerud 1988:72).

On the other hand, migrating caribou and wild reindeer often continue to pass annually at traditional river crossings and other localities despite human harvest of caribou at these localities year after year (Kelsall 1968:211–214, Borzhonov et al. 1975, Johnson and Todd 1977:314, Bergerud et al. 1984b:10). But Baskin (1975:261) found that shooting reindeer at such crossings may cause them to change crossing places. Ingstad (1954) noted that Eskimo hunters at Anaktuvuk Pass traditionally allowed some lead caribou to pass through unharmed, presumably to prevent their future abandonment of the pass during migration. The tenacity with which caribou and reindeer cling to learned travel routes appears strong (Miller et al. 1972). The apparent avoidance of some unpleasant locations by caribou and the recurrence of their annual movements at specific other locations both suggest that caribou have a strong sense and memory of place.

The ability of ungulates to discriminate spatially suggests another possibility—that they may be able to habituate to a stimulus in one area that they have learned to fear in another. As hinted earlier, this thesis has some experimental basis. Parker and Graham (1971:398) noted that elephants and hippopotamus in Uganda parks are relatively tame to the presence of tourists, despite the cropping of some individuals from the populations (presumably in places other than tourist viewing areas). Geist (1971a:415, 1971b) noted the extreme tameness of bighorn sheep in Banff National Park (individuals were petted and ear-tagged without restraining them) though some of the same individuals were hunted outside the park. MacArthur et al. (1982:353) routinely approached bighorn sheep in a hunted population to within 25–50 m on their winter range in Sheep River Wildlife Sanctuary, Alberta, without the sheep withdrawing or their heart rate increasing.

Effects of Motivation

The rate and extent of habituation to a stimulus often increases when there is an increase in motivation to conserve energy or to inhabit or pass through the area where the stimulus occurs. The increased tolerance to human presence shown by winter–starved deer as they invade farms and stockyards in search of food (Reed 1981:515) is well known. Moose have shorter flight distances in winter than in other seasons, presumably due to a general lowering of nutritional vigor (Altmann 1958:208); similarly, caribou along the Trans–Alaska Pipeline haul road showed more tolerance of traffic during winter than in other seasons (Roby 1978:149). Mule deer sometimes cluster around human settlements in national parks, perhaps in response to predator scarcity near the settlements (Geist 1981:168).

We already noted the persistence with which reindeer and caribou cling to traditional migration routes despite the presence of unfamiliar obstacles or the recurrence of human–caused mortalities along the routes (Kelsall 1968:211–214; Miller et al. 1972; Bergerud et al. 1984b:10). Caribou near oil field activities show increased tolerance for human activities and structures when the caribou are attempting to escape harassment by insects, particularly oestrid flies (Roby 1978:136; Curatolo and Murphy 1986:220; Murphy 1988:203). Thus, the impetus for animals to avoid human presence may often be dampened by the presence of other risks.

Habituation in the Central Arctic Herd

Evidence for habituation to anthropogenic stimuli by the CAH in and around the oil fields is fragmentary and anecdotal. Roby (1978:134) believed that habituation to traffic on the haul road was occurring as early as 1975–76. He thought that habituation was facilitated by higher rates of traffic but could not clearly distinguish between habituation effects and the barrier ("fencing") effect caused by high traffic levels that caused caribou to accumulate near the road. The early green–up of vegetation in the dust shadow along the road may also have contributed to caribou lingering near the road in spring.

In the course of testing for selection of pipeline height categories as crossing sites, Curatolo and Murphy (1986) found statistically significant selection of higher elevation classes in 1981, the first year of their study, but not in the subsequent two years. They believed (p.223) that this difference among years may have been due to habituation (1981 was the first year that the pipeline under study was in place). However, alternate explanations, perhaps more plausible, include the possibility that the 1981 results represent a Type I error. Curatolo and Murphy (1986:221) also suggested that the much lower apparent effectiveness of elevated pipe sections reported by Child (1973, 1974), in comparison with their own results, may have been due to habituation occurring in the population in the intervening years. Murphy (1984:34) noted that there were no data to support claims of habituation. Nevertheless, he believed that there was subjective evidence that crossing success was increasing. He reported that,

> "...it is generally agreed among ABR caribou researchers that we have seen a reduction in the severity of reactions of caribou to pipelines in the past four years...it may follow that they are able to cross with greater frequency. We have not, however, seen a similar reduction in the severity of caribou reactions to vehicles."

This subjective evidence is intriguing, even substantial, and it agrees with patterns reported elsewhere. The observation also suggests that caribou are learning to negotiate structures, a process that is difficult to isolate from habituation. There have been no long-term studies carried out with the CAH with sufficiently consistent methodology from year to year to establish conclusively the degree to which learning and habituation have occurred.

Enhancing Habituation in Oil Fields

As indicated above, caribou potentially can habituate to a wide array of human activities and landscape alterations. The rapidity and extent of habituation depends not only on the innate response tendencies of caribou (e.g., motion elicits more response than noise, females with newborn are more sensitive than males) but also on the learning experiences of individuals. Oil field designers and operators can enhance habituation by creating an environment in which caribou quickly learn that activities and infrastructure are harmless and thereafter ignore them. Below, we (1) assess which types of stimuli in oil fields present the greatest barriers to habituation and (2) propose design and operations criteria for overcoming these barriers.

Aversion to moving objects will probably be the most difficult response for caribou to overcome. Moving vehicles and people on foot not only constitute potential predators, their unpredictable appearance in space and time and their movement at different speeds and approach angles present some degree of continuing novelty. These qualities in combination suggest that caribou will habituate relatively slowly and incompletely to moving objects.

Caribou should habituate readily to the visual presence of stationary objects. Not only do stationary objects elicit weaker initial responses than moving objects (even when they contrast with surrounding landscapes), they also present a continuous and unvarying presence which, when harmless, engenders rapid habituation.

Caribou should likewise habituate readily to oil field noises. As we have seen, ungulates and other mammals accommodate quickly to unfamiliar but harmless noises, as do caribou (Kelsall 1968:44; Bergerud 1974:579). Some of the louder noises in oil fields occur more or less constantly and from non–moving sources, thus, their "novelty" effect is relatively short–lived. Caribou readily habituate to stationary sources of noise (Klein 1980:524). Further, most oil field noise seems to attenuate to background amplitudes within short distances (in comparison with distances at which objects are visible).

Odors associated with oil fields seem unlikely to elicit alarm from caribou very far from odor sources. Although strong odor is known to cause alarm, and often flight in the absence of visual contact (Bergerud 1974:579), it seems likely that the effects of human and other odors attenuate quickly with distance. Kelsall (1968:44) observed on numerous occasions the ineffectiveness of nearby human odor alone to cause flight in caribou, (but quoted Banfield [1954] who observed caribou "warned by human scent" a mile from its source).

Presumably human odor has fewer novel dimensions than does a moving object, i.e. it is either present or it isn't. Other strong odor types in oil fields (e.g. emissions from combustion) seem likely to be encountered frequently by caribou in the oil fields because of the tendency for such odors to be strong and spread widely downwind. These qualities of olfactory stimuli suggest that caribou should be able to habituate to common odors relatively quickly.

Promoting habituation by caribou to moving objects in oil fields, thus, seems a high priority. The most common sources of motion in oil fields are vehicles on roads, low-flying aircraft, and people on foot. There seems to be consensus that aircraft traffic at currently-imposed restrictions on altitude ceilings pose no major threats; thus, ground-based motion is the most important consideration. We suggest below several strategies that the literature reviewed implies may increase the rate and extent of habituation to moving objects.

1. Localize (consolidate) vehicular traffic in space and in time to the extent possible during caribou presence especially during June when cows with young increase their avoidance of moving objects.

2. Maintain relatively constant speeds in vehicular traffic during June–July, restricting roadside stops by vehicles and people exiting vehicles to few and specific localities. (Regular spacing of vehicles or convoying at specific times of the day during this period may also be worth considering to reduce the temporal novelty of the vehicles in motion.)

3. Orient roads and pipelines perpendicular to known caribou travel routes.

4. In less-used areas of oil fields, reduce activities of people on foot and in vehicles to an absolute minimum during June (or until most caribou have left).

5. Discourage vehicle-based hunting of caribou in all parts of the caribou herd's range.

6. Standardize shape, proportions, and other design features of structural elements, such as ramps, used in mitigation. Such standardization should facilitate learning and habituation.

7. Recognize that increased habituation will lead to increased vehicle–caribou encounters as animals become increasingly present in work areas; take appropriate safety and enforcement measures.

Habituation to human activity may result in adverse consequences under some circumstances. For example, habituation to roads with traffic may have exacerbated traffic mortalities in bighorn sheep in Banff National Park, Canada (Geist 1971a:415) and in mountain caribou in Kootenay Pass, British Columbia (Johnson and Todd 1977:314). Habituation to human presence could also increase the vulnerability of caribou to hunting in other parts of their range. Whether the adverse consequences of habituating to oil field activities will outweigh the disadvantages of not habituating is a difficult question to resolve on the basis of existing evidence, though it seems implicit in most information we reviewed that caribou avoidance of human activities in oil fields is assumed to be a greater problem than is their habituation to activities.

Summary and Conclusions: Habituation

Caribou can habituate to a wide range of potentially harmful stimuli. CAH caribou appear to have partially habituated to oil field structures and operation since construction. Habituation to the field may still be occurring. Caribou will habituate slowly to large moving objects, such as trucks, but probably have little or no problem with structures, noise, or odors. Recommendations for increasing habituation to vehicles and structures in oil fields include: localize traffic in space and time; orient roads and pipelines perpendicular to known caribou travel routes; maintain constant speeds; reduce foot traffic; discourage vehicle–based hunting; and standardize shapes and proportions of structures and mitigation measures.

Literature Cited

Altmann, M. 1958. The flight distance in free-ranging big game. J. Wildl. Manage. 22:207–209.

Banfield, A.W.F. 1954. Preliminary investigation of the barren-ground caribou. Canadian Wildl. Serv., Wildl. Manage. Bull. Ser. 1, Nos. 10A and 10B.

Baskin, L.M. 1975. Behavior of wild reindeer as a basis for game management. Pp. 260–266 in E.E. Syroechkovskii, ed. Wild reindeer of the Soviet Union. Proc. 1st interdepartmental conf. on the preservation and rational utilization of wild reindeer resources. Translation from Russian in 1984 by Amerind Publishing Co. Pvt. Ltd., New Delhi. 309 pp.

Beanlands, G.E., and P.N. Duinker. 1983. An ecological framework for environmental impact assessment in Canada. Institute for Resource and Environmental Studies, Dalhousie University. Halifax, Nova Scotia. 132 pp.

Bergerud, A.T. 1974. The role of the environment in the aggregation, movement, and disturbance behaviour of caribou. Pp. 552–585 *in* V. Geist and F. Walther, eds. The behaviour of ungulates and its relation to management, Vol. 2. Int. Union Conserv. Nature, New Ser. Publ. 24, Morges, Switzerland.

Bergerud, A.T. 1978. Caribou. Pp. 83–101 *in* J.L. Schmidt and D.L. Gilbert, eds. Big game of North America. Stackpole Books, Harrisburg, Pa. 494 pp.

Bergerud, A.T. 1988. Caribou, wolves, and man. Trends Ecol. Evol. 3:68–72.

Bergerud, A.T., H.E. Butler, and D.R. Miller. 1984a. Antipredator tactics of calving caribou: dispersal in mountains. Can. J. Zool. 62:1566–1575.

Bergerud, A.T., R.D. Jakimchuk, and D.R. Carruthers. 1984b. The buffalo of the North: caribou (*Rangifer tarandus*) and human developments. Arctic 37:7–22.

Borzhonov, B.B., V.D. Savel'ev, B.M. Pavlov, and V.A. Kuksov. 1975. Experience in shooting wild reindeer at water crossings. Pp. 240–242 *in* E.E. Syroechkovskii, ed. Wild reindeer of the Soviet Union. Proc. 1st interdepartmental conf. on the preservation and rational utilization of wild reindeer resources. Transl. from Russian in 1984 by Amerind Publ. Co. Pvt. Ltd., New Dehli. 309 pp.

Bronson, G.W. 1968. The fear of novelty. Psychol. Bull. 69:350–358.

Clough, N.K., P.C. Patton, and A.C. Christianson, eds. 1987. Arctic National Wildlife Refuge, Alaska, coastal plain resource assessment—Rep. and recommendation of the Congress of the United States and final legislative environmental impact statement. Vol. 1. U.S. Fish Wildl. Serv., U.S. Geol. Surv., and Bur. Land Manage. Washington, D.C. 208 pp.

Cottereau, P. 1978. Effect of sonic boom from aircraft on wildlife and animal husbandry. Pp. 63–79 in J.L. Fletcher and R.G. Busnel, eds. Effects of noise on wildlife. Academic Press, New York. 305 pp.

Curatolo, J.A. 1985. Sexual segregation and habitat use by the central arctic caribou herd during summer. Pgs. 193–198 *in* T.C. Meredith and A.M. Martell (eds.). Proc. 2nd N. Am. Caribou Workshop. McGill Subarct. Res. Pap. No. 40, Centre for Northern Studies and Res., McGill Univ., Montreal.

Curatolo, J.A., and S.M. Murphy. 1986. The effects of pipelines, road, and traffic on the movement of caribou, *Rangifer tarandus*. Can. Field–Nat. 100:218–225.

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

Curio, E. 1963. Probleme des Feinderkennens bei Volgen *in* Proc. 13th Intern. Ornith. Congr. Pp. 206–239.

Curio, E. 1976. The ethology of predation. Springer–Verlag, New York. 250 pp.

Dau, J.R. 1986. Responses of caribou to petroleum development, weather, and parasitic insects. M.S. thesis, Univ. Alaska, Fairbanks. 149 pp.

Dau, J.R., and R.D. Cameron. 1986a. Effects of a road system on caribou distribution during calving. Rangifer, Spec. Issue No. 1:95–101.

Dau, J.R., and R.D. Cameron. 1986b. Responses of barren–ground caribou to petroleum development near Milne Point, Alaska. Final Rep. to Conoco, Inc. and Continental Pipeline Company, Alaska Dep. Fish Game, Fairbanks, Alaska. 18 pp.

Davis, J.L., P. Valkenburg, and R.D. Boertje. 1985. Disturbance and the Delta caribou herd. Pp. 2–6 *in* A.M. Martell and D.E Russell, eds. Caribou and human activity. Proc. 1st N. Am. caribou workshop, Whitehorse, Yukon. Can. Wildl. Serv. Spec. Publ., Ottawa.

Day, G.I. Undated. Javelina research and management in Arizona. Arizona Game and Fish Dept., Phoenix. 127 pp.

Gates, C.C., J. Adamczewski, and R. Mulders. 1986. Population dynamics, winter ecology, and social organization of Coats Island caribou. Arctic 39:216–222.

Geist, V. 1971a. A behavioural approach to the management of wild ungulates. Pp. 413–424 in E. Duffey and A.S. Watt, eds. The scientific management of animal and plant communities for conservation. Eleventh Symp. Brit. Ecol. Soc. Blackwell Scientific Publ., Oxford, London. 652 pp.

Geist, V. 1971b. Mountain sheep: a study in behavior and evolution. Univ. Chicago Press, Chicago. 383 pp.

Geist, V. 1978. Behavior. Pp. 283–296 *in* J.L. Schmidt and D.L. Gilbert, eds. Big game of North America: ecology and management. Stackpole Books, Harrisburg, Pa. 494 pp.

Geist, V. 1981. Behavior: adaptive strategies in mule deer. Pages 157–223 *in* O.C. Wallmo (ed.). Mule and Black–tailed Deer of North America. University of Nebraska Press, Lincoln. 605 pp.

Geist, V. 1982. Adaptive behavioral strategies. Pp. 219–277 in J.W. Thomas and D.E. Toweill, eds. Elk of North America: ecology and management. Stackpole Books, Harrisburg, Pa. 698 pp.

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley and Sons, New York. 257 pp.

Gunn, A., and F.L. Miller. 1980. Responses of Peary caribou cow–calf pairs to helicopter harassment in the Canadian high arctic. Pp. 497–507 *in* E. Reimers, E. Gaare, and S. Skjenneberg, eds. Proc. 2nd int. reindeer/caribou symp., Røros, Norway, 1979. Direktoratet for vilt og ferskvannsfisk, Trondheim.

Halls, L.K. 1978. White–tailed deer. Pp. 43–65 *in* J.L. Schmidt and D.L. Gilbert, eds. Big game of North America: ecology and management. Stackpole Books, Harrisburg, Pa. 494 pp.

Hansen, C.G. 1980. Senses and intelligence. Pp. 113–123

Heard, D.C., and T.M. Williams. 1991. Wolf den distribution on migratory barren–ground caribou ranges in the Northwest Territories (Abstract). Pp. 249–250 *in* C. Butler and S.P. Mahoney, eds. Proc. 4th N. Am. caribou workshop, St. John's, Newfoundland.

Helle, T., and J. Aspi. 1983. Does herd formation reduce insect harassment among reindeer? A field experiment with traps. Acta Zool. Fenn. 175:129–131.

Hill, E.L. 1985. A preliminary examination of the behavioural reaction of caribou to the Upper Salmon Hydroelectric Development in Newfoundland. Proc. 2nd N. Am. Caribou Workshop. McGill Subarctic Res. Pap., 40:85–96.

Hirth, D.H., and D.R. McCullough. 1977. Evolution of alarm signals in ungulates with special reference to white–tailed deer. Am. Nat. 111:31–42.

Horejsi, B.L. 1981. Behavioral response of barren ground caribou to a moving vehicle. Arctic 24:180–185.

Hutchins, M., and V. Geist. 1987. Behavioural considerations in the management of mountain–dwelling ungulates. Mountain Research and Development, 7:135–144.

Ingstad, H. 1954. Nunamiut: Among Alaska's inland Eskimos. W.W. Worton & Co., New York. 303 pp.

Jakimchuk, R.D. 1980. Disturbance to barren–ground caribou: a review of the effects and implications of human developments and activities. Rep. by R.D. Jakimchuk Management Associates Ltd. to Polar Gas Project (Canada). 140 pp.

Jakimchuk, R.D., S.H. Ferguson, and L.G. Sopuck. 1987. Differential habitat use and sexual segregation in the Central Arctic Herd. Can. J. Zool. 65:534–541.

Johnson, C.B., and B. Lawhead 1989. Distribution, movements and behavior of caribou in the Kuparuk oilfield, summer 1988. Alaska Biological Research Rep. to ARCO Alaska, Inc.

Johnson, D.R., and M.C. Todd. 1977. Summer use of a highway crossing by mountain caribou. Canad. Field–Nat. 91:312–314.

Kelsall, J.P. 1968. The migratory barren–ground caribou of Canada. Queen's Printer, Ottawa, Canada. 339 pp.

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

Klein, D.R. 1980. Reaction of caribou and reindeer to obstructions—a reassessment. Pp. 519–527 in E. Reimers, E. Gaare, and S. Skjenneberg, eds. Proc. 2nd int. reindeer/caribou symp., Røros, Norway, 1979. Direktoratet for vilt og ferskvannsfisk, Trondheim.

Krämer, A. 1971. Zum Fluchtverhalten des Steinwildes (*Capra ibex*) im Oberangaden, Schwiez. Saugetierk. Mitt., 19:164–171.

Krulitz, L.M. 1979. Federal legal background for mitigation. Pp. 19–26 in The mitigation symposium. Gen. Tech. Rep. RM–65. U.S. Forest Service, Fort Collins, Colorado.

Lawhead, B.E. 1988. Distribution and movements of Central Arctic Herd caribou during the calving and insect seasons. Pp. 8–13 *in* R.D. Cameron and J.L. Davis, eds. Reproduction and calf survival. Proc. 3rd N. Am. Caribou Workshop. 229 pp.

Lawhead, B.E., 1990. 1989 Endicott environmental monitoring program (draft), Endicott Unit owners. Rep. for Science Applications Intern. Corp.

Lawhead, B.E., and S.M. Murphy. 1988. Caribou, 1987 Endicott Environmental Monitoring Program. Draft report to Envirosphere Co. and U.S. Army Corps of Engineers, Anchorage, by Alaska Biological Research, Fairbanks. 66 pp + Appendices.

Lawhead, B.E., and L. Smith. 1990. 1988 Endicott environmental monitoring program (draft), Endicott Unit owners and BP Exploration. Rep. for Science Applications Intern. Corp.

Lent, P.C. 1964. Calving and related social behavior in the barren–ground caribou. Ph.D. Diss., Univ. of Alberta. 220 pp.

Lent, P.C. 1966. Calving and related social behaviour in the barren–ground caribou. Z. Tierpsychologie 23:701–756.

Leuthold, W. 1977. African ungulates: a comparative review of their ethology and behavioral ecology. Springer–Verlag, New York. 307 pp.

Luick, J.R. 1980. Circumpolar problems in managing populations of wild and domestic reindeer. Pp. 686–688 *in* E. Reimers, E. Gaare, and S. Skjenneberg, eds. Proc. 2nd int. reindeer/caribou symp., Røros, Norway, 1979. Direktoratet for vilt og ferskvannsfisk, Trondheim.

MacArthur, R.A., V. Geist, and R.H. Johnston. 1982. Cardiac and behavioral responses of mountain sheep to human disturbance. J. Wildl. Manage. 46:351–358.

McCabe, T.R., ed. 1989. Terrestrial research: 1002 Area—Arctic National Wildlife Refuge, Ann. Progr. Rep., 1988. U.S. Fish Wildl. Serv., Anchorage, AK. 168 pp.

McCabe, T.R., ed. 1990. Terrestrial research: 1002 Area—Arctic National Wildlife Refuge, Ann. Progr. Rep., 1989. U.S. Fish Wildl. Serv., Anchorage, AK. 168 pp.

McCourt, K.H., J.D. First, D. Doll and J.J. Russell. 1974. Disturbance studies of caribou and other mammals in the Yukon and Alaska. Arctic Gas Biological Rep. Ser. No. 5. 246 pp.

Messier, F., J. Huot, D. Le Henaff, and S. Luttich. 1988. Demography of the George River caribou herd: evidence of population regulation by forage exploitation and range expansion. Arctic 41:279–287.

Miller, F.L., and A. Gunn. 1979. Responses of Peary caribou and muskoxen to helicopter harassment. Can. Wildl. Serv. Occ. Pap. No. 40. 90 pp.

Miller, F.L., and A. Gunn. 1980. Behavioral responses of muskox herds to simulation of cargo slinging by helicopters. Can. Field–Nat. 94:52–60.

Miller, F.L., 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.

Morgantini, L.E., and R.J. Hudson. 1979. Human disturbance and habitat selection in elk. Pp. 132–139 *in* M.S. Boyce and L.D. Hayden–Wing, eds. North American elk: ecology, behavior, and management. Univ. Wyoming Press, Laramie.

Muller–Schwarze, D. 1972. Responses of young black–tailed deer to predator odors. J. Mammal. 53:393–394.

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. Alaska Biological Research, Fairbanks. 40 pp.

Murphy, S.M. 1988. Caribou behavior and movement in the Kuparuk Oilfield: implications for energetic and impact analysis. Pp. 196–210 *in* R.D. Cameron and J.L. Davis, eds. Reproduction and calf survival. Proc. 3rd N. Am. caribou workshop. Alaska Dep. Fish Game Wildl. Tech. Bull. No. 8.

Murphy, S.M., and J.A. Curatolo. 1984. Responses of caribou to ramps and pipelines, Kuparuk Oilfield, Alaska 1983. Prepared for ARCO Alaska, Inc. Alaska Biological Research, Fairbanks, AK. 40 pp.

Murphy, S.M., and J.A. Curatolo. 1987. Activity budgets and movement rates of caribou encountering pipelines, road, and traffic in northern Alaska. Can. J. Zool. 65:2483–2490.

Newhouse, S.J. 1973. Effects of weather on behavior of white–tailed deer of the George Reserve, Michigan. M.S. Thesis. Univ. Michigan, 154 pp.

Parker, I.S.C., and A.D. Graham. 1971. The ecological and economic basis for game ranching in Africa. Pp. 393–404 *in* E. Duffey and A.S. Watt, eds. The scientific management of animal and plant communities for conservation. Eleventh Symp. Brit. Ecol. Soc. Blackwell Scientific Publications, Oxford, London. 652 pp.

Pollard, R.H., and W.B. Ballard. 1993. Caribou distribution in the Prudhoe Bay oil field, summer 1992. Final Report prepared by LGL Alaska Research Associates, Inc. for BP Exploration (Alaska) Inc., Anchorage, AK. 24 pp. + Appendix.

Pollard, R.H., and D.G. Roseneau. 1992. Distribution of the Porcupine Caribou Herd during calving in the 1002 Area of the Arctic National Wildlife Refuge, Alaska, 1991. Final Rep. prepared by LGL Alaska Research Associates, Inc. and Biosystems Alaska for BP Exploration (Alaska) Inc., Anchorage, Alaska. 13 pp.

Pollard, R.H., M.E. Miller, and R.C. Wilkinson. 1992a. Caribou distribution in the Prudhoe Bay oil field, Summer 1990. Final report by LGL Alaska Research Associates, Inc. Prepared for BP Exploration (Alaska) Inc., Anchorage, Alaska. 40 pp + appendices.

Pollard, R.H., P.C. Lent, M.E. Miller, and R.C. Wilkinson. 1992b. Caribou distribution in the Prudhoe Bay and Kuparuk oil fields, summer 1991. Final Rep. by LGL Alaska Research Associates, Inc. Prepared for BP Exploration (Alaska) Inc., Anchorage, Alaska. 25 pp + Appendix.

Pruitt, W.O., Jr. 1960. A flight releaser in wolf–caribou relations. J. Mamm. 46:350–351.

Rappoport, A. 1979. The mitigation problem: A background review for the Mitigation Symposium. Pp. 1–5 *in* The mitigation symposium, Gen. Tech. Rep. RM–65. U.S. Forest Service, Fort Collins, Colorado.

Reed, D.F. 1981. Conflicts with civilization. Pp 509–535 *in* O.C. Wallmo, ed. Mule and black–tailed deer of North America. Univ. Nebraska Press, Lincoln. 605 pp.

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

Reimers, E., L. Villmo, E. Gaare, V. Holthe, and T. Skogland. 1980. Status of *Rangifer* in Norway including Svalbard. Pp. 774–785 *in* E. Reimers, E. Gaare, and S. Skjenneberg, eds. Proc. 2nd Int. Reindeer/Caribou Symp., Røros, Norway, 1979. Direktoratet for vilt og ferskvannsfisk, Trondheim.

Robertson, S.B. 1989. Impacts of petroleum development in the Arctic. Science 245:764–765.

Robus, M. 1983. Caribou movements and responses to roads in the CPF 2–Oliktok region, Kuparuk oil field, Alaska, 1982. Alaska Biological Research report to ARCO Alaska, Inc. (draft). 84 pp.

Roby, D.D. 1978. Behavioral patterns of barren–ground caribou of the Central Arctic Herd adjacent to the Trans–Alaska Pipeline. M.S. thesis, Univ. Alaska, Fairbanks. 200 pp.

Rognmo, A., K. Markussen, E. Jacobsen, H. Grav, and A. Blix. 1983. Effects of improved nutrition in pregnant reindeer on milk quality, calf birth weight, growth, and mortality. Rangifer 3:10–18.

Schaller, G.B. 1972. Serengeti: a kingdom of predators. Alfred A. Knopf, New York.

Schleidt, W.M., M.D. Shalter, and T.C. Carawan. 1983. The effect of spatial context on habituation to a predator model. Z. Tierpsychol. 61:67–70.

Shalter, M.D. 1984. Predator–prey behavior and habituation. Pp. 349–391 *in* H.V.S. Peeke and L. Petrinovich, eds. Habituation, sensitization, and behavior. Academic Press, New York. 471 pp.

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. Tech. Rep. No. 86–3. Habitat Div., Alaska Dep. of Fish and Game. 128 pp.

Simpson, K. 1987. The effects of snowmobiling on winter range use by mountain caribou. Wildl. Working Rep. WR–25. Ministry of Environment and Parks, Nelson, BC. 14 pp.

Singer, F.J. 1978. Behavior of mountain goats in relation to U.S. Highway 2, Glacier National Park, Montana. J. Wildl. Manage. 42:591–597.

Skogland, T., and B. Grøvan. 1988. The effects of human disturbance on the activity of wild reindeer in different physical condition. Rangifer 8:11–19.

Skogland, T., and O. Molmen. 1980. Prehistoric and present habitat distribution of wild mountain reindeer at Dovrefjell. Pp. 130–141 *in* E. Reimers, E. Gaare, and S. Skjenneberg, eds. Proc. 2nd int. reindeer/caribou symp., Røros, Norway, 1979. Direktoratet for vilt og ferskvannsfisk, Trondheim.

Smith, M.D. 1991. Coastal/inland differences in caribou habitat in the Arctic coastal plain during the summer mosquito season. Presentation at Arctic Ungulate Conf., Nuuk, Greenland. Rangifer (In press).

Smith, T.E. 1988. Effects of hunting with the use of snowmachines on movements of Western Arctic Herd Caribou, Seward Peninsula, Alaska. Pp. 211–219 *in* R.D. Cameron and J.L. Davis, eds. Reproduction and calf survival. Proc. 3rd N. Am. caribou workshop, Chena Hot Springs, Alaska. 4–6 November 1987. 229 pp.

Smith, W.T., and R.D. Cameron. 1985a. Factors affecting pipeline crossing success of caribou. Pp. 40–46 *in* A.M. Martell and D.E. Russell eds. Caribou and human activity. Proc. 1st N. Am. Caribou Workshop, Whitehorse, Y.T.

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.

Smith, W.T., and R.D. Cameron. 1990. Caribou responses to development infrastructures and mitigation measures implemented in the Central Arctic Region. Pp. 47–64 *in* T.R. McCabe, ed. Terrestrial research: 1002 Area—Arctic National Wildlife Refuge, Ann. Progr. Rep., 1988. U.S. Fish Wildl. Serv., Anchorage, AK. 168 pp.

Stefansson, V., 1921. The Friendly Arctic. Macmillan. 784 pp.

Strong, D.R., Jr. 1982. Null hypotheses in ecology. Pp. 245–259 *in* E. Saarinen, ed. Conceptual issues in ecology. D. Reidl Publ. Co., Dordrecht.

Thomson, B.R. 1973. Wild reindeer activity. Hardangervidda:1971. Statens Viltundersøkelser. Dir. jakt, vittstell og fersksvannfiske. Trondheim, Norway. 76 pp.

Thomson, B.R. 1980. Behaviour differences between reindeer and caribou (*Rangifer tarandus* L.). Pp. 545–549 *in* E. Reimers, E. Gaare, and S. Skjenneberg, eds. Proc. 2nd int. reindeer/caribou symp., Røros, Norway, 1979. Direktoratet for vilt og ferskvannsfisk, Trondheim.

Trudell, J., and R.G. White. 1981. The effect of forage structure and availability on food intake, biting rate, bite size, and daily eating time of reindeer. J. Applied Ecol. 18:63–81.

Truett, J.C., and K. Kertell. 1992. Tundra disturbance and ecosystem production: implications for impact assessment. Environmental Management Vol. 16.

Truett, J.C., A.T. Bergerud, and D. Roseneau. 1989. Caribou calving areas and neonatal mortality: a review. Rep. to Alaska Oil and Gas Association, Anchorage. 148 pp.

Tukey, J.W. 1960. Conclusions vs. decisions. Technometrics, 2:423–433.

Tyler, N.J.C. 1991. Short–term behavioural responses of Svalbard reindeer *Rangifer tarandus platyrhynchus* to direct provocation by a snowmobile. Biological Conserv. 56:179–194.

U.S. Army Corps of Engineers (USACE). 1984. Endicott Development Project Final Environmental Impact Statement; Vol. II: Technical Discussion. U.S. Dep. Army, Corps of Eng., Alaska District, and Environmental Research and Technology, Inc. (Original not seen.)

Valkenburg, P., and J.L. Davis. 1985. The reaction of caribou to aircraft: a comparison of two herds. Pp. 7–9 *in* A.M. Martell and D.E. Russell, eds. Caribou and human activity. Proc. 1st N. Am. caribou workshop, Whitehorse, Yukon, 28–29 Sept. 1983. Can. Wildl. Serv. Spec. Publ., Ottawa.

Villmo, L. 1975. The Scandinavian viewpoint. Pp. 4–9 *in* J.R. Luick, P.C. Lent, D.R. Klein, and R.G. White, eds. Proc. 1st int. reindeer/caribou symp., Fairbanks, Alaska, 1972. Biol. Pap. Univ. Alaska, Spec. Rep. No. 1. 551 pp.

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

Weiler, G.J., G.W. Garner, R. Ambrose, H.V. Reynolds, and T.R. McCabe. 1989. Differential impacts of predators (brown bears, wolves, eagles) on caribou calving in the 1002 Area and potential displacement areas: an assessment of predation risk. Pp. 25–37 *in* T.R. McCabe, ed. Terrestrial research: 1002 Area—Arctic National Wildlife Refuge, Ann. Progr. Rep., 1988. U.S. Fish Wildl. Serv., Anchorage, AK. 168 pp.

White, R.G. 1983. Foraging patterns and their multiplier effects on productivity of northern ungulates. Oikos 40:377–384.

Whitten, K.R., and R.D. Cameron. 1985. Distribution of caribou calving in relation to the Prudhoe Bay Oil field. Pages 35–39 *in* A.M. Martell and D.E. Russell (eds.). Proceedings of the First North American Caribou Workshop, Whitehorse, Yukon. Canadian Wildlife Service, Ottawa, Ontario.

Whitten, K.R., and R.D. Cameron. 1986. Groups versus individuals in the determination of caribou distribution. Rangifer, Special Issue No. 1:325–329.

Whitten, K.R., and S.G. Fancy. 1990. Effect of potential displacement of caribou from the 1002 Area on mortality rates of calves. Pp. 16–19 *in* T.R. McCabe, ed. Terrestrial research: 1002 Area—Arctic National Wildlife Refuge, Ann. Progr. Rep., 1988. U.S. Fish Wildl. Serv., Anchorage, AK. 168 pp.

Whitten, K.R., S.G. Fancy, and N.E. Walsh. 1992a. Effect of potential displacement of caribou from the 1002 area on mortality rates of calves. Pp. 21–36 in T.R. McCabe, B. Griffith, N.E. Walsh and D.D. Young, eds. Research on the potential effects of petroleum development on wildlife and their habitat, Arctic National Wildlife Refuge. Interim Rep. 1988–1990. U.S. Fish and Wildlife Service, Anchorage, AK.

Whitten, K.R., F.J. Mauer, and G.W. Garner. 1987. Calving distribution, initial productivity, and neonatal mortality of the Porcupine Caribou herd, 1985. Pp. 49–573 *in* G.W. Garner and P.E. Reynolds, eds. Arctic National Wildlife Refuge coastal plain resource assessment, 1985 update report baseline study of the fish, wildlife, and their habitats. Vol. II. USDI Fish and Wildl. Serv., Anchorage.

Whitten, K.R., F.J. Mauer, and G.W. Garner. 1988. Calf mortality in the Porcupine Caribou Herd (Abstract). Page 88 *in* R.D. Cameron and J.L. Davis, eds. Reproduction and calf survival. Proc. 3rd N. Am. caribou workshop, Chena Hot Springs, AK., 4–6 November 1987. Alaska Dep. Fish Game Wildl. Tech. Bull. No. 8. 229 pp.

Whitten, K.R., G.W. Garner, F.J. Mauer, and R.B. Harris. 1992b (in press). Productivity and early calf survival in the Porcupine caribou herd. J. Wild. Manage., 56.

Whitten, K.R., T.J. Roffe, R.B. Harris, and S.G. Fancy. 1989. Effects of potential displacement of caribou from the 1002 Area on mortality rates of calves. Pp. 12–24 *in* T.R. McCabe, ed. Terrestrial research: 1002 Area—Arctic National Wildlife Refuge, Ann. Progr. Rep., 1988. U.S. Fish Wildl. Serv., Anchorage, AK. 168 pp.

Wildlife Management Institute (WMI). 1991. Review of North Slope Alaska caribou research. Rep. to the Alaska Dep. Fish Game. Wildlife Management Institute, Washington, DC. 51 pp.

Wright, J.M. 1980. Spring and summer vegetation preferences of semi–domestic reindeer on the northwest Seward Peninsula. Pp. 167–173 *in* E. Reimers, E. Gaare, and S. Skjenneberg, eds. Proc. 2nd Int. Reindeer/caribou symp, Røros Norway. Direktoratet for vilt og ferskvannsfisk, Trondheim.

Young, D.D., G.W. Garner, R.E. Ambrose, H.V. Reynolds, and T.R. McCabe. 1990. Differential impacts of predators (brown bears, wolves, golden eagles) on caribou calving in the 1002 Area and potential displacement risks: an assessment of predation risks. Pp. 20–32 *in* T.R. McCabe, ed. Terrestrial research: 1002 Area—Arctic National Wildlife Refuge, Ann. Progr. Rep., 1988. U.S. Fish Wildl. Serv., Anchorage, AK. 168 pp.

Zar, J.H. 1984. Biostatistical analysis. Prentice Hall, Inc. Englewood, NJ. 718 pp.

Zigunov, P.S., ed. 1961. Reindeer husbandry. (English translation [1968] from Russian.) U.S. Dep. Commerce. 348 pp.

APPENDIX B

DEFINITION OF TERMS

Barrier	– An obstruction which cannot or will not be negotiated.
Crossing	– An event in which one or more caribou moves across a road or pipeline(s) or a corridor comprised of road and pipeline(s).
Crossing structure	– A structure designed or modified in order to facilitate crossings as a mitigation measure.
Displacement	– Deviation from normal distribution. Characterized by reduced occupancy (density).
Disturbance	– A stimulus which causes, or a state characterized by, deviation from normal patterns of behavior, activity, and/or distribution of a species.
Effect	– The full range of direct and indirect consequences of environmental change.
Group	– Variable definition, see Appendix A, p. 13 *et seq.*
Habituation	– The waning of an animal's response as a result of repeated stimuli or constant stimulation.
Harassment	– An adverse stimulus that is intentional, persistent, and/or repetitive.
Learning	– Long–term changes in likelihood of a particular response due to successive associations of a stimulus and response.
Maternal group	– See discussion on Appendix A, p. 13 *et seq.*
Maternal caribou cow	– A female accompanied by her offspring of the year.
Mitigation	– Actions to avoid, minimize, rectify, reduce or compensate for impacts on natural resources.

Motivation – Nonstructural (physiological) changes in an animal that cause it to direct its activities toward a specific goal, to change the intensity or patterning of responses or to switch from one activity to another (Based on Colgan 1989:1, 3).

Neonate – Newly born; generally less than a week old.

Null hypothesis (H_0) – The hypothesis of equality or no change. That is, that two populations are the same with respect to some parameter or attribute. In our context, null hypotheses are either those of no effect of some treatment (or stimulus) on the behavior or distribution of a population or of no change in such an effect as a result of a mitigation measure.

Obstruction – A naturally occurring or man-made physical feature which causes a delay in, or deviation from, the normal progress of movement.

Perinatal – Immediately before, during, or soon after parturition.

Sensitivity – Responsiveness to a given stimulus or combination of stimuli; not necessarily harmful.

Sensitization – An increase in the magnitude of response as a result of repeated stimuli. The opposite of habituation, that is, the increasing of response level with repeated exposure.

Stimulus – An environmental variable (or event) that provokes a response from an animal.

Type I error – A conclusion that the null hypothesis is false (rejected) when in fact it is true. Type I error level (the probability that a Type I error is being committed) is indicated by the symbol α.

Type II error – A conclusion that the null hypothesis is true when in fact it is not true. Type II error level (the probability that a Type II error is being committed) is indicated by the symbol β.

Literature Cited

Colgan, P. 1989. Animal motivation. Chapman and Hall, London. 159 pp.