CARIBOU MITIGATION MONITORING FOR THE MELTWATER PROJECT, 2001

FIRST ANNUAL REPORT

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EXECUTIVE SUMMARY

- The 10.1-mile (16.3-km) gravel access road to the Meltwater Project site (Kuparuk Drill Site 2P) was constructed during the winter of 2000–2001. The Meltwater road is located on the western periphery of the concentrated calving area used since at least 1993 by the western segment of the Central Arctic Herd of caribou.
- Several mitigation measures — most notably convoying of traffic during and immediately after the caribou calving period (25 May–30 June) and elevation of project pipelines to a minimum height of 7 feet (2.1 m) above ground level — were instituted in the project mitigation plan to minimize the local displacement of caribou near the road during calving and the potential for disruption of caribou movement patterns to preferred insect-relief habitat and to traditional subsistence harvest areas.
- Spring migration of caribou into the study area occurred later than usual in 2001, presumably due to the cold spring and late snowmelt.
- Because of rapid deterioration of the Meltwater road during the spring thaw, all traffic except maintenance crews was halted before large numbers of caribou migrated into the study area. Convoys operated from 25 May to 4 June, when all traffic was halted, and corrective road maintenance work was conducted during 5–8 June. The road remained closed after that point, making it difficult to assess the effectiveness of vehicle convoying at minimizing caribou displacement. However, data from 2001 will provide a useful comparison for future years, as an evaluation of a gravel road without traffic in a caribou calving area.
- The regional distribution of caribou during calving was similar to previous years of late snowmelt. Consistent with the pattern seen since the early 1990s, the highest densities of caribou occurred east of the study area and south of the Kuparuk Oilfield.
- Caribou were most numerous east of the Tarn and Meltwater roads during calving. In late June, caribou with calves formed large nursery bands in the northeast corner of the study area.
- During the insect season, caribou traveled to insect-relief habitat near and along the coast when mosquito harassment occurred and returned inland when mosquito levels abated. Large numbers of caribou occurred in the study area in the upper Miluveach and Kachemach river drainages in times of low mosquito activity. We found no indications of caribou displacement or blocked movements due to the Meltwater Project during the insect season.
- Following a period of extended insect harassment and westerly winds in the third week of July, most of the western segment of the Central Arctic Herd traveled west onto the Colville River delta, with many subsequently continuing west into NPRA.
- Caribou density in the study area was low during late summer and fall (August–October).
- Caribou selected areas with more moist sedge/shrub tundra and less shallow water/fresh sedge marsh and wet sedge/willow meadow (lowlands) than was available, but vegetation type was not a strong predictor of caribou distribution during calving and post-calving.
- We found no evidence that caribou selected for rugged terrain within the study area.
- Based on the Normalized Difference Vegetation Index (NDVI), caribou appeared to select areas with newly emergent vegetation during calving. NDVI is influenced by differences in standing water, habitat type, and timing of snowmelt, however, making interpretation of NDVI values difficult.
- Caribou densities during annual regional calving surveys were lower near the Tarn road in the 4 years after construction (1998–2001) than in 4 years prior to construction (1993, 1995–1997) of the road, although 3 of the last 4 years were years of late snowmelt. Few calves were observed within 2 km of the Tarn road during calving.
- Densities of caribou were low near the Meltwater road during the 2001 calving

season. Despite the very low levels of traffic, there was some indication of displacement of calving caribou within 2 km of the road.

- Future research will continue to focus on the effectiveness of mitigation measures along the Meltwater road, evaluating the importance of various habitat factors to the annual calving distribution and the responses of caribou to traffic convoying.

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ACKNOWLEDGMENTS

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INTRODUCTION

PROJECT DESCRIPTION

The Meltwater Project consists of a new petroleum drill site (DS-2P) with an associated gravel access road, elevated pipeline, fiberoptic cable, and powerline, all constructed during the winter of 2000–2001. The project is located in northern Alaska in the southwestern corner of the Kuparuk Oilfield (Greater Kuparuk Area, or GKA), south of DS-2N, the southernmost drill site constructed for the Tarn Project in winter 1997–1998. Details of the project proposal were provided by ConocoPhillips Alaska, Inc. (formerly PHILLIPS Alaska, Inc.) in permit application materials submitted for agency and public comments in August 2000, and as modified through subsequent review and discussions.

The project includes the following components:

- A single drill site (4.25 hectares, or 10.5 acres);
- A 16.3-km (10.1-mile) gravel access road extending south from DS-2N to DS-2P;
- Three adjacent pipelines elevated to a minimum height of 2.13 m (7 feet) above the ground surface and constructed on a single set of vertical support members (VSMs), running generally parallel to the road at an average distance of 616 ft (188 m; range 515–845 feet, or 157–257 m), to transport water, miscible injectant, and produced fluids between DS-2P and Central Processing Facility 2 (CPF-2);
- An above-ground powerline from DS-2N to DS-2P;
- A fiber-optic cable and communications tower; and
- A new gravel mine site (Mine Site S), located 3.7 km (2.3 miles) southeast of DS-2P.

During the permitting process for construction of the Meltwater Project, concerns were voiced by state and federal regulatory agencies (the Alaska Department of Fish and Game [ADFG] and the U.S. Fish and Wildlife Service [USFWS]) and local residents of Nuiqsut about the potential effects of the project on the distribution and movements of caribou of the Central Arctic Herd (CAH), which occurs in the study area. In response to these concerns, a mitigation plan was developed to reduce the potential impacts of the project on caribou, and this study was designed to evaluate the effectiveness of the mitigation plan.

ISSUES OF CONCERN

CALVING SEASON

During the calving season (late May to mid-June) and immediately thereafter, the primary development issue is potential displacement of maternal caribou from calving areas because of behavioral disturbance by human activities or physical barriers to movement. Energetic stress resulting from decreased quality or quantity of forage intake and greater exposure to predation is the major potential consequence of displacement from preferred habitats. Post-parturient females are sensitive to disturbance and avoid roads and gravel pads with human activity for up to 2–3 weeks after birth, within a zone of localized displacement that ranges from 1 km to 4–6 km (Dau and Cameron 1986, Lawhead 1988, Cameron et al. 1992, Cronin et al. 1994). Some researchers (Cameron and Ver Hoef 1996, Wolfe 2000) have suggested that this localized avoidance has translated into regional displacement from preferred calving areas, with potentially negative consequences for the herd, although to date no negative population-level effects have been documented.

INSECT SEASON

The ability of caribou to move unimpeded from the calving grounds north to insect-relief habitat at or near the coast is important. During mid- to late summer (late June to mid-August), access to insect-relief habitat is the primary issue of concern. Harassment by mosquitoes and oestrid flies are the dominant forces influencing caribou movements during this period, with caribou moving repeatedly between inland foraging areas and coastal insect-relief areas (White et al. 1975, Lawhead and Curatolo 1984, Smith 1996, Murphy and Lawhead 2000). These oscillatory movements are most pronounced during the period when mosquitoes are most active (late June–late July).

Energetic stress resulting from increased time spent under insect harassment, increased movements, and corresponding decreases in the quality or quantity of forage intake are the major potential consequences of displacement from preferred habitats in this season (White 1983, Murphy et al. 2000). The condition of female caribou entering autumn has been linked to the likelihood of successful reproduction the following year (Cameron et al. 1993). Murphy et al. (2000) hypothesized that this energetic pathway is the most likely way in which development-related impacts on individual females might be expressed at the population level .

LATE SUMMER AND FALL MIGRATION

Caribou are the most important land mammals harvested for subsistence in northern Alaska. Nuiqsut residents hunt both CAH caribou, which generally range east of the village, and Teshekpuk Herd caribou, which typically range west of the village in the National Petroleum Reserve–Alaska (NPRA). Telemetry data indicate that caribou of the CAH begin dispersing inland to the south by late July or August (Lawhead 1988) and Teshekpuk Herd caribou disperse to the south in fall as well (Prichard et al. 2001). The harvest of caribou by local residents of Nuiqsut reaches annual peaks in late summer and fall (July–October; Pedersen 1995, Brower and Opie 1997, Fuller and George 1997). At that time, local hunters expect CAH caribou to approach Nuiqsut and the Colville River delta from the east and become available for harvest in traditional subsistence hunting areas at various locations along the Colville River. In public meetings before the Meltwater Project was built, Nuiqsut residents reported that caribou had not been available for harvest at times and in places where they were expected in the late 1990s, and residents were concerned about the potential for elevated pipelines to deflect caribou movements away from traditional hunting areas. Caribou movements during the summer insect season are influenced strongly by temperature and wind direction (White et al. 1975, Roby 1978, Lawhead and Curatolo 1984), resulting in large stochastic variation in movement patterns, so the low availability of caribou in the late 1990s may have resulted from such variation. To address the concerns of Nuiqsut, the North Slope Borough added stipulations to the Meltwater permit requiring PAI to study the migratory movements of caribou in the Meltwater area, in an attempt to determine if reported changes in CAH movement patterns are influenced by pipeline placement as well as weather patterns.

MITIGATION PLAN ELEMENTS

TRAFFIC CONVOYING DURING CALVING SEASON

Access to the Meltwater road was regulated by means of a locked gate at the western edge of DS-2N. In accordance with the Meltwater Caribou Mitigation Plan, traffic access was restricted during the 5-week period from 25 May to 30 June (designated broadly in the mitigation plan as the caribou calving "window"). During this period, the gate was locked and vehicles were allowed to drive on the road only when escorted by a pilot vehicle during a scheduled convoy (with allowances for emergency situations). Traffic was restricted to four routine convoy round trips (CRT) every 24 hours and two special crew changeout CRTs per week from 25 May to 30 June during the 2001 caribou calving season (Table 1).

Convoy travel was intended to be used for all work activities and travel to and from DS-2P during the period of 25 May–30 June each year. The restricted travel corridor consisted of the entire 16-km road south of DS-2N to DS-2P (Meltwater). In the event that future developments are constructed in the area, the convoying requirement will apply to all traffic using the DS-2P access road.

The period of 15–25 May was considered a "shoulder season" in which traffic restrictions began to be implemented to decrease disturbance as caribou moved into and through the project area en route to calving locations farther north. Traffic speeds were reduced to 25–30 mph; material was stockpiled on the DS-2P gravel pad to avoid a flurry of traffic activity right before convoying began on 25 May; and all foot traffic was eliminated. Routine late-winter removal of snow and ice from cross-drainage structures occurred during this period, and was completed before traffic convoying began on 25 May.

Table 1. Scheduled convoy times between DS-2N and DS-2P, 25 May–4 June 2001.

Convoy Number	Leave DS-2N	Travel Time	Arrive DS-2P	Time at DS-2P	Leave DS-2P	Travel Time	Arrive DS-2N	Comments
1	1:00 AM	0:30	1:30 AM	1:30	3:00 AM	0:30	3:30 AM	Daily – general traffic
2	7:00 AM	0:30	7:30 AM	3:00	10:30 AM	0:30	11:00 AM	Daily – general traffic
Crew change	1:00 PM	0:30	1:30 PM	1:30	3:00 PM	0:30	3:30 PM	Twice per week
3	1:00 PM	2:00	3:00 PM	0:30	3:30 PM	2:00	5:30 PM	Daily gravel maintenance
4	7:00 PM	0:30	7:30 PM	2:30	10:00 PM	0:30	10:30 PM	Daily – general traffic

INSECT SEASON AND LATE SUMMER–FALL

The mitigation measures implemented to accommodate caribou movements during the insect season (late June to mid-August) primarily consisted of design elements of the pipeline and road corridor. These mitigation measures also applied to the late summer and fall migration period.

Specific mitigation measures for the Meltwater project included the following, based on research conducted in the North Slope oilfields since the early 1980s (summarized by Cronin et al. 1994):

- Pipelines were constructed at a minimum height of 7 feet (~2.1 m) above ground level, measured at the VSM), and occasionally higher, such as in variable terrain (e.g., riparian crossings).
- Oscillation dampeners (Tuned Vibration Absorbers, or TVA) were the "potato-masher" style rather than the hanging-ball style; the minimum ground clearance for the TVAs (at the bottom of their range of motion) is 5 feet (~1.5 m) minimum.
- The elevated pipeline was separated from the Meltwater road by several hundred feet (mean distance 616 feet, or 188 m) over as much of its length as possible.
- Drivers were informed of the proper conduct for responding to caribou groups near the road, such as stopping completely when caribou are crossing or attempting to cross the road (and recognizing when caribou are not trying to cross); remaining inside vehicles and avoiding loud noises when caribou were nearby; and recognizing seasonal differences in caribou behavior and responses to human activities and infrastructure.

PLAN GOALS

The primary goals of the mitigation plan are to minimize the impacts on caribou associated with the Meltwater Project and all other future projects in the area and to design a study to evaluate the effectiveness of the mitigation plan. The intent is to minimize potentially negative impacts by controlling the variables known or suspected to have affected caribou in other areas, and then to measure any remaining impacts of the activities regulated under the plan.

The mitigation plan has two specific objectives:

- Minimize disturbance of caribou (especially maternal females), including behavioral disturbance and resulting displacement from preferred habitats, which may negatively affect energy assimilation or expenditure, potentially leading to decreased productivity, either on an individual or population level.
- Minimize disruption, delay, and deflection of caribou movements during the calving and insect seasons and seasonal migrations (particularly in late summer and fall) through the Meltwater project area.

The study was designed to evaluate the effectiveness of convoying as a mitigation technique during and immediately after the calving period. If convoying is successful, then the displacement of maternal caribou from the vicinity of the road should be minimal and lower than the displacement observed along the Tarn road, which has unregulated traffic. Because the study area is on the periphery of the area of most concentrated calving, a natural density gradient is expected to occur through the study area, with fewer caribou on the west side and more caribou on the east side. Factors associated with calving habitat quality such as vegetation type, terrain ruggedness, and vegetation quantity and quality (as measured by the Normalized Difference Vegetation Index [NDVI]) were assessed. The caribou densities observed in each year of study will be compared with these habitat values as well as with the densities observed in previous years. Movement patterns were recorded during the insect season and distribution patterns were recorded from August to October to assess the impact of development on movement to and from insect-relief habitat. This distributional information can be used to assess potential effects of the Meltwater road on accessibility of caribou to subsistence hunters.

STUDY AREA

The study was conducted in northern Alaska between the Kuparuk and Colville Rivers and near the Beaufort Sea coast, within the calving grounds of the Central Arctic Herd and in the southwestern portion of the Greater Kuparuk Area. The landscape in the region slopes gently from upland, moist tussock tundra in the upper reaches of the Sakonowyak, Ugnuravik, Kalubik, Miluveach, and Kachemach drainages, down to moist and wet coastal tundra communities near the coast. The study area is characterized by permafrost-related features such as oriented thaw-lakes, beaded streams, and pingos. The physiography, vegetation, and climate of the central Arctic Coastal Plain have been described by Walker et al. (1980).

The Meltwater study area was subdivided into three contiguous survey blocks: the Meltwater block, located around the Meltwater road (DS-2N to DS-2P; constructed in winter 2000–2001), the Tarn block, located along the Tarn Road (DS-2L to DS-2N; constructed in winter 1997–1998), and the Reference block, an undeveloped area south of DS-2P. In addition, we outlined an area east of the Meltwater road (Eastern area) that was included in some analyses because it encompasses an area of concentrated calving activity used in recent years and presumably contains high-quality calving habitat (Figure 1). The upper Miluveach and Kachemach rivers flow through the study area. In general, the Reference block is higher in elevation and has more hills and fewer lakes than the Tarn block. The Reference block was shifted several kilometers east relative to the other two blocks to reduce habitat differences within the study area resulting from the bluffs and lowlands along the Itkillik River.

The Meltwater Project was constructed on the periphery of an area that has been used by caribou of the western segment of the Central Arctic Herd (CAH) during the calving season from the late 1980s to the present. Although the most concentrated calving activity has occurred east of the Meltwater Project area (Lawhead et al. 1994, 1997, 1998; Smith et al. 1994, Johnson et al. 1996; Lawhead 1999; Lawhead and Johnson 2000; Lawhead and Prichard 2001, 2002), relatively high densities of calving caribou occasionally occur in the study area, primarily in years of delayed snowmelt when calving occurs farther inland than in years of early melt (Lawhead and Prichard 2001, 2002).

After calving, caribou remain in the general area until mosquitoes emerge, which has occurred between June 20 and June 30 in recent years. During periods of insect harassment in late June and July, caribou move north out of the Meltwater area, returning only when insect activity is suppressed by cool, windy weather conditions (Burgess et al. 2000; Lawhead and Prichard 2001, 2002). In most years, variation in weather conditions between warm, calm periods and cool, windy periods keeps caribou north of the Meltwater Project area; 2000 and 2001 were unusual in this regard, with a fair amount of caribou activity in the Meltwater Project area in July (Lawhead and Prichard 2001, 2002).

Inland dispersal of caribou into and south of the Meltwater Project area begins to occur by August, and caribou may be found in the area in small numbers through the period of fall migration in September and into the rut in October. Late

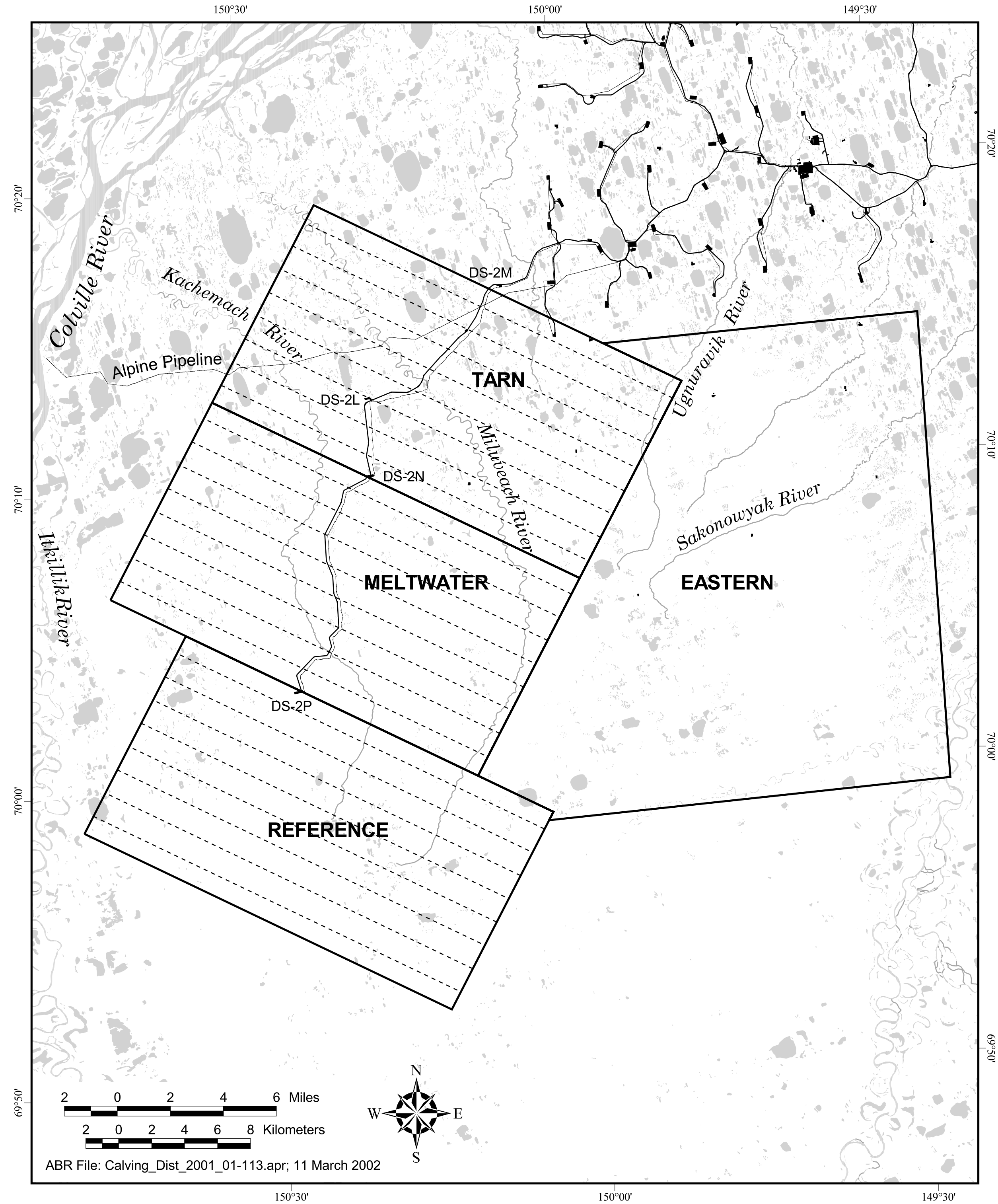


Figure 1. Meltwater study area (Tarn, Meltwater, and Reference survey blocks) and the adjacent Eastern area of concentrated calving, southwestern Kuparuk Oilfield, Arctic Coastal Plain, Alaska.

summer and fall migratory movements reported by Nuiqsut residents indicate that caribou also cross the study area when moving west toward the Colville River and Nuiqsut. Although winter surveys of the Meltwater area have not been conducted, surveys of radio-collared caribou by ADFG indicate that few CAH caribou remain on the Arctic Coastal Plain in the winter months (Lenart 1999).

METHODS

CONVOY AND ROAD SURVEYS

The Meltwater Road (DS-2N to DS-2P) was open to unregulated traffic until 25 May 2001, when traffic convoys were implemented. All traffic was required to travel by convoy and at reduced speeds of 25–30 mph (40–50 km/h) from 25 May through 4 June; the road was closed on the latter date because of deterioration from the high water content in the road-bed material. From 5 to 8 June, maintenance crews worked on the road continuously, and then the road was closed to all traffic. Maintenance crews worked on the road occasionally during scheduled convoy times between 9 June and the end of the convoy period on 30 June and throughout most of July and August after traffic restrictions were lifted.

ABR observers began caribou observations along the Meltwater and Tarn (DS-2M to DS-2N) roads on 16 May and continued surveys until convoys began (Table 2). During the period of active convoying, ABR observers rode along on most scheduled convoys and also were present during the period of intensive road maintenance (5–8 June); maintenance personnel also collected a few observations of caribou. Observers recorded the number, location, and behavior of any caribou seen from the Meltwater and Tarn roads. We also sampled traffic rates by tallying the number of vehicles traveling the Tarn or Meltwater roads in half-hour sampling periods. These observations were gathered opportunistically before and after caribou surveys and convoys.

AERIAL SURVEYS

MELTWATER STUDY AREA

Aerial surveys began on 17 May and continued until 28 June. We surveyed systematically spaced strip transects in a 1004-km^2 (388-mi^2) survey area, extending 42 km (26 mi) southwest from DS-2M to 14 km (8.7 mi) beyond DS-2P and 12 km (7.5 mi) to the northwest and southeast of the Tarn and Meltwater roads. These dimensions ensured that the survey area would be substantially wider (at least 12 km on each side of roads) than the maximal displacement distance (6 km) reported from studies in the 1980s along the Milne Point Road (Dau and Cameron 1986, Lawhead 1988, Cameron et al. 1992, Cronin et al. 1994). The study area was subdivided into three 24.5 × 13.6-km (15.2 × 8.5-mi) survey blocks (Tarn block, Meltwater block, Reference block; Figure 1) for survey scheduling and data analyses.

A pilot and two observers in a fixed-wing Cessna 206 followed transect lines oriented across the survey area, roughly perpendicular to the Tarn and Meltwater road and pipeline alignments. A third observer recorded data. Surveys were flown at an altitude of 300 feet (~90 m) above ground level (agl) and an aircraft speed of ~160 km/h. GPS receivers were used to navigate and to record the locations of caribou along transects. Transects were spaced at intervals of 1 mile (1.6 km). The two observers surveyed 400-m (~0.25-mi) wide strips on opposite sides of the aircraft, resulting in ~50% sampling intensity over the three survey blocks. The strip width was delimited visually using tape markers on the struts and windows of the aircraft, following the method of Pennycuick and Western (1972). Tape markers were positioned to indicate strip widths of 200 and 400 m. When a caribou group was observed within the 400-m strip, the location on the transect line was recorded using a GPS receiver, the number of adults and calves was recorded, and the distance was estimated to the nearest 100 m. Eleven surveys were conducted between 17 May and 28 June: four were grouped into the pre-calving period (17, 21, 24, 28 May), three into the calving period (4, 8, 13 June), and the remaining four into the post-calving period (16, 20, 24, 28 June).

The percentage of ground surface covered by snow was estimated visually in the survey area as an index to survey conditions. The patchy visual image of broken snow cover during spring snowmelt drastically reduces an observer's ability to detect caribou. Patchy snow cover is the most important factor diminishing sightability (defined

Table 2. Caribou surveys conducted in the 2001 field season.

Type	Dates	Description
Meltwater & Tarn road surveys	16 May–4 June	Record caribou visible from road (within 1 km)
Meltwater, Tarn, & Reference surveys	17 May–28 June	Aerial strip-transect surveys (1-mi spacing) of three survey blocks composing Meltwater study area
Meltwater road convoy observations	25 May–4 June	Recorded caribou observed from lead convoy vehicle
Early June regional calving survey	5–7 June	Aerial strip-transect survey (1-mi spacing) of Colville East and Kuparuk South calving survey areas (Kuparuk Field not surveyed)
Mid-June regional calving survey	10–12 June	Aerial strip-transect survey (1-mi spacing) of Colville East, Kuparuk South, and Kuparuk Field survey areas
Composition count	14–15 June	Record sex and age composition from helicopter
Insect-season surveys	26 June–27 July	Reconnaissance (non-systematic) helicopter and road surveys to monitor regional movements
Colville East surveys (aerial strip transects)	4 Aug.–26 Oct.	Aerial strip-transect surveys (2-mi spacing) of Colville East survey area

as "the probability that an animal within the observer's field of search will be seen by that observer" [Caughley 1974: 923]) of caribou during the calving season (Lawhead and Cameron 1988). One way to adjust counts made during poor viewing conditions is to estimate sightability using a double-survey technique and then calculate a sightability correction factor (SCF) for post-survey adjustment of counts (Gasaway et al. 1986). In 1993, a SCF (1.88) was calculated for patchy (20–70%) snow cover during calving season surveys in the Colville and Kuparuk survey areas (Smith et al. 1994, Lawhead et al. 1994) and this was used for correction of counts for this project. We extrapolated population estimates for total caribou and for calves from their respective counts and standard errors using formulas modified from Gasaway et al. (1986). To estimate the "observable population" (i.e., the estimated number of caribou in the entire survey area, unadjusted for sightability), counts of total caribou and calves seen on each survey were expanded by the ratio of the entire area within the survey boundaries to the area surveyed within the strip transects.

KUPARUK–COLVILLE REGIONAL CALVING SURVEYS

Regional surveys of caribou distribution and numbers in three calving survey areas (Kuparuk Field, Kuparuk South, Colville East; Figure 2) were conducted during 5–7 and 10–12 June 2001 (Lawhead and Prichard 2002). Caribou were counted by two observers looking on opposite sides of a Cessna 206 airplane using the same methodology as the Meltwater surveys. In each survey area, the pilot navigated along north–south-oriented transect lines using a topographic map and coordinates programmed into a global positioning system (GPS) receiver. The pilot maintained the aircraft speed at ~160 km/h and the altitude at ~90 m above ground level (agl). Transect lines were spaced at intervals of 1.6 km, following section lines on U.S. Geological Survey maps.

To summarize the calving distribution and abundance data for each year of these regional surveys (1993 and 1995–2001), we applied the Inverse Distance-Weighted (IDW) interpolation technique of the *Spatial Analyst* extension of *ArcView* GIS software to the transect data from early (2–7) June and mid- (9–16) June surveys for each year, as well as to the mean value for each transect segment over all years surveyed. This

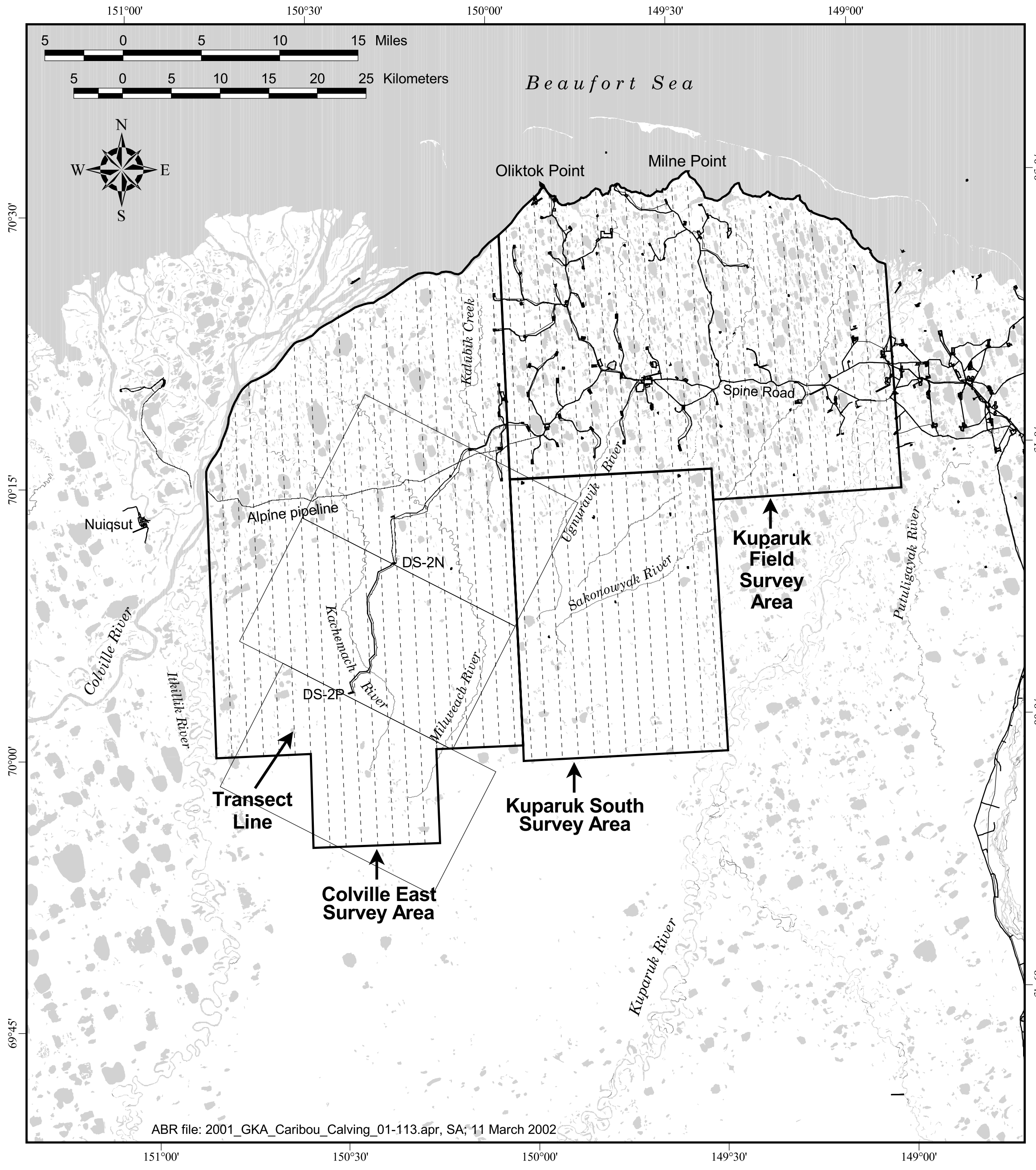


Figure 2. Survey areas and aerial survey transect lines followed in early and mid-June calving surveys of the Kuparuk–Colville region, 2001 (from Lawhead and Prichard 2002).

analysis was conducted on caribou numbers pooled over 3.2-km segments along the length of transects. The IDW interpolator calculated a density surface using each segment centroid and the distance-weighted values for the 14 nearest centroids. This analysis produced color maps showing surface models of the density of all caribou observed (adults + calves) over the entire regional survey area, to create an easily understood visual portrayal of the data. The resulting color map plots are visual depictions of distribution and relative abundance within each year and were not used for statistical analyses.

INSECT-SEASON SURVEYS

We conducted surveys during the insect season (the time of year when mosquitoes and oestrid flies harass caribou) to document the abundance, distribution, and movements of caribou between the east (main) channel of the Colville River and the east side of the Kuparuk River, thus encompassing both the Kuparuk and Milne Point oilfields as well as the Meltwater study area. A single observer was based at the Kuparuk Operations Center (KOC) facility from 26 and 27 June and 2 July through 27 July 2001 (Lawhead and Prichard 2002). Additional observations were provided by researchers surveying other species or working on other projects in the region. Daily observations included weather conditions, levels of insect harassment, and caribou movements, which were monitored primarily by aerial surveys. Supplemental observations from a truck were used to monitor the general movements of caribou in the vicinity of the oilfield road system when the survey helicopter was not available.

Insect-season surveys consisted of nonsystematic reconnaissance flights specifically for caribou, as well as incidental observations during other wildlife surveys (e.g., for fox dens and waterbird broods). The aerial surveys used a helicopter (Bell 206-LIII "Long Ranger") on an opportunistic basis. A broad search path (~2 mi wide) was followed on reconnaissance surveys over larger areas, with the observer using 10×30 image-stabilizing binoculars to scan ahead and to the sides of the aircraft. Survey intensity varied among surveys, depending on the prior distribution and movements of caribou in the study area. This approach allowed us to use limited helicopter time most efficiently to track large-scale movements sequentially on a daily basis, enabling observation of the major patterns of distribution and movements of caribou in the western segment of the CAH during the insect season. We mapped the locations and number of caribou groups and recorded group type (cow/calf-dominated, bull-dominated, mixed). When possible, the age and sex composition of groups (bull, cow, yearling, calf, and unknown) was recorded.

LATE SUMMER–FALL SURVEYS

Aerial strip transect surveys were conducted over the Colville East survey area (Figure 2) described for calving surveys. Surveys followed the same protocol as described previously, but because visibility was generally good with no snow cover or 100% snow cover, surveys were flown at 500 ft (~150 m) agl and observers recorded caribou within 800 m of the airplane. Transects were spaced 2 mi (3.2 km) apart to maintain 50% coverage. Surveys were conducted three times in August, once in September, and twice in October.

VEGETATION MAPPING

Vegetation was mapped by classifying spectral data from satellite imagery. A System Terrain-Corrected Landsat Enhanced Thematic Mapper (ETM+) scene (path 74, row 11; 14 July 2001) was acquired from Radarsat. The registration was refined by *x/y* translation to match previously existing 1:6000-scale base maps of facilities and hydrology for the region (prepared by Aeromap, Anchorage, Alaska). No cloud cover occurred in the study area at the time the image was taken.

We performed an unsupervised classification of the spectral data using ERDAS Imagine software, version 8.5 (ERDAS, Inc., Atlanta, GA). The spectral bands included in the classification were Bands 1, 2, 3, 4, 5, and 7, in 25-m pixels. All classifications were performed to 95% convergence. We evaluated three unsupervised classifications—30, 50, and 75 spectral classes—by comparing the resulting images with the original spectral data and with false color infrared (CIR) (July 1979) and true-color aerial photography (August 2000). After selecting the 30-class image, we assigned preliminary vegetation types to the spectral classes using 141 ground-data points collected between 1996 and 2000 (Anderson et al. 1998, Burgess et al. 2000) and CIR and true-color photography.

Maximum “green-up” of vegetation generally occurs between late July and early August on the central Arctic Coastal Plain. The mid-July satellite scene, coupled with a late start of the growing season in 2001, caused some problems in distinguishing certain land-cover types using the initial unsupervised classification. It was difficult to distinguish marshes from shallow water, lush wet sedge/willow meadow (lowlands) from some low shrub tundra, and some moist sedge/shrub from tussock tundra. To address these problems, we created “areas of interest” (AOIs) on the satellite scene of known vegetation types based on ground data. These AOIs then were used as supervised training areas to reclassify the image. The new classes were compared with ground points and aerial photography and then were merged with existing classes or used to create additional types. This iterative process continued until the best representation of the ground classes and imagery was reached. The final classification comprised the 30 original classes and an additional 13 supervised training signatures. For the final map, 11 vegetation cover classes were assigned to the spectral signatures and the classification was smoothed to eliminate individual pixel classes. No ground data collection was associated with this mapping effort, so an assessment of map accuracy is not available.

The use of vegetation types by caribou was calculated by selecting all pixels within a 50-m radius of the GPS location recorded for each caribou group, thereby adjusting our percentages to incorporate the positional uncertainty in our locations. Because the number of pixels selected varied for each caribou group (minimum = 7, maximum = 14), we calculated the percentage of each of the 11 vegetation types within the selected pixels. We then calculated the average proportion of each vegetation type used for each survey block in each season by taking the average of all average values for each group within a given study area and season.

We compared vegetation types used by caribou groups among seasons using a chi-square test (Agresti 1990). We also compared the vegetation types used by caribou (based on mapped locations from surveys) to those available (determined from the vegetation map) using a chi-square goodness-of-fit test (Neu et al. 1974, Byers et al. 1984). If significant differences were found, we then compared individual vegetation types using Bonferroni multiple comparison tests (Neu et al. 1974, Byers et al. 1984). Because caribou locations were assigned to the midpoints of 100-m distance zones in the transect strip, we calculated the proportion of vegetation used based on circles with a 50-m radius centered on each caribou group location. Because no caribou were observed within 50 m of fresh grass marsh and the expected values were low for water and snow, those types were not included in the analysis.

In addition, the 800-m-wide survey strips on each transect line were subdivided into 12 quadrats, each 2 km long (~1.6 km^2), for a total of 288 quadrats in all three survey blocks combined. We used linear regression to compare the percentage of moist sedge/shrub tundra with mean caribou densities in each time period. Caribou densities were square-root-transformed to meet the normality assumptions of regression before proceeding with this analysis.

TERRAIN RUGGEDNESS

Terrain ruggedness was calculated using program TERRAIN (written by J. Greslin), the same program used by Wolfe (2000) and Kelleyhouse (2001). This program calculates the terrain ruggedness at a given location using a digital elevation model with 30-m-pixel resolution. A pre-specified number of pixels are identified (according to the scale selected by the user) in both directions parallel to the aspect of the starting pixel. The sum of absolute elevation changes (SEC) and the number of changes in direction of the slope (SDC) were calculated and the Digital Terrain Ruggedness Index (DTRI) was calculated as

$$(SEC \times SDC) \div (SEC + SDC)$$

after Wolfe (2000). Wolfe (2000) concluded that this index is highly correlated with the Terrain Ruggedness Index used previously in the region by Nellemann and Thomsen (1994), which was based on topographic map measurements made by hand.

DTRI was calculated at each location where caribou were observed and at random locations in each of the three survey blocks. A total of 1000 random locations were selected within 400 m of flight lines in each of the three survey blocks and 2000 random locations were selected in the larger eastern area where most concentrated calving activity occurred.

Tests for differences in DTRI calculated for 2-km transects in these four areas (Tarn, Meltwater, and Reference blocks and the Eastern concentration area) were conducted using analysis of variance (ANOVA) of square-root-transformed values calculated at random points. Individual area means were compared using Tukey's HSD multiple comparisons test (Zar 1984).

The use of rugged terrain by caribou versus its availability was tested statistically using Monte Carlo simulations (Manly 1997). For each combination of area and season, a number of random points equal to the number of caribou observed was selected with replacement from 1000 random points generated within each survey block. The mean of the new data set was calculated and a new sample was generated. This process was repeated 2000 times to generate 2000 mean values. If the observed mean calculated from caribou locations was more extreme than 5% of randomly generated means, then use was considered to be significantly different from availability at $P = 0.05$. A similar process was used to compare use of all three survey blocks combined, using all 3000 random points.

In addition, the 800-m-wide survey transect strips were split into 2-km-long quadrats (~1.6 km^2), giving a total of 96 quadrats in each survey block. The terrain ruggedness of each quadrat was calculated by calculating DTRI for 2-km transects at the centroid of each quadrat. DTRI also was calculated at points 100 m to the east, west, north, and south of each centroid. The maximum DTRI value from these five points was used as the measure of terrain ruggedness for that centroid. We used linear regression to compare the maximum DTRI to mean caribou densities for each season. Caribou densities were square root transformed to meet the normality assumptions of regression.

VEGETATIVE BIOMASS (NDVI)

The Normalized Difference Vegetation Index (NDVI) was calculated using images obtained from the Advanced Very High Resolution Radiometers (AVHRR) onboard the National Oceanic and Atmospheric Administration (NOAA-16) polar-orbiting satellite. NDVI values represent a measure of the vegetative biomass within a pixel at the time the image was taken. The rate of increase in NDVI between two images taken on different days during green-up has been considered to represent the amount of new growth occurring in that pixel over that time frame (Wolfe 2000, Kelleyhouse 2001). AVHRR images were obtained for 11, 19, and 24 June 2001; these dates were selected because of the low occurrence of obscuring cloud cover. NDVI was calculated as:

$$NDVI = (NIR–VIS) \div (NIR + VIS)$$

where NIR = near-infrared reflectance (0.725–1.10 µm wavelength) and VIS = visible light reflectance (0.58–0.68 µm wavelength) (Rouse et al. 1973). NDVI was calculated for each pixel (1 km^2). All negative values were set to zero and then a smoothing process was applied to account for potential errors in image registration. All pixel values were recalculated as the mean of that pixel value and the values for the surrounding 8 pixels. No correction for the effect of large waterbodies on NDVI was applied due to the lack of an accepted method. Wolfe (2000) applied a water correction that was rejected by Kelleyhouse (2001). More attention will be devoted to this important topic in future analyses, but it was omitted from this first year of analysis.

NDVI was first calculated for each pixel using the image taken on 11 June 2001 (NDVI611). To compare with previous studies (Wolfe 2000, Kelleyhouse 2001), we estimated the NDVI values on 21 June. The value for each pixel was calculated as the NDVI value on 19 June plus 2/5 of the increase in NDVI between 19 and 24 June. For some pixels, NDVI values were lower on 24 June than 19 June; because it is unlikely that the actual biomass levels decreased over that period, we used the maximum of the values from 19 June and the estimated value on 21 June as our estimate of NDVI on 21 June (NDVI621). We also calculated the daily rate of change of NDVI (NDVIrate) between 11 June and 21 June by subtracting NDVI611 from NDVI621 and dividing by the number of days (10).

Tests for differences in NDVI611, NDVI621, and NDVIrate among the four areas (Tarn, Meltwater, and Reference survey blocks and the Eastern concentration area) were conducted using ANOVA. Individual area means were compared using Tukey's HSD multiple comparisons tests (Zar 1984).

The use of high-NDVI areas by caribou was compared statistically with their availability using Monte Carlo simulations. For each combination of area and season, a number of NDVI values equal to the number of caribou observed was selected with replacement from all available pixels within 400 m of survey transects (the surveyed area) within each survey block. The mean of the new data set was calculated and a new sample was generated. This process was repeated 2000 times to generate 2000 mean values. If the observed mean calculated from caribou locations was more extreme than 5% of randomly generated means, then use was considered to be significantly different from availability at $P = 0.05$. A similar process was used to compare use of all three survey blocks combined. These tests were conducted for caribou distributions during three time periods (prior to 11 June, between 11 June and 21 June, after 21 June), which were chosen to correspond to the dates for which biomass was estimated.

We calculated the value of NDVI611, NDVI621, and NDVIrate for each of 288 quadrats (2 × 0.8-km grid cells) along aerial survey transect lines by subdividing each pixel into 100 100 × 100-m pixels having the same NDVI values. The mean NDVI value of 100 × 100 m pixels completely or partially within each grid cell was calculated. We used linear regression to compare NDVI 611, NDVIrate, and NDVI621 with the mean caribou density for each period. A square-root transformation was applied to the caribou densities to meet the normality assumptions of regression.

DISTANCE TO ROAD

TARN ROAD COMPARISON, 1993–2001

Calving surveys of the Kuparuk–Colville region were conducted as described above in mid–June of 1993 and 1995–2001. Because surveys were conducted 4 years before construction of the Tarn Road (1993 and 1995–1997) and 4 years after construction (1998–2001), we used these data within our Tarn survey block to examine potential changes in caribou distribution after construction of the Tarn road.

For each 3.2 × 0.8-km segment (quadrat) of the strip transects used in regional calving surveys in preceding years, we calculated the annual calf density and total density as well as the distance of the quadrat centroid from the Tarn road. Densities were adjusted using a sightability correction factor (SCF) in years of patchy snow cover (1997 and 2000). We used an ANOVA model to compare caribou densities in each 3.2 × 0.8-km quadrat by five distance-to-road categories (>6 km west, 2–6 km west, 2 km west–2 km east, 2–6 km east, and >6 km east), pre- or post-construction, and an interaction term to account for potential differences in changes between pre-and post-construction for different distance categories. A square-root transformation was applied to the densities to better meet the assumptions of normality. We also plotted mean calf densities (determined from the IDW surface model) versus distance to road for each year.

Because caribou densities in the quadrats often were low or zero, we also compared the proportion of quadrats with caribou present to the number without caribou and calves present pre- and post-construction for each of the five distance to road categories using a Fisher's Exact Test (Agresti 1990) and a Bonferroni adjustment for multiple comparisons.

TARN AND MELTWATER ROADS, 2001

Using *ArcView GIS 3.2a* GIS software, we divided the three survey blocks into different areas based on distance to the nearest road. For each area, we calculated the average density and number of groups of caribou during each period. In addition, we calculated the mean DTRI of all the previously selected random points falling within that segment. We also used the IDW maps created for the mean density of caribou during mid July surveys conducted 1993 and 1995–2000 to calculate a mean density for each segment over that time period.

We used chi-square tests to compare the number of caribou groups, the number of groups with calves, and the number of groups without calves in five distance categories (>6 km west, 2–6 km west, 2 km west to 2 km east, 2–6 km east, >6 km east) with expected numbers of groups based on the area (in km^2) in each distance category. Separate tests were conducted for Meltwater and Tarn in each period. Each distance category was tested for significance using Bonferroni Multiple Comparison tests (Neu et al. 1974, Byers et al. 1984).

We then used the data for the 2 × 0.8-km quadrats previously described to analyze caribou distribution by distance from roads. For each of the 192 quadrats in the Tarn and Meltwater blocks, we calculated the maximum DTRI, the percentage of moist sedge/shrub tundra, the NDVIrate, and the distance of the quadrat centroid to the nearest road. We then used a Generalized Linear Model (GLM) to compare the mean quadrat density over five distance-to-road categories (>6 km west, 2–6 km west, 2 km west to 2 km east, 2–6 km east, >6 km east) for each survey block (Meltwater or Tarn; the Reference block was not included) with the percentage of moist sedge/shrub tundra, NDVIrate, and maximum DTRI as covariates. Square-root transformation was applied to the mean density values to better meet the normality assumptions of GLM.

RESULTS

HABITAT AND SURVEY CONDITIONS

Snowmelt in the Kuparuk–Colville region was delayed in 2001. The mean daily temperature was below average in May but higher than average in early June (Appendix A). Despite the early June warming trend, snow cover did not disappear completely until mid-June, similar to the other late springs of 1997, 1999, and 2000, and the average daily temperature remained below freezing in May and early June (Appendix A). In years of early snowmelt, such as 1996 and 1998, snow cover disappeared by the end of May, and even in years of intermediate snow melt, snow cover typically is gone by the time of the mid-June calving surveys.

Survey conditions were generally good during periods when snow cover was either nearly complete or very low. During the period of rapid snowmelt sightability of caribou was greatly depressed due to the interspersed patches of snow and ground. Snow cover was high during May surveys and low by 13 June. Sightability was low due to patchy snow cover during the aerial survey on 4 June and was somewhat higher on 8 June.

CONVOY TIMES AND ROAD CLOSURE

Initial convoys followed the schedule closely, but as temperatures increased and the condition of the road deteriorated, convoys took longer to reach their destination (Table 3). The average convoy size was ~9 vehicles. The average convoy time was 27 minutes prior to 30 May and 96 minutes after the road condition deteriorated as thaw progressed in early June. Convoy restrictions were effective at reducing both the overall volume of traffic and the number of potential disturbance events per day (Figure 3).

The Tarn road remained open throughout the study period and was not restricted to convoying. However, because much of the traffic between DS-2L and DS-2N continued on to DS-2P, the traffic patterns and volume on the Tarn road changed due to convoying and closure of the Meltwater road (Figure 3). Traffic on the Tarn road appeared to be heaviest prior to departure and after return of Meltwater convoys. Thus, although no traffic mitigation was in place specifically for the Tarn road, convoying and closure of the Meltwater road probably decreased the potential for disturbance of caribou by traffic along the Tarn road as well.

CONVOY AND ROAD SURVEYS

No caribou were observed along the Tarn or Meltwater roads before 25 May 2001 when convoying of vehicles began. From 25 May to 4 June, only two groups of caribou were seen along the Tarn road during 9 road surveys and all trips to DS-2N for convoy observations (Table 4). Only three groups were seen along the Meltwater road during the convoys. Two additional groups of seven and four caribou were seen approximately 4 km to the southwest of DS-2P on 29 May. These low numbers were consistent with the results of the aerial surveys, which showed few caribou in the Meltwater and Tarn blocks on the 4 June survey

Table 3. Number, size, and duration of convoys between DS-2N and DS-2P, 25 May–4 June 2001.

Date	No. of Convoys	No. of Vehicles				Average Duration (minutes)
		Total	Average	Minimum	Maximum	
May 25	8	54	6.8	3	13	28
May 26	8	72	9	4	15	25
May 27	8	63	7.9	3	12	28
May 28	8	63	7.9	2	11	26
May 29	8	57	7.1	4	11	29
May 30	8	45	5.6	1	10	64
May 31	8	80	10	4	15	114
June 1	8	72	9	5	15	108
June 2	8	64	8	4	13	103
June 3	6	54	9	5	16	84
June 4	2	29	14.5	10	19	100
Total	80	653	8.2	1	19	58

and a large increase in the number of caribou in the area by 8 June.

AERIAL SURVEYS

MELTWATER STUDY AREA

Few caribou were observed in the study area during May (Figure 4, Tables 5–6; mean density = 0.055 caribou/km^2, min. = 0.038, max. = 0.087). It is likely that those groups observed stayed in the general area and were seen on consecutive surveys. No calves were observed until 8 June. Reconnaissance surveys flown as far south as the northern foothills of the Brooks Range between 18 May and 1 June revealed that few caribou were present on the coastal plain during that period. Snow cover in the study area was 100% during the May surveys. By the first survey during the calving period on 4 June, snowmelt had progressed so that snow cover was very patchy, making sightability difficult.

Large numbers of caribou and newborn calves were first observed during the survey on 8 June when a total of 203 adults and 22 calves were counted. After adjusting for 50% survey coverage, we estimated that 450 caribou were in the study area. The maximum number of caribou was an estimated 2954 observed on 24 June, for a density of 3.14 caribou/km^2 over all three survey blocks combined and 7.70 caribou/km^2 in the Tarn block (Table 6).

As expected from previous studies (Lawhead et al. 1994, Smith et al. 1994, Johnson et al. 1996, Lawhead et al. 1997, Lawhead et al. 1998, Lawhead 1999, Lawhead and Johnson 2000, Lawhead and Prichard 2001), the highest densities of caribou occurred in the eastern portion of the study area. Few groups were west of the Meltwater and Tarn roads during calving (Figures 5–6). During the post-calving period, the highest densities were in the northeast portion of the Tarn survey block as large nursery bands congregated in that area (Figures 7–8).

COLVILLE–KUPARUK CALVING SURVEY AREAS

Snow cover was extensive during the surveys of the Kuparuk South and Colville East areas on 5–7 June (the Kuparuk Field area was not surveyed due to poor weather). Therefore, we applied the sightability correction factor, developed in 1993 for patchy snow cover conditions ranging from 20 to 70% cover (Lawhead et al. 1994), to the early June survey counts.

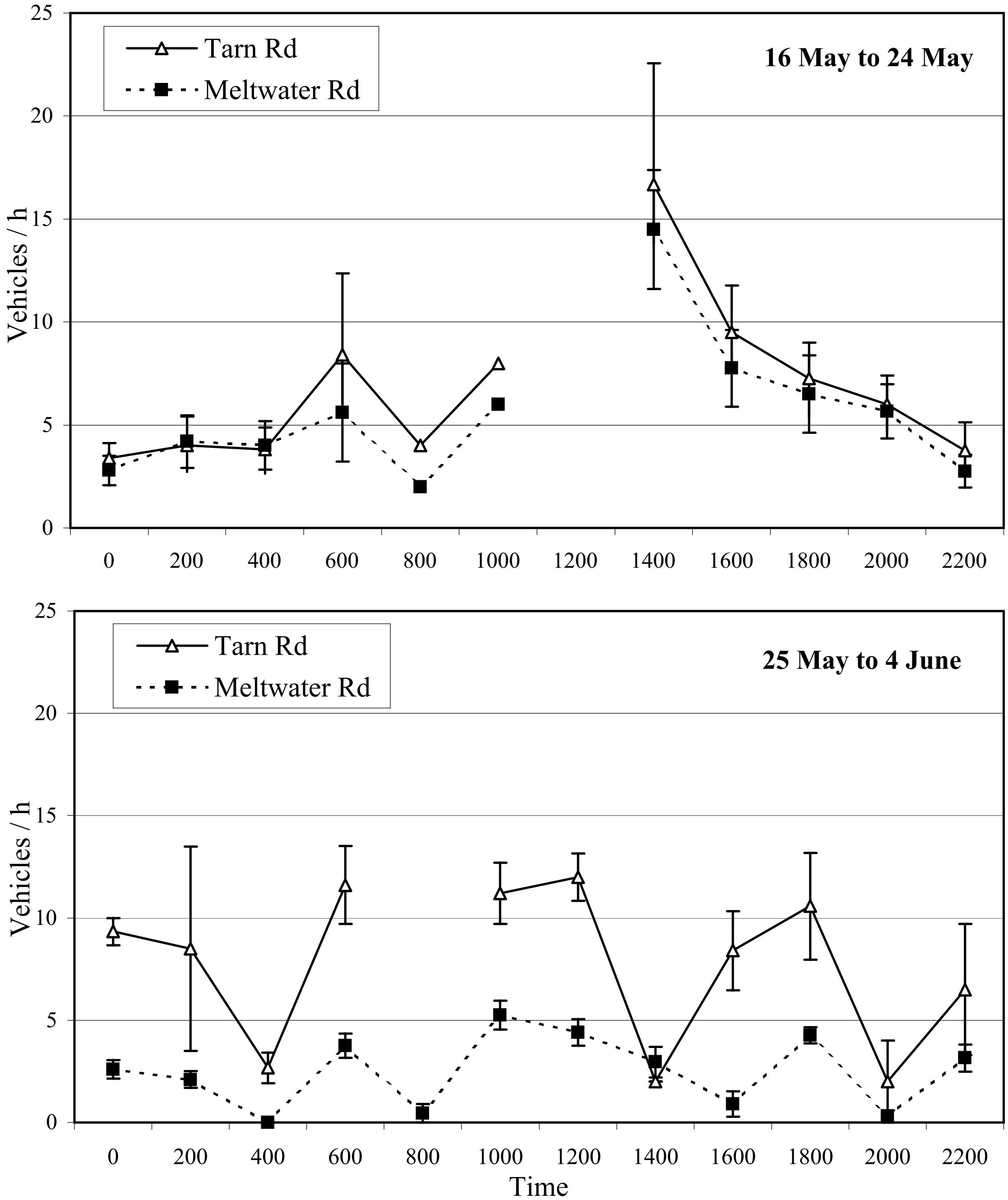


Figure 3. Traffic rates on the Tarn and Meltwater roads with and without convoying, 16 May–4 June 2001.

Table 4. Caribou groups observed along Meltwater and Tarn roads during the Meltwater road convoy period (25 May–4 June 2001).

Location	Date	Distance (m)	Number of Caribou Cows	Calves	Yrlgs.	Bulls	Unclass.	Total	Behavioral Reaction
Tarn	May 27	>2000	0	0	0	0	3	3	None
	June 1	800	1	0	1	0	0	2	None
Meltwater	May 27	>1000	0	0	0	0	4	4	None
	May 29	>3000	0	0	0	0	11	11	None
	June 3	150	1	0	0	0	7	8 *	None
	June 4	400	5	0	1	1	0	7	Ran ahead of convoy

* Not seen by ABR observer, reported by truck driver in convoy.

During the mid-June surveys (10–12 June), snow cover persisted in relatively small amounts in the three calving survey areas (mostly 10% or less). Because of the generally low snow cover, we did not apply the sightability correction to the mid-June counts. Caribou numbers were low throughout the survey areas relative to previous years (1993, 1995–2000; Table 7). Caribou densities were higher than other years of late snowmelt in the Kuparuk Field and Kuparuk South survey areas but the second lowest, after 2000, of all years in the Colville East survey area (Table 7).

The distribution of caribou was similar to previous years (Figures 9–10). The highest densities of caribou were found to the east of the study area south of the Kuparuk Oilfield (Figure 9, Appendix B), and a small concentration was present in the Milne Point area as in previous years. As in 2000, few caribou were found north of the Meltwater study area (Lawhead and Prichard 2001) and west of the Kuparuk Oilfield, an area that contained a small concentration of calving caribou in the mid-1990s (Figures 9–10).

INSECT SEASON

Caribou observations were recorded from 26 June through 27 July 2001. The distribution and movements of caribou in the Kuparuk–Colville region were surveyed and mapped on 28 days in this period (no observations were made on 28–30 June or 24 July). Aerial surveys were conducted on 24 days and road surveys on 15 days (Table 8). Overall, data were recorded on 587 groups totaling 86,089 caribou (obviously including repeated observations of the same animals among successive days) (Figures 11–12, Table 8). The second half of June and first half of July 2001 were cooler than average and the second half of July was warmer than average (Appendix C). The occurrence of weather conducive to insect harassment (as indicated by Mörschel and Klein's (1999) index of fly harassment) was low in the first half of July and increased substantially in the second half of the month (Appendix D).

The reconnaissance nature of our aerial survey effort needs to be considered when reviewing the distribution data during the insect season because the entire area was surveyed selectively, not systematically. Similar to previous years caribou were widely scattered inland during times of low mosquito activity (either low temperatures or high winds), this generally included large numbers of groups within the study area and along the upper stretches of the Miluveach and Kachemach rivers, as well as along the bluffs east of the Itkillik River (Figures 11–12).

Mosquito harassment occurred on most days in the study period, peaking at only mild levels (typically resulting in upwind movements) on 6 days (21% of the 28 days recorded) and at moderate or severe levels (typically resulting in movements to coastal relief habitat) on another 13 days (46%) (Table 8). Major mosquito-induced movements to the coast occurred on 2–3 July and

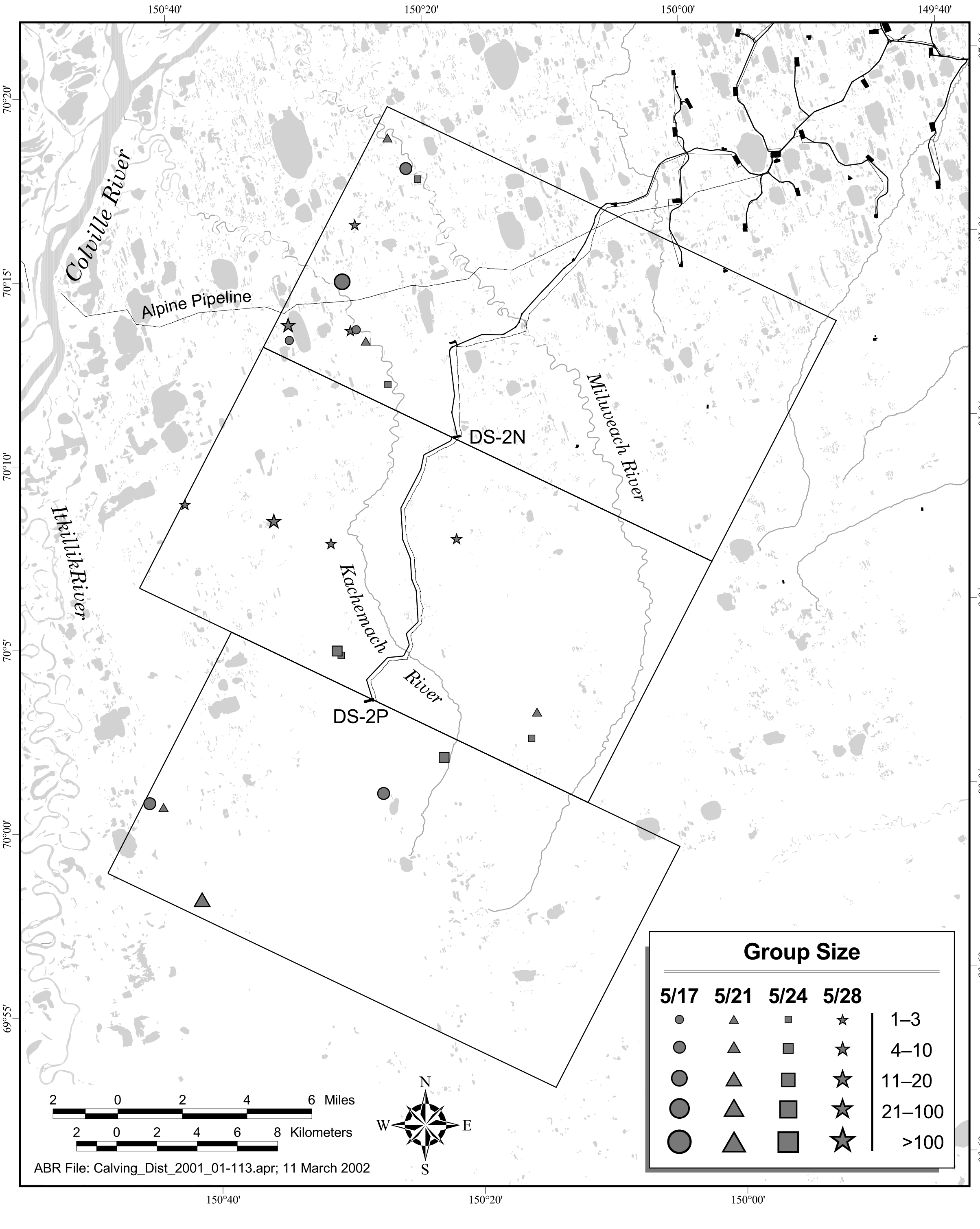


Figure 4. Location and size of caribou groups observed on four aerial surveys of the Meltwater study area during the pre-calving period, 17–28 May 2001.

Table 5. Number of total caribou and calves observed during aerial transects of the Meltwater study area (Tarn, Meltwater, and Reference survey blocks), May–June 2001.

Age	Date	Tarn	%	Meltwater	%	Reference	%	Total
Total	May 17	25	61.0	0	0	16	39.0	41
	May 21	6	26.1	3	13.0	14	60.9	23
	May 24	6	33.3	7	38.9	5	27.8	18
	May 28	11	50.0	11	50.0	0	0	22
	June 4	4	11.4	16	45.7	15	42.9	35
	June 8	65	28.9	80	35.6	80	35.6	225
	June 13	558	39.4	352	24.8	508	35.8	1418
	June 16	468	41.4	309	27.4	353	31.2	1130
	June 20	437	45.9	261	27.4	255	26.8	953
	June 24	1207	81.7	152	10.3	118	8.0	1477
	June 28	548	52.1	342	32.5	162	15.4	1052
	Total	3335	52.2	1533	24.0	1526	23.9	6394
Calves	May 17	0	0	0	0	0	0	0
	May 21	0	0	0	0	0	0	0
	May 24	0	0	0	0	0	0	0
	May 28	0	0	0	0	0	0	0
	June 4	0	0	0	0	0	0	0
	June 8	4	18.2	9	40.9	9	40.9	22
	June 13	105	33.4	68	21.7	141	44.9	314
	June 16	119	47.8	57	22.9	73	29.3	249
	June 20	77	41.0	66	35.1	45	23.9	188
	June 24	332	93.3	15	4.2	9	2.5	356
	June 28	111	69.8	31	19.5	17	10.7	159
	Total	748	58.1	246	19.1	294	22.8	1288

15–16 July. In the first instance, the duration of harassment was relatively brief and caribou rapidly returned inland when mosquito activity subsided, dispersing relatively far inland during the cold weather that prevailed for most of the first half of July. In the second instance, harassment was more prolonged and resulted in large numbers of caribou moving west across the Colville River delta and into NPRA. The greatest extent of inland movement occurred during the extended period of cool weather in the first half of July (Figure 11). The inland extent of movements by caribou in July 2001 (up to 60 km) was greater than expected from past telemetry studies (30–35 km; Lawhead and Curatolo 1984, Curatolo 1986, Cameron et al. 1989), similar to July 2000 (Lawhead and Prichard 2001). Oestrid fly harassment was confirmed by behavioral observations of caribou on 7 days and suspected on another 3 days in July, although this is probably an underestimate, judging from the occurrence of weather conditions conducive to fly activity (Appendix D).

The most intensive insect harassment in the 2001 season occurred in the second half of July. The largest mass movement occurred into westerly winds on 17–18 July, when at least 10,700 caribou (comprising the majority of the western segment of the CAH) moved west from the Kuparuk River delta through the Milne Point and northern Kuparuk oilfields and across Kalubik Creek. During the following week, those animals subsequently continued west, onto and across the Colville River delta north of Nuiqsut and into NPRA. Although CAH caribou often move onto

Table 6. Estimated total number of caribou (with SE and 90% CI) in the Tarn, Meltwater, and Reference survey blocks and the total Meltwater study area, 17 May–28 June 2001.

	Tarn				Meltwater				Reference				Total			
Date	Est.	SE	lci	uci	Est.	SE	lci	uci	Est.	SE	lci	uci	Est.	SE	lci	uci
May 17	50	18.9	25	95	0	0.0	0	0	32	14.8	16	67	82	24.0	95	134
May 21	12	5.6	6	25	6	4.2	3	16	28	16.8	14	68	46	18.2	25	87
May 24	12	5.6	6	25	14	9.9	7	37	10	7.1	5	27	36	13.4	25	64
May 28	22	8.8	11	43	22	10.0	11	46	0	0.0	0	0	44	13.3	43	73
June 4*	15	8.5	4	35	60	28.1	16	127	56	32.7	15	134	132	48.6	35	247
June 8	130	24.1	73	187	160	38.9	80	252	160	19.1	115	205	450	49.6	333	556
June 13	1116	70.0	951	1281	704	69.9	539	869	1016	197.5	549	1483	2836	220.8	2314	3328
June 16	936	203.6	468	1418	618	97.2	388	848	706	137.6	381	1031	2260	264.3	1635	2823
June 20	874	280.2	437	1536	522	122.5	261	812	510	153.1	255	872	1906	342.0	1536	2645
June 24	2414	323.5	1649	3179	304	75.0	152	481	236	32.9	158	314	2954	333.7	3179	3743
June 28	1096	164.8	706	1486	684	93.9	462	906	324	73.0	162	497	2104	203.2	1624	2540

* Applied Sightability Correction Factor of 1.88 (Lawhead et al. 1994).

Table 7. Estimated density (number/km2) of caribou among Kuparuk–Colville calving survey areas in mid-June 1993–2001.

	Colville East		Kuparuk Field		Kuparuk South		Timing of
Year	Total	Calf	Total	Calf	Total	Calf	Snow Melt
1993	2.40	0.61	0.65	0.16	–	–	Intermediate
1995	1.52	0.23	–	–	5.05	0.97	Intermediate
1996	1.97	0.58	2.16	0.79	7.25	2.62	Early
1997*	3.05	0.92	0.28	0.07	2.40	0.69	Late
1998	1.39	0.23	0.62	0.18	10.22	3.68	Early
1999	1.47	0.37	1.17	0.41	3.26	1.03	Late
2000*	0.65	0.13	0.36	0.09	0.53	0.14	Late
2001	0.78	0.13	0.60	0.15	3.54	1.01	Late
Mean	1.65	0.40	0.83	0.26	4.61	1.45	

* Applied Sightability Correction Factor of 1.88 (Lawhead et al. 1994)

the Colville Delta following periods of westerly winds and severe insect harassment, the scale of this movement was unprecedented, constituting the largest westward movement by the CAH across the Colville River observed in the last two decades (Lawhead and Prichard 2002). After this large-scale movement of caribou into NPRA in mid-July 2001, large numbers of caribou were not encountered east of the Colville River for the rest of the summer and fall. Large numbers of caribou were observed in NPRA in October, suggesting that many CAH caribou stayed farther west than typically occurs.

The overall pattern of movements exhibited by the western segment of the CAH in the 2001 insect season generally was consistent with that seen in other recent years, except for the major westward movement across the Colville River in late July. The Meltwater study area continued to be used heavily when insects were inactive. Although caribou were only occasionally observed crossing infrastructure due to the nature of the aerial surveys and the large area covered, large numbers of caribou were able to move between the coast and the study area, successfully crossing the Meltwater and Tarn roads and pipelines as well as the Alpine pipeline.

LATE SUMMER–FALL

Caribou densities were low within the Colville East survey area during six aerial surveys conducted between 4 August and 26 October (mean = 0.09 caribou/km^2; min. = 0.01; max. = 0.17; Table 9). In general, caribou appeared to be concentrated south of DS-2P in the Itkillik hills in August and closer to the coast in late September and October (Figure 13). Group size was low in August (1.2–2.8), was at a maximum on 30 September prior to rut (6.3), and then decreased slightly in October (Table 9).

Although some caribou were observed off transect along the Itkillik River, subsistence hunting opportunities appeared to be limited east of the Colville River. Caribou were more numerous west of the Colville River during the same period (Burgess et al. 2002). It is unclear how many caribou west of the Colville River were Central Arctic Herd animals and how many were Teshekpuk Herd animals. The range of the Teshekpuk Herd typically extends as far east as the Colville River (Prichard et al. 2001), and there may have been more CAH animals than usual west of the Colville River due to the unusual movement of caribou west during July.

ROAD CROSSINGS

During aerial surveys in late May and June (17 May–28 June), a total of 12 groups were observed near roads or other infrastructure within the Greater Kuparuk Area (Table 10). During the same period four groups were observed crossing

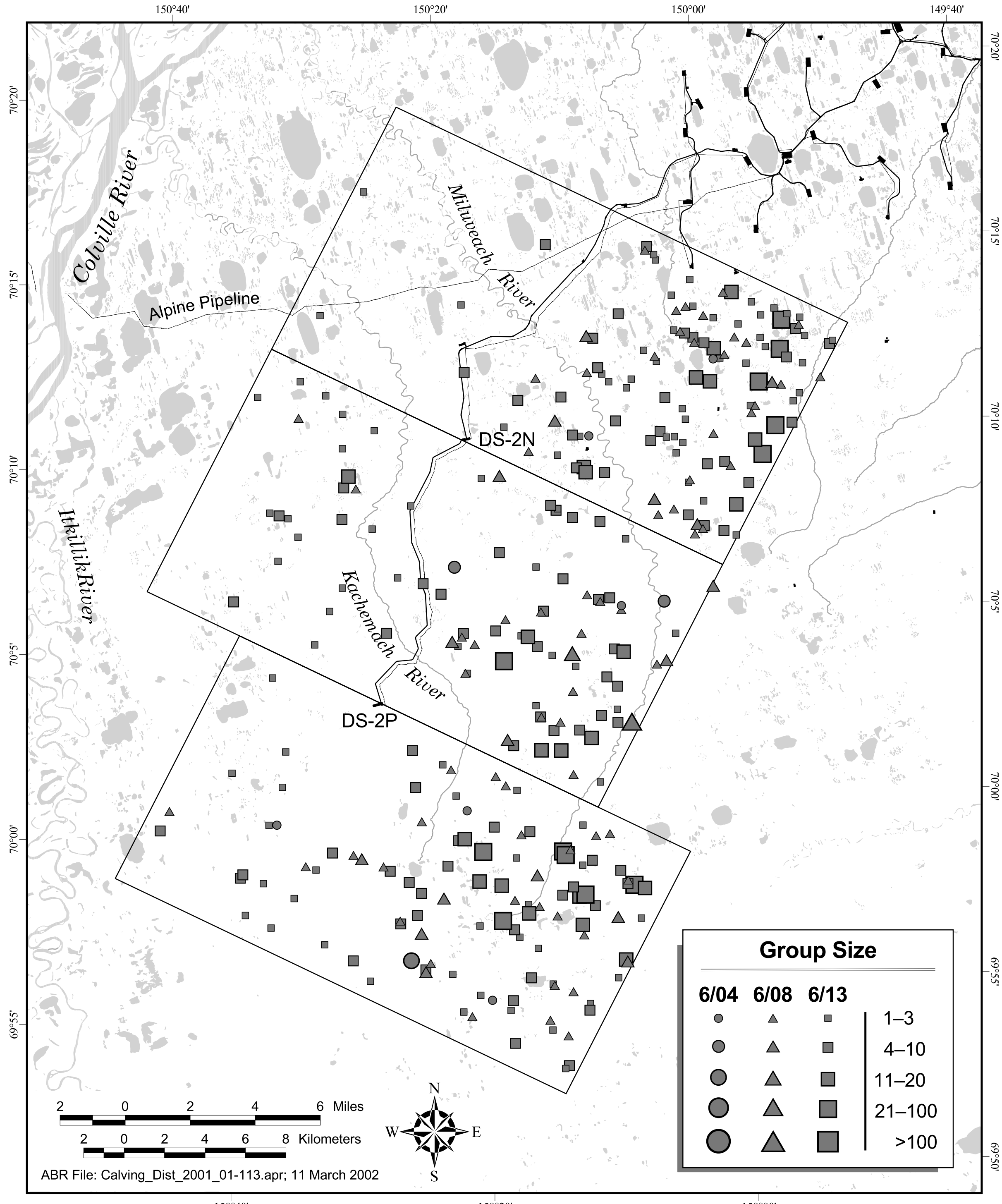


Figure 5. Location and size of caribou groups observed on three aerial surveys of the Meltwater study area during the calving period, 4–13 June 2001.

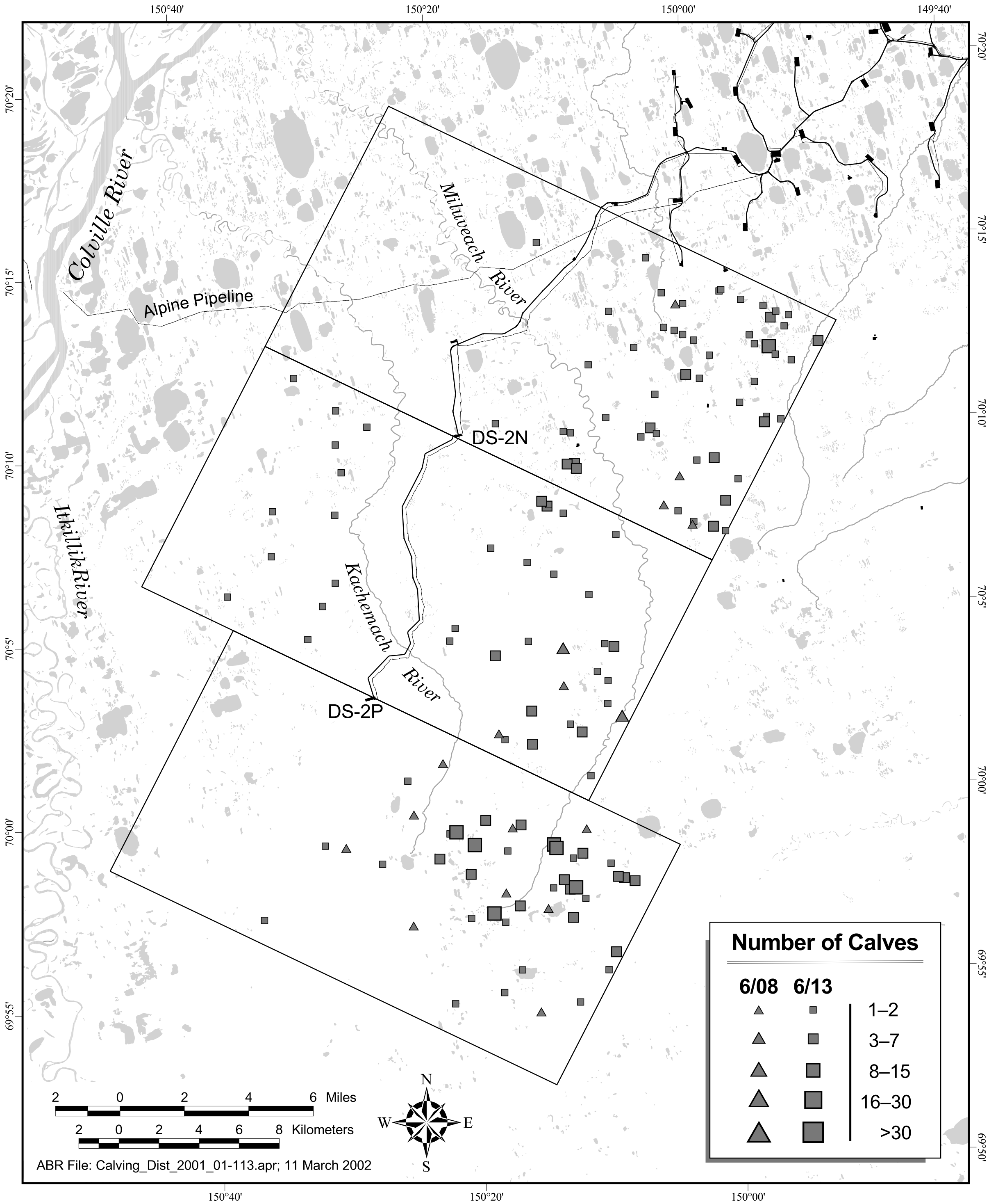


Figure 6. Location and number of caribou calves observed on three aerial surveys of the Meltwater study area during the calving period, 4–13 June 2001.

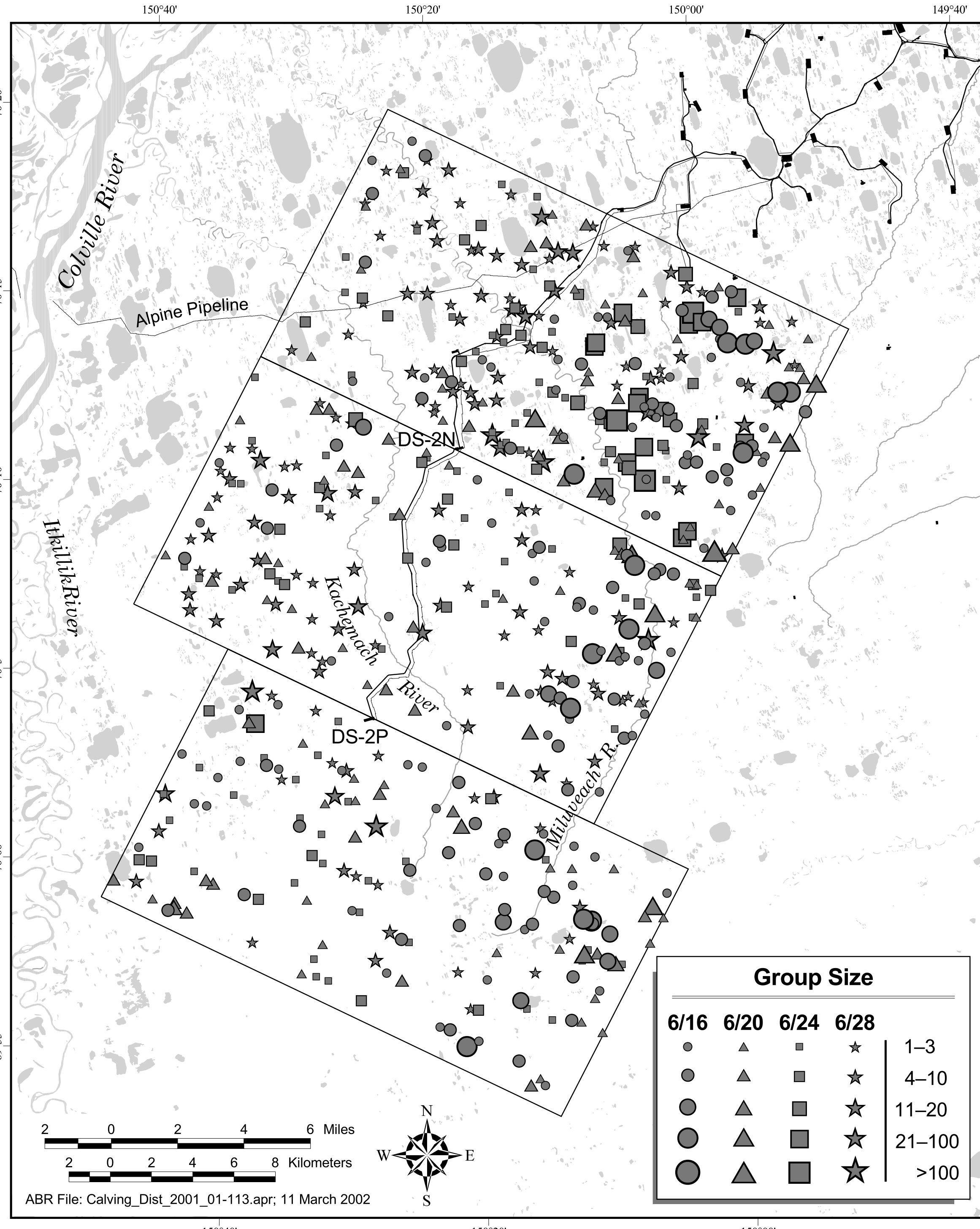


Figure 7. Location and size of caribou groups observed on four aerial surveys of the Meltwater study area during the post-calving period, 16–28 June 2001.

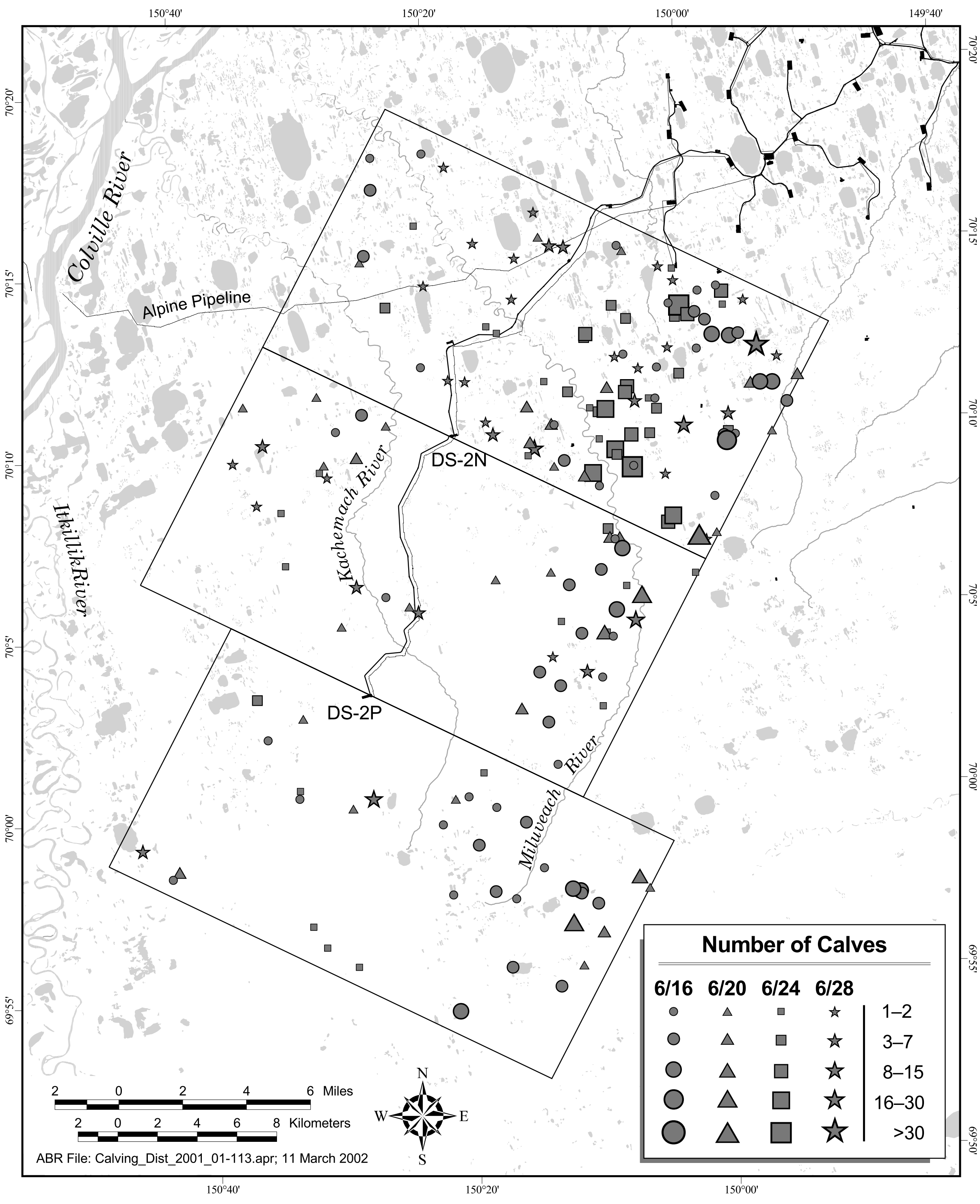


Figure 8. Location and number of caribou calves observed on four aerial surveys of the Meltwater study area during the post-calving period, 16–28 June 2001.

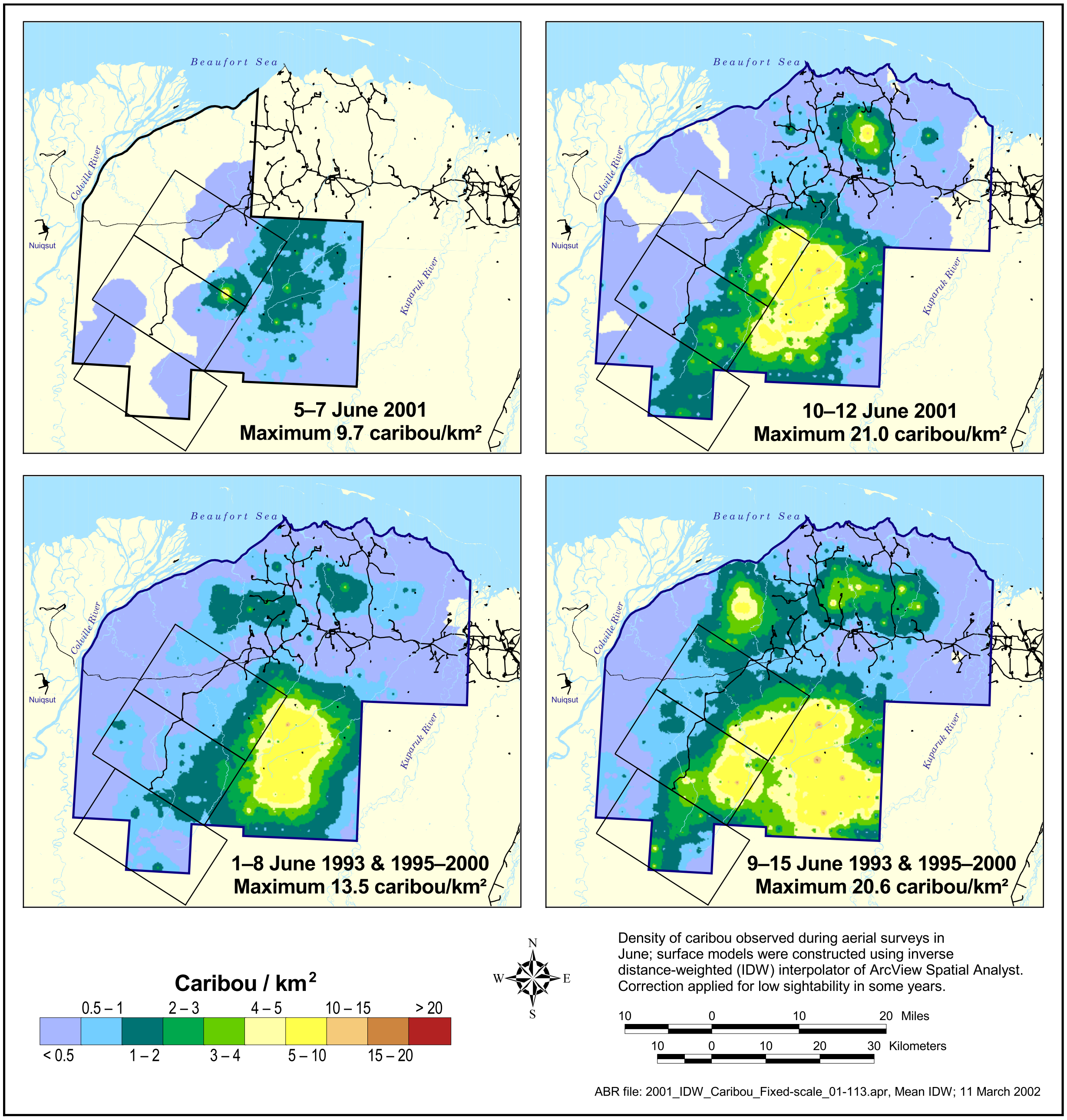


Figure 9. Density of all caribou observed during calving surveys in early and mid-June 2001 (top) and mean density for the years 1993–2000 (bottom).

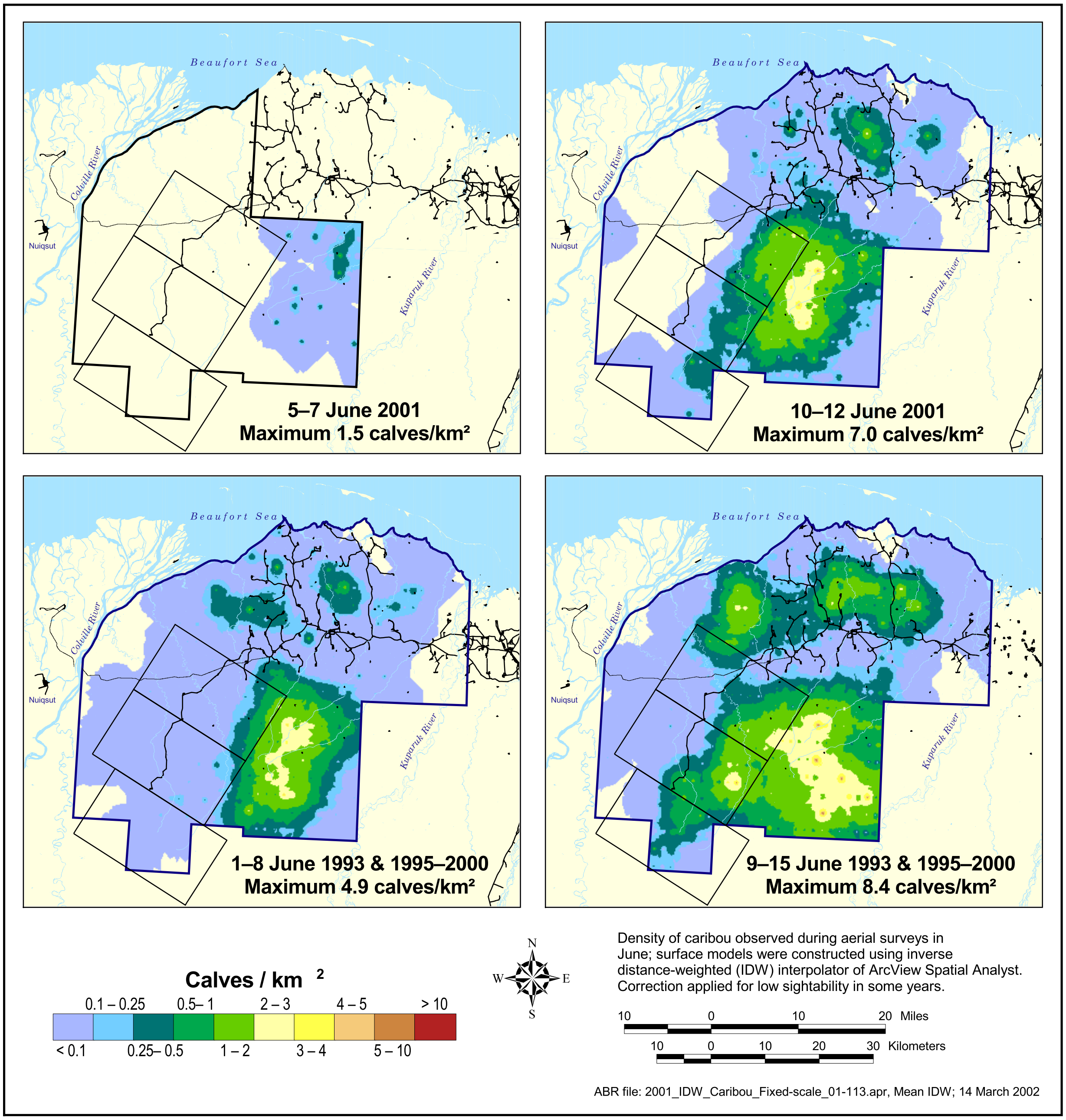


Figure 10. Density of caribou calves observed during calving surveys in early and mid-June 2001 (top) and mean density for the years 1993–2000 (bottom).

Table 8. Numbers of caribou groups and individuals mapped (see Figures 11–12) and levels of insect harassment recorded on reconnaissance aerial and road surveys in the Kuparuk Oilfield region during 26 June–27 July 2001.

	Survey Type [a]		Temperature (°C) at Kuparuk		Wind Direction (degrees) & Speed (knots) at Alpine		# Caribou Observed in Meltwater	Total			Insect Harassment	
Date	A.M.	P.M.	Min.	Max.	A.M.	P.M.	Study Area*	# Groups	# Caribou	Av. Group Size	Mosq.	Flies
June 26		R	1	7	050 @ 7	var. @ 4	67	41	553	13.5	mild	none
27		A	4	9	320 @ 10	340 @ 8	83	37	427	11.5	none	none
July 1	A	A	2	14	060 @ 10	070 @ 14	354	34	535	15.7	none	none
2	A	R	4	26	200 @ 2	230 @ 9	2	9	2562	284.7	moderate	none
3	R	A	7	27	var. @ 2	270 @ 12		4	5806	1451.5	moderate	none
4	A	R	1	16	060 @ 5	040 @ 12		26	3564	137.1	none	none
5	R	A	–2	7	060 @ 15	040 @ 18	337	40	4017	100.4	mild	none
6		A	–1	4	300 @ 7	360 @ 11	3661	37	5257	142.1	mild	none
7		A	0	5	000 @ 0	050 @ 5		38	2256	59.4	mild	none
8		A	–2	4	030 @ 13	060 @ 13	1694	35	2747	78.5	none	none
9		A	–1	3	060 @ 9	050 @ 16	37	8	74	9.3	none	none
10	R	A	0	4	060 @ 12	060 @ 12	3031	57	3672	64.4	none	none
11		B	0	4	060 @ 8	060 @ 13	55	20	743	37.2	none	none
12		R	0	6	080 @ 16	070 @ 16	96	8	111	13.9	none	none
13		A	0	8	060 @ 16	060 @ 18	1570	44	2030	46.1	none	none
14		A	0	9	070 @ 18	070 @ 16	1024	40	1495	37.4	mild	none
15		A	1	14	070 @ 16	090 @ 20		13	2282	175.5	moderate	unknown
16		A	5	28	090 @ 10	070 @ 10		13	8220	632.3	severe	active
17	R	B	9	26	150 @ 5	300 @ 10		13	15,217	1170.5	severe	unknown
18	R	A	8	20	230 @ 10	090 @ 10		15	9842	656.1	moderate	none
19	R	B	4	15	100 @ 10	200 @ 10		10	3543	354.3	severe	unknown
20	R	R	14	18	260 @ 6	210 @ 11		4	139	34.8	severe	active
21	R		12	20	240 @ 12	240 @ 10		3	4	1.3	mild	active
22	R	B	9	21	030 @ 8	360 @ 6		3	4	1.3	moderate	active
23		A	7	23	190 @ 7	300 @ 14		15	7389	492.6	severe	active
25	R	A	2	10	240 @ 7	010 @ 7	158	9	890	98.9	moderate	unknown
26		A	3	12	000 @ 0	090 @ 4		5	1183	236.6	moderate	active
27	A		7	16	200 @ 8	230 @ 10	150	6	1527	254.5	moderate	active
Total								587	86,089	146.7		

[a] Survey type: A = aerial survey, R = road survey, B = both.
[b] Mosquitoes: 0 = none, 1 = mild, 2 = moderate, 3 = severe.
[c] Oestrid flies: 0 = not active, 1 = active, 9 = unknown
* Amount of time spent surveying study area varied among days.

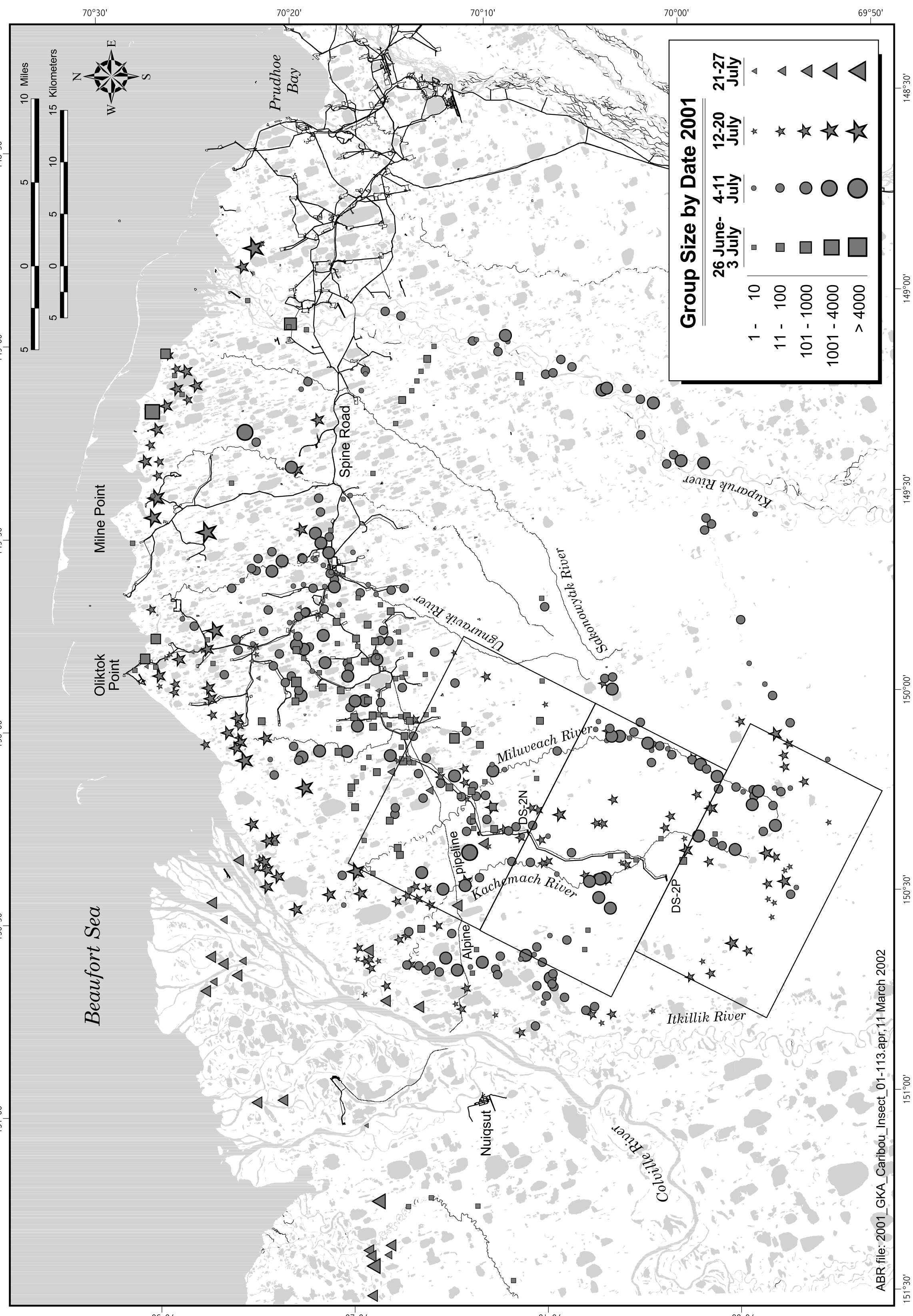


Figure 11. Location and size of caribou groups observed during insect-season surveys, by week, 26 June–27 July 2001. Survey coverage was not uniform over entire area portrayed.

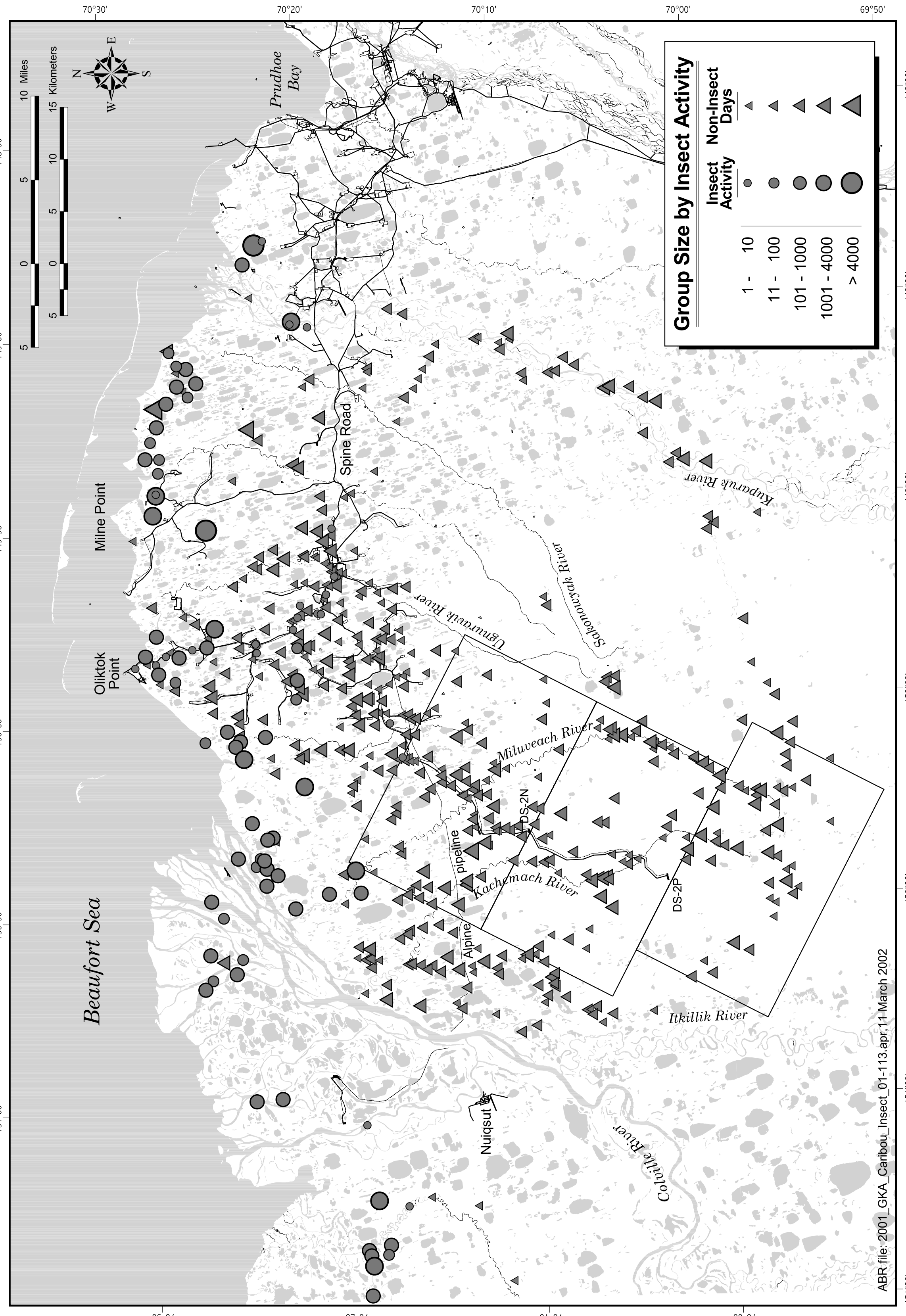


Figure 12. Location and size of caribou groups observed during insect-season surveys, by insect activity (days with and without harassment), 26 June–27 July 2001. Survey coverage was not uniform over entire area portrayed.

Table 9. Number and density of caribou observed in the Colville East survey area (including the Meltwater study area) during late summer and fall aerial surveys, 2001.

Date	Area (km²)	No. of Caribou	Density (caribou/km²)	No. of Groups	Av. Group Size
Aug. 4–5	849.7	11	0.01	4	2.8
Aug. 15	849.7	7	0.01	6	1.2
Aug. 28 & 30	849.7	135	0.16	52	2.6
Sep. 30 *	746.7	69	0.09	11	6.3
Oct. 12–13	849.7	77	0.09	15	5.1
Oct. 24 & 26	849.7	147	0.17	29	5.1
Total		446	0.09	117	3.8

* Part of survey area obscured by fog

roads during road surveys, and three groups were observed crossing infrastructure along the Meltwater road (two road crossings, one pipeline crossing) during the period of intensive road maintenance (5–8 June). In addition, 19 groups were observed successfully crossing roads or pipelines in the GKA during insect-season surveys (2–27 July). One caribou observed on the side of the Oliktok Point Road turned around, apparently failing to cross (2 July). A number of caribou were seen using roads, pads, and pipelines as fly-relief habitat in late July (Table 10).

As in previous years, road and pipeline crossings can be inferred from the locations of various large groups throughout the oil field. On two occasions during July 2001, a large portion of the western segment of the CAH was observed moving to the coast for insect relief. In both cases, caribou had to cross either the Spine Road or the Oliktok Point Road. In early July, caribou moved to the east with large numbers crossing to the east side of the Kuparuk River before insect conditions abated and caribou returned inland to the upper Kuparuk River or the upper Kachemach and Miluveach rivers. In mid-July, most of the western portion of the herd moved west from the Kuparuk River to the Colville River, crossing the Oliktok Point and Milne Point roads and pipelines along the way.

MAPPING AND SELECTION OF VEGETATION TYPES

Ground data from previous studies in the northern half of the mapped area and previous experience suggest that most spectral signatures corresponded well with the assigned vegetation cover classes (Figure 14). Differentiating among moist tundra classes represents the most likely source of mapping error. Tussock tundra, moist sedge/shrub tundra, and occasionally dwarf shrub tundra, occur in similar positions on the landscape, have very similar species composition (with the exception of *Eriophorum vaginatum*; Appendix E), and similar spectral characteristics. A second source of mapping error resulted from the range of characteristics associated with the Dwarf Shrub Tundra class. Because this class included three types of dwarf scrub, the spectral signature was broader and thus more inclined to misclassification. These classification challenges will be addressed through future ground-truthing field work.

Vegetation types varied among the survey blocks (Figure 14, Table 11). For example, the Tarn block and the Eastern area had lower percentages of dwarf shrub tundra and tussock tundra than did the Meltwater block, the Eastern area had the highest percentage of moist sedge/shrub tundra, and the Tarn block had the highest proportion of wet sedge/willow meadow (lowlands).

For the three study blocks where we conducted intensive aerial surveys (Tarn,

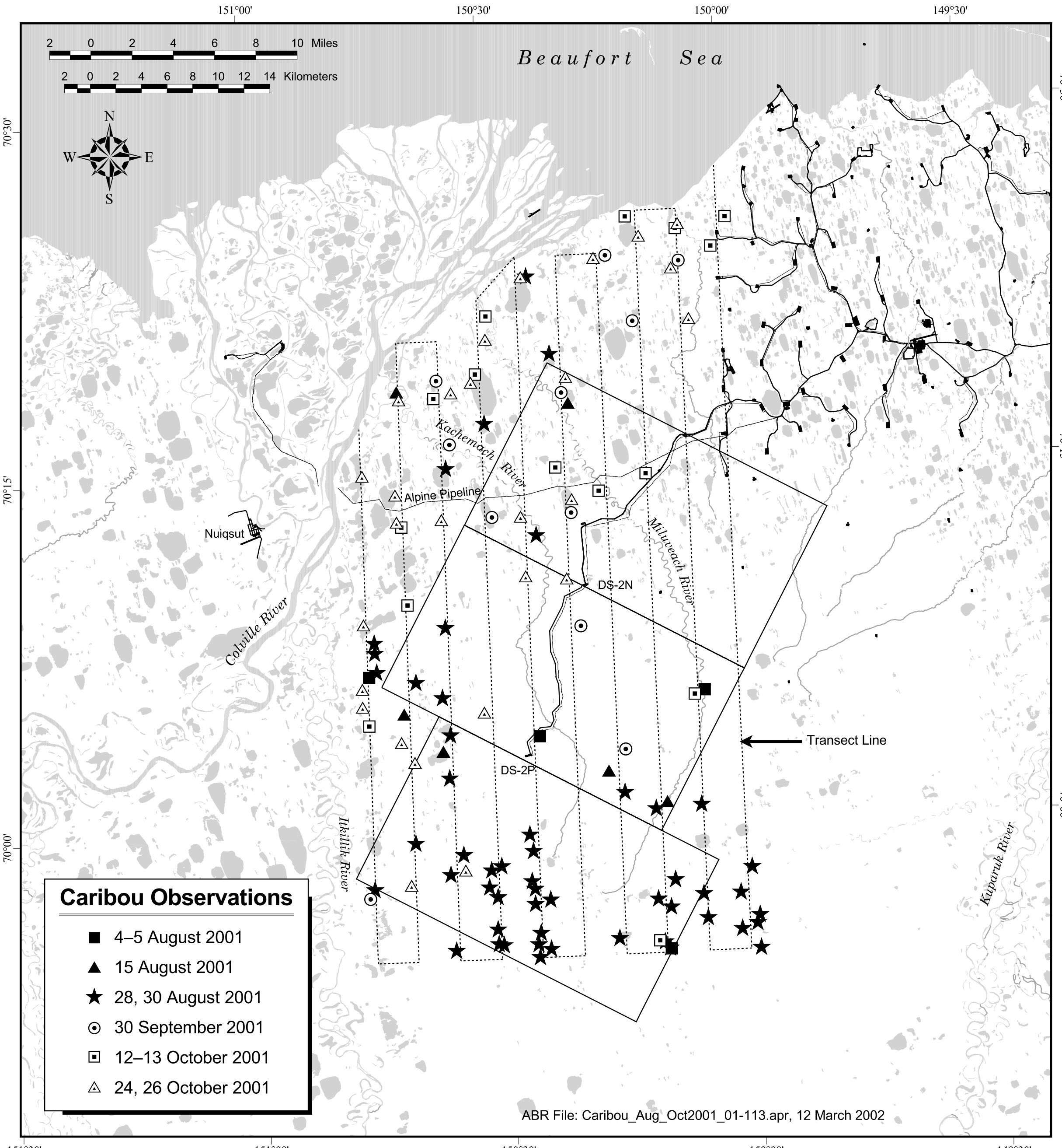


Figure 13. Location of caribou groups observed during late summer and fall surveys of the Colville East survey area (including the Meltwater study area), 4 August–26 October 2001.

Table 10. Caribou encounters with roads and infrastructure recorded during May–July 2001.

Date	Survey Type	Location	Total No.	No. of Calves	Structures Crossed	Description
May 24	Aerial	Meltwater	8	0	None	Tracks approached within ½ mile of DS-2P on W side, then veered NW
May 26	Road	DS-2B	4	0	Road	Ran across road in front of water truck
June 4	Road	Meltwater	7	0	Road, Pipeline	At approach of convoy, stopped trotting W, walked north paralleling road
June 5	Tucker	Meltwater	5	0	Pipeline	Caribou crossed pipeline, stopped to feed
June 6	Tucker	Meltwater	5	0	Road	Crossed road recently, heading SE
June 8	Tucker	Meltwater	14	0	Road	2 cows crossed road, headed toward other 12, then turned around and crossed road again
June 16	Aerial	Meltwater	2	0		Near powerline
June 20	Aerial	Tarn	10	0		Near Tarn road
June 20	Aerial	Meltwater	1	0		Bull near Meltwater road
June 20	Aerial	Meltwater	4	0		Near Meltwater road
June 20	Aerial	Meltwater	5	0		Near Meltwater road
June 26	Road	DS-2G	4	0	Road	1 caribou crossed road
June 27	Road	Spine Road	27	5	Road	Crossed road; 1 calf frightened by traffic, eventually crossed
June 28	Aerial	Tarn	11	0		Near road
June 28	Aerial	Tarn	4	0		Near powerline
June 28	Aerial	Tarn	4	0		Near Alpine pipeline
June 28	Aerial	Tarn	4	1		Near road
June 28	Aerial	Meltwater	15	unk		Near road (off transect)
June 28	Aerial	Meltwater	15	unk		Between pipeline and road (off transect)
July 2	Road	Kuparuk	>2000	unk	Road	Crossed near Kuparuk Bridge; hundreds seen near Oliktok Pt Rd and DS-1E
July 2	Road	Oliktok Pt.	1	0	None	Failed crossing
July 4	Road	KIC	~50	~15	Road	Scattered on both sides of road
July 4	Road	DS-1G	90	~40	Road	Scattered on both sides of road
July 4	Road	DS-1G	9	3	Road	Crossed road, climbed road berm, turned back
July 4	Road	Mine D	100	40	Road	Scattered on both sides of road
July 4	Road	DS-2C	73	25	Road	Trotted across road when it saw truck
July 5	Road	Tarn Rd	26	9	Road	Crossed road
July 5	Road	DS-1Y	86	34	Road	Crossed road
July 13	Aerial	Alpine Pipeline	28	0	Pipeline	Appeared to have just crossed pipeline
July 14	Aerial	Tarn Road	77	22	Road	Crossing Tarn road just south of W. Sak 15
July 14	Aerial	Meltwater	45	8	Road	Crossed Meltwater road near DS-2N
July 15	Aerial	Oliktok Pt.	9	4	Pipeline	Just crossed pipeline S of ramp
July 17	Road	Oliktok Pt.	>4000	unk	Road	Moved W across Oliktok Pt Rd near DS-3K
July 20	Road	DS-1Y	1	0	Road	Fly-harassed bull crossed road, went under pipeline
July 20	Road	DS-1Q	2	0	Road	Left road when close to vehicle
July 22	Road	Milne Pt	1	0	Road, pipeline	Crossed road, stood under pipeline, ran along in shadow of pipeline
July 22	Road	Milne Pt	2	1	Pad	On pad near rig camp, avoiding flies?
July 25	Road	CPF-3	3	1	Pipeline	1 feeding, 2 lying under pipeline
July 26	Road	KOC	1	0	Pad	1 bull standing under KOC
July 26	Aerial	DS-1Q	1	0	Pad	Standing on pad
July 27	Aerial	Alpine Pipeline	150	unk	Pipeline	Crossed pipeline from N, moving quickly
July 27	Aerial	DS-1A	1	0	Road	Walking on road ahead of truck

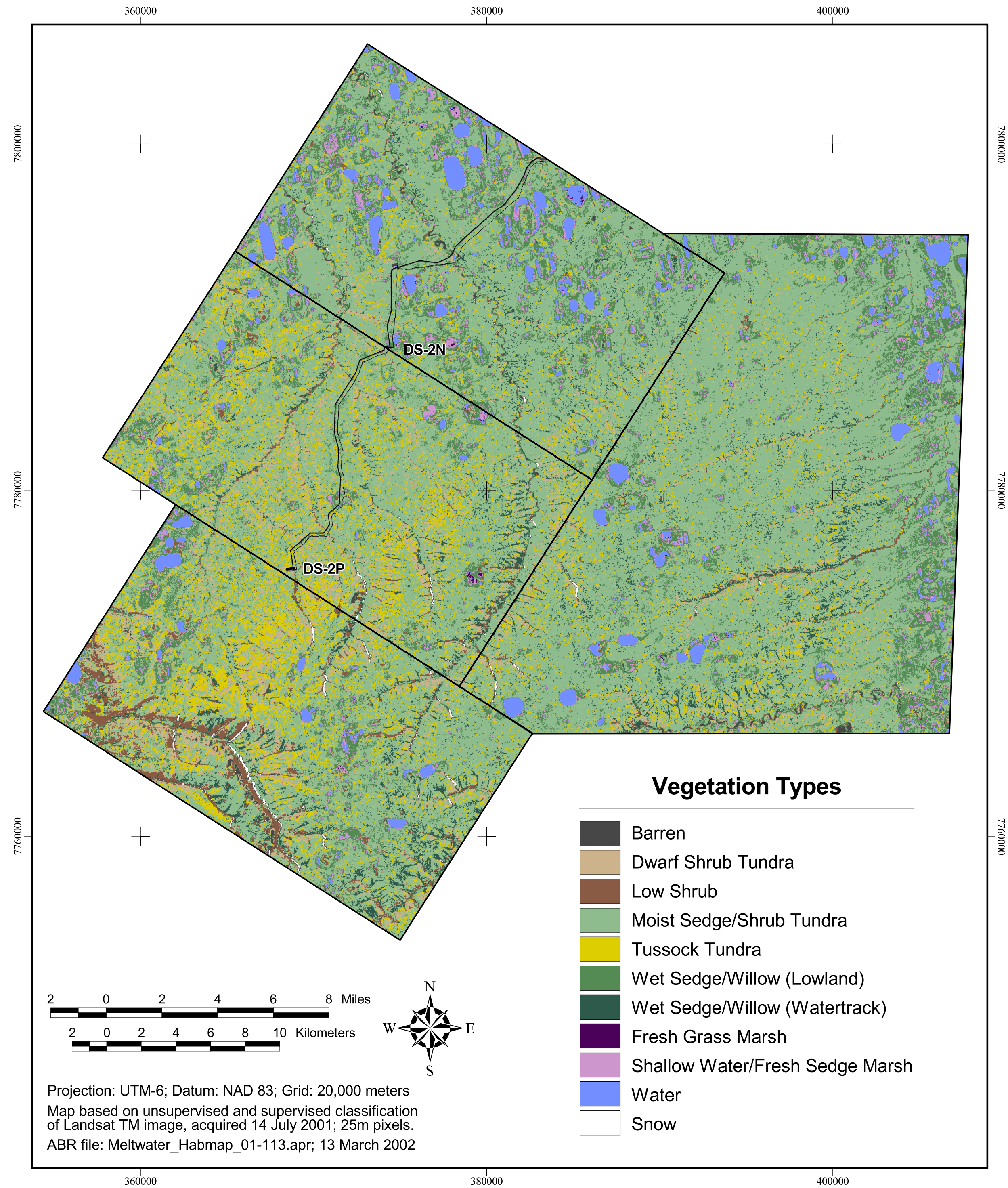


Figure 14. Vegetation types mapped in the Meltwater study area and Eastern area of concentrated calving, based on satellite image (Landsat TM) from 14 July 2001.

Table 11. Occurrence (percentage) of 11 vegetation types in the Meltwater study area (Tarn, Meltwater, and Reference survey blocks) and Eastern concentration area, 2001.

Distance from Road	Vegetation Type	Tarn	Meltwater	Reference	Entire Study Area	Eastern Area
< 4 km	Barren	1.22	0.96	0.06	1.02	–
	Dwarf Shrub Tundra	3.99	11.81	13.53	8.10	–
	Fresh Grass Marsh	0.03	0.00	0.00	0.02	–
	Low Shrub	0.58	1.31	2.45	1.05	–
	Moist-Sedge Shrub Tundra	56.74	59.64	42.49	56.82	–
	Shallow Water/Fresh Sedge Marsh	4.26	0.65	0.08	2.38	–
	Snow	0.03	0.09	0.21	0.07	–
	Tussock Tundra	4.56	15.48	34.26	11.63	–
	Water	6.69	0.15	0.00	3.36	–
	Wet Sedge/Willow (Lowland)	20.15	7.49	5.86	13.58	–
	Wet Sedge/Willow (Watertrack)	1.75	2.42	1.06	1.98	–
> 4 km	Barren	0.90	0.39	0.77	0.69	–
	Dwarf Shrub Tundra	3.37	9.14	10.16	8.02	–
	Fresh Grass Marsh	0.01	0.01	0.01	0.01	–
	Low Shrub	0.80	1.68	5.71	3.18	–
	Moist-Sedge Shrub Tundra	61.55	57.60	49.79	55.28	–
	Shallow Water/Fresh Sedge Marsh	3.95	1.07	1.41	1.99	–
	Snow	0.08	0.14	0.49	0.27	–
	Tussock Tundra	4.72	15.75	14.85	12.37	–
	Water	4.34	0.71	2.12	2.30	–
	Wet Sedge/Willow (Lowland)	16.84	9.39	9.29	11.36	–
	Wet Sedge/Willow (Watertrack)	3.44	4.13	5.41	4.49	–
Total	Barren	1.00	0.64	0.83	0.82	0.36
	Dwarf Shrub Tundra	3.47	10.03	10.54	8.01	3.46
	Fresh Grass Marsh	0.07	0.06	0.01	0.05	0.02
	Low Shrub	0.61	1.61	6.45	2.89	0.74
	Moist-Sedge Shrub Tundra	59.31	58.00	49.09	55.46	67.93
	Shallow Water/Fresh Sedge Marsh	4.22	1.15	1.34	2.24	2.27
	Snow	0.05	0.11	0.45	0.20	0.05
	Tussock Tundra	4.65	15.73	15.66	12.01	5.57
	Water	5.93	0.68	1.70	2.77	2.95
	Wet Sedge/Willow (Lowland)	18.21	8.71	8.45	11.79	13.01
	Wet Sedge/Willow (Watertrack)	2.48	3.30	5.50	3.76	3.64

Meltwater, and Reference) combined, there were no significant differences in vegetation type used by caribou groups during calving and post-calving (P = 0.848; Table 12); pre-calving was not included due to small sample sizes. Use of vegetation types did not differ from availability during pre-calving (P = 0.972), but did differ during calving (P = 0.004), post-calving (P = 0.031), and all seasons combined (P < 0.001). After adjusting significance levels for the multiple comparisons, however, the use of individual vegetation types during post-calving did not differ significantly from availability (P > 0.05). During calving and for all three seasons combined, caribou selected moist sedge/shrub tundra (P < 0.05, Bonferroni Multiple Comparison) and avoided shallow water/fresh sedge marsh and wet sedge/willow meadow (lowlands) (P < 0.05, Bonferroni Multiple Comparison).

Results of the quadrat analysis also indicated that caribou selected moist sedge/shrub tundra (Figure 15). There was a significant positive correlation between the percent moist sedge/shrub tundra in a quadrat and caribou densities both during calving (P < 0.001) and post-calving (P < 0.001).

In the Tarn block, caribou used a significantly higher proportion of moist sedge/shrub tundra than the proportion available and avoided shallow water/fresh sedge marsh and wet sedge/willow meadow (lowlands) (P < 0.05, Bonferroni Multiple Comparison) during calving, post-calving, and overall. The quadrat analysis revealed that caribou densities increased with increasing percentage of moist sedge/shrub tundra during post-calving and overall (P = 0.001), but not during calving (P = 0.075).

There were no significant differences in use versus availability in any season in either the Meltwater or Reference blocks (Table 11); however, the quadrat analysis showed increasing densities with increasing percentages of moist sedge/shrub tundra in both blocks during calving (P < 0.024) and overall (P < 0.009), but not during post-calving (P > 0.012).

Within 4 km of roads the only significant difference in habitat use versus availability was avoidance of shallow water/fresh sedge marsh in the Tarn block (P < 0.05; Table 13). More than 4 km from a road, the only significant difference in habitat use versus availability was selection for moist sedge/shrub tundra within the Tarn block and overall, and avoidance of wet sedge/willow meadow (lowlands) in the Tarn block and overall (P < 0.05; Table 14).

TERRAIN RUGGEDNESS

There were significant differences in terrain ruggedness among the four areas (P < 0.001). Rugged terrain tended to occur along stream courses in the Meltwater and Tarn blocks and in hilly portions of the Reference block (Figure 16). Multiple comparisons of random points showed that the Tarn, Meltwater, and Reference blocks all differed significantly from each other with regard to terrain ruggedness (P < 0.001). The Tarn block and the Eastern concentration area were not significantly different (P = 0.386) and had the lowest DTRI values, the Meltwater block had intermediate values, and the Reference block had the most rugged terrain (Table 15).

There were no significant differences in the use of rugged terrain among the three seasons for any of the three survey blocks (P > 0.25) when analyzed separately. For all three blocks combined, caribou used significantly more rugged terrain during calving than post-calving (P = 0.012; Table 15). Based on Monte Carlo simulations, mean terrain ruggedness of caribou locations did not differ from availability during any season for the three survey blocks or for all blocks combined (P > 0.05). In addition, based on 288 2×0.8-km quadrats, caribou densities were not significantly correlated with maximum DTRI either during calving (P = 0.266; Figure 17) or post-calving (P = 0.303).

VEGETATIVE BIOMASS (NDVI)

Biomass estimates based on NDVI values in June were generated for the three survey blocks in the Meltwater study area and for the Eastern concentration area (see Methods). There were significant differences in NDVI611 among areas (P < 0.001), and multiple comparisons revealed that all four differed significantly from the other three (all P < 0.007). NDVI611 was highest in the Meltwater and Tarn blocks and lowest in the Eastern concentration area (Figure 18, Table 16). NDVIrate was almost identical in the three

Table 12. Use (percentage) of 11 vegetation types by caribou groups during the pre-calving, calving, and post-calving periods, May–June 2001.

Period	Vegetation Type	Tarn	Meltwater	Reference	Total
Pre-Calving	Barren	0.70	0.89	0	0.62
	Dwarf Shrub Tundra	2.75	17.66	30.88	13.58
	Fresh Grass Marsh	0	0	0	0
	Low Shrub	0	8.04	0	2.68
	Moist-Sedge Shrub Tundra	78.17	45.98	42.40	59.99
	Shallow Water/Fresh Sedge Marsh	0	2.08	0	0.69
	Snow	0	0	0	0
	Tussock Tundra	6.19	15.97	20.44	12.42
	Water	0	0	0	0
	Wet Sedge/Willow (Lowland)	11.43	9.38	1.67	8.71
	Wet Sedge/Willow (Watertrack)	0.76	0	4.62	1.31
	n	11	8	5	24
	P-value	0.980	0.862	0.909	0.972
Calving	Barren	0.06 –	0	0.48	0.19
	Dwarf Shrub Tundra	4.43	7.22	6.95	6.08
	Fresh Grass Marsh	0	0	0	0
	Low Shrub	0.36	1.82	5.07	2.39
	Moist-Sedge Shrub Tundra	73.88 +	65.55	55.45	65.23 +
	Shallow Water/Fresh Sedge Marsh	1.01 –	0	0.42	0.53 –
	Snow	0	0	0	0
	Tussock Tundra	4.30	17.32	17.30	12.41
	Water	0.45	0	1.34	0.63
	Wet Sedge/Willow (Lowland)	10.97 –	3.44 –	5.46	6.97 –
	Wet Sedge/Willow (Watertrack)	4.53	4.66	7.53	5.59
	n	121	90	160	321
	P-value	0.084	0.507	0.559	0.004
Post-Calving	Barren	0.45	0.39	0.88	0.54
	Dwarf Shrub Tundra	3.21	9.67	11.90	7.50
	Fresh Grass Marsh	0	0	0	0
	Low Shrub	0.55	1.37	5.05	1.97
	Moist-Sedge Shrub Tundra	70.12 +	60.98	47.72	61.44
	Shallow Water/Fresh Sedge Marsh	1.58 –	0.66	1.22	1.20
	Snow	0	0	0.39	0.10
	Tussock Tundra	5.97	14.28	17.95	11.70
	Water	1.54	0.22	0.83	0.94
	Wet Sedge/Willow (Lowland)	13.00 –	6.92	5.93	9.25
	Wet Sedge/Willow (Watertrack)	3.58	5.52	8.11	5.36
	n	263	196	110	619
	P-value	0.037	0.802	0.612	0.031
Total	Barren	0.34	0.29	0.70	0.43
	Dwarf Shrub Tundra	3.57	9.13	10.27	7.18
	Fresh Grass Marsh	0	0	0	0
	Low Shrub	0.48	1.69	4.97	2.13
	Moist-Sedge Shrub Tundra	71.50 +	61.97	50.72	62.66 +
	Shallow Water/Fresh Sedge Marsh	1.36 –	0.49	0.88	0.96 –
	Snow	0	0	0.23	0.07
	Tussock Tundra	5.47	15.26	17.74	11.95
	Water	1.16	0.15	1.02	0.81
	Wet Sedge/Willow (Lowland)	12.33 –	5.92	5.66	8.47 –
	Wet Sedge/Willow (Watertrack)	3.79	5.10	7.81	5.34
	n	395	294	275	964
	P-value	<0.001	0.450	0.291	<0.001

\+ = Significantly greater than availability ($P < 0.05$)
– = Significantly less than availability ($P < 0.05$)

Table 13. Use (percentage) of 11 vegetation types by caribou within 4 km of roads during the pre-calving, calving, and post-calving periods, May–June 2001.

Period	Vegetation Type	Tarn	Meltwater	Reference	Total
Pre-Calving	Barren	0	0		0
	Dwarf Shrub Tundra	0	9.62		7.81
	Fresh Grass Marsh	0	0		0
	Low Shrub	0	0		0
	Moist-Sedge Shrub Tundra	100.00	69.23		75.00
	Shallow Water/Fresh Sedge Marsh	0	0		0
	Snow	0	0		0
	Tussock Tundra	0	21.15		17.19
	Water	0	0		0
	Wet Sedge/Willow (Lowland)	0	0		0
	Wet Sedge/Willow (Watertrack)	0	0		0
	n	1	4	0	5
	P-value	0.999	0.999		0.987
Calving	Barren	0	0	0	0
	Dwarf Shrub Tundra	3.47	7.62	15.38	5.51
	Fresh Grass Marsh	0	0	0	0
	Low Shrub	0	0	0	0
	Moist-Sedge Shrub Tundra	75.68	68.90	7.69	71.51
	Shallow Water/Fresh Sedge Marsh	1.74	0	0	0.94
	Snow	0	0	0	0
	Tussock Tundra	4.22	20.12	76.92	12.50
	Water	0	0	0	0
	Wet Sedge/Willow (Lowland)	10.42	2.44	0	6.72
	Wet Sedge/Willow (Watertrack)	4.47	0.91	0	2.82
	n	33	26	1	60
	P-value	0.590	0.885	0.996	0.476
Post-Calving	Barren	0.80	0	0	0.53
	Dwarf Shrub Tundra	3.81	10.55	15.85	6.50
	Fresh Grass Marsh	0	0	0	0
	Low Shrub	0.33	1.79	8.54	1.32
	Moist-Sedge Shrub Tundra	67.91	64.29	37.80	64.76
	Shallow Water/Fresh Sedge Marsh	0.40	0.16	0	0.31 –
	Snow	0	0	0	0
	Tussock Tundra	7.89	16.88	37.20	12.43
	Water	1.14	0	0	0.75
	Wet Sedge/Willow (Lowland)	15.44	5.52	0.61	11.69
	Wet Sedge/Willow (Watertrack)	2.27	0.81	0	1.71
	n	120	50	13	183
	P-value	0.154	0.968	0.897	0.445
Total	Barren	0.63	0	0	0.39
	Dwarf Shrub Tundra	3.72	9.54	15.82	6.29
	Fresh Grass Marsh	0	0	0	0
	Low Shrub	0.26	1.10	7.91	0.97
	Moist-Sedge Shrub Tundra	69.75	66.06	35.59	66.60
	Shallow Water/Fresh Sedge Marsh	0.68 –	0.10	0	0.45
	Snow	0	0	0	0
	Tussock Tundra	7.06	18.17	40.11	12.55
	Water	0.89	0	0	0.55
	Wet Sedge/Willow (Lowland)	14.29	4.22	0.56	10.25
	Wet Sedge/Willow (Watertrack)	2.72	0.80	0	1.95
	n	154	80	14	248
	P-value	0.047	0.729	0.896	0.110

\+ Significantly greater than availability ($P < 0.05$)
– Significantly less than availability ($P < 0.05$)

Table 14. Use (percentage) of 11 vegetation types by caribou more than 4 km from roads during the pre-calving, calving, and post-calving periods, May–June 2001.

Period	Vegetation Type	Tarn	Meltwater	Reference	Total
Pre-Calving	Barren	0.78	2.08	0	0.83
	Dwarf Shrub Tundra	3.13	22.92	31.25	14.58
	Fresh Grass Marsh	0	0	0	0
	Low Shrub	0	18.75	0	3.75
	Moist-Sedge Shrub Tundra	75.78	22.92	42.19	56.25
	Shallow Water/Fresh Sedge Marsh	0	4.17	0	0.83
	Snow	0	0	0	0
	Tussock Tundra	7.03	10.42	20.31	11.25
	Water	0	0	0	0
	Wet Sedge/Willow (Lowland)	12.50	18.75	1.56	10.83
	Wet Sedge/Willow (Watertrack)	0.78	0	4.69	1.67
	n	10	4	5	19
	P-value	0.992	0.201	0.887	0.983
Calving	Barren	0.09	0	0.51	0.25
	Dwarf Shrub Tundra	4.87	6.95	6.97	6.26
	Fresh Grass Marsh	0	0	0	0
	Low Shrub	0.09	2.28	4.99	2.68
	Moist-Sedge Shrub Tundra	73.71	64.73	55.91	64.03
	Shallow Water/Fresh Sedge Marsh	0.74 –	0	0.44	0.43 –
	Snow	0	0	0	0.00
	Tussock Tundra	3.95	15.93	16.87	12.31
	Water	0.55	0	1.39	0.77
	Wet Sedge/Willow (Lowland)	11.31	3.79	5.50	7.03 –
	Wet Sedge/Willow (Watertrack)	4.69	6.32	7.41	6.23
	n	88	64	109	261
	P-value	0.343	0.683	0.586	0.042
Post-Calving	Barren	0.23	0.55	0.93	0.57
	Dwarf Shrub Tundra	2.65	9.56	11.68	8.01
	Fresh Grass Marsh	0	0	0	0
	Low Shrub	0.79	1.26	4.69	2.27
	Moist-Sedge Shrub Tundra	71.27	59.42	48.74	59.69
	Shallow Water/Fresh Sedge/ Marsh	2.70	0.77	1.36	1.60
	Snow	0	0	0.44	0.15
	Tussock Tundra	4.45	13.51	15.88	11.35
	Water	1.97	0.27	0.87	1.03
	Wet Sedge/Willow (Lowland)	11.15	7.41	6.71	8.40
	Wet Sedge/Willow (Watertrack)	4.79	7.25	8.68	6.93
	n	143	146	147	436
	P-value	0.419	0.662	0.694	0.086
Total	Barren	0.20	0.41	0.74	0.46
	Dwarf Shrub Tundra	3.48	9.02	10.10	7.55
	Fresh Grass Marsh	0	0	0	0
	Low Shrub	0.50	1.88	4.73	2.46
	Moist-Sedge Shrub Tundra	72.35 +	60.34	51.61	61.18 +
	Shallow Water/Fresh Sedge Marsh	1.87	0.60	0.95	1.16
	Snow	0	0	0.25	0.09
	Tussock Tundra	4.38	14.17	16.39	11.69
	Water	1.37	0.19	1.07	0.91
	Wet Sedge/Willow (Lowland)	11.27 –	6.54	6.11	7.97 –
	Wet Sedge/Willow (Watertrack)	4.58	6.84	8.07	6.53
	n	241	214	261	716
	P-value	0.057	0.455	0.365	0.002

+ Significantly greater than availability ($P < 0.05$)
– Significantly less than availability ($P < 0.05$)

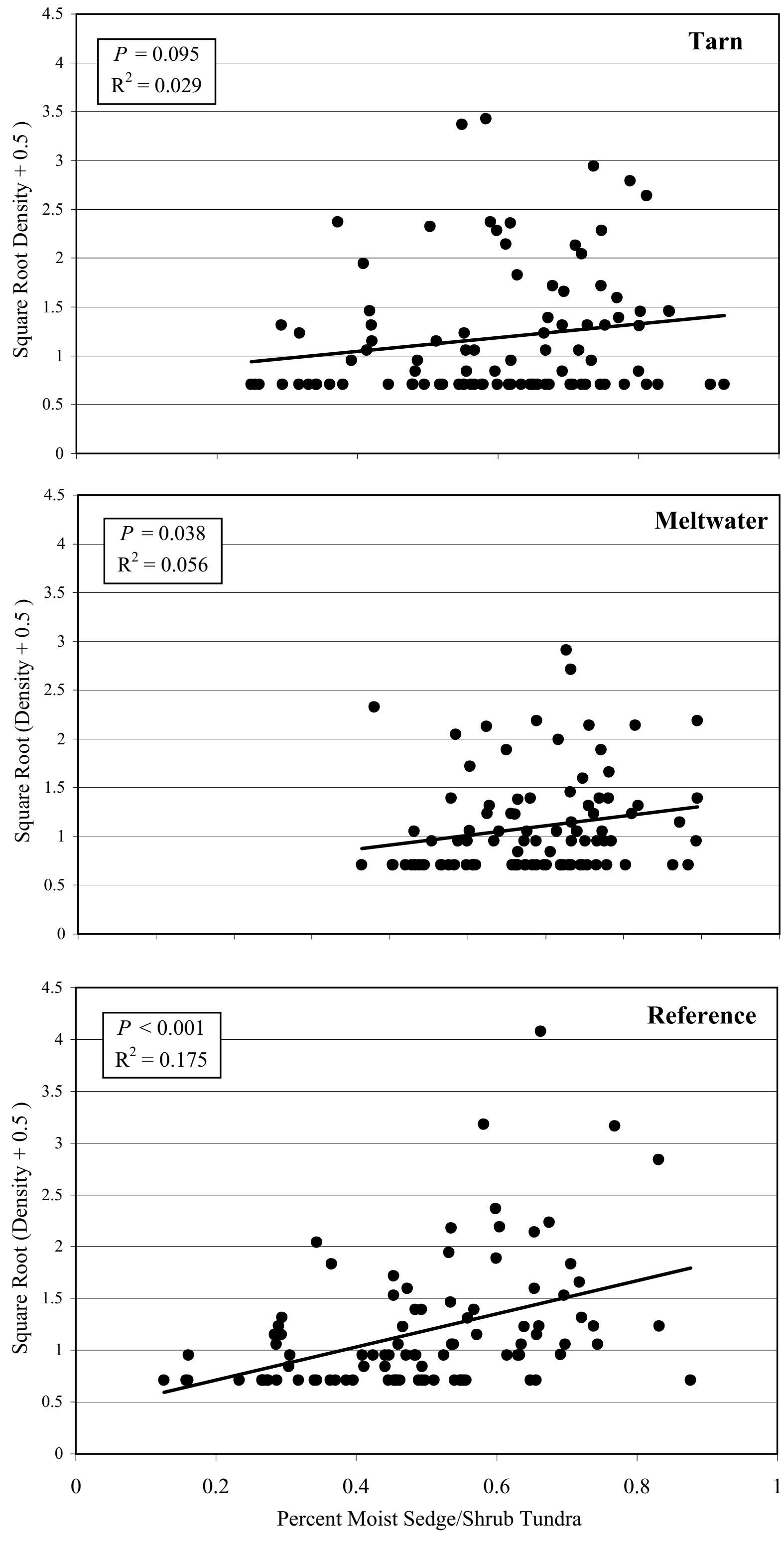


Figure 15. Caribou density (square-root-transformed means) during calving (4–13 June 2001) in relation to the occurrence (percentage) of moist sedge–shrub tundra in the Meltwater study area (96 quadrats, each 2 × 0.8 km, in each of 3 survey blocks).

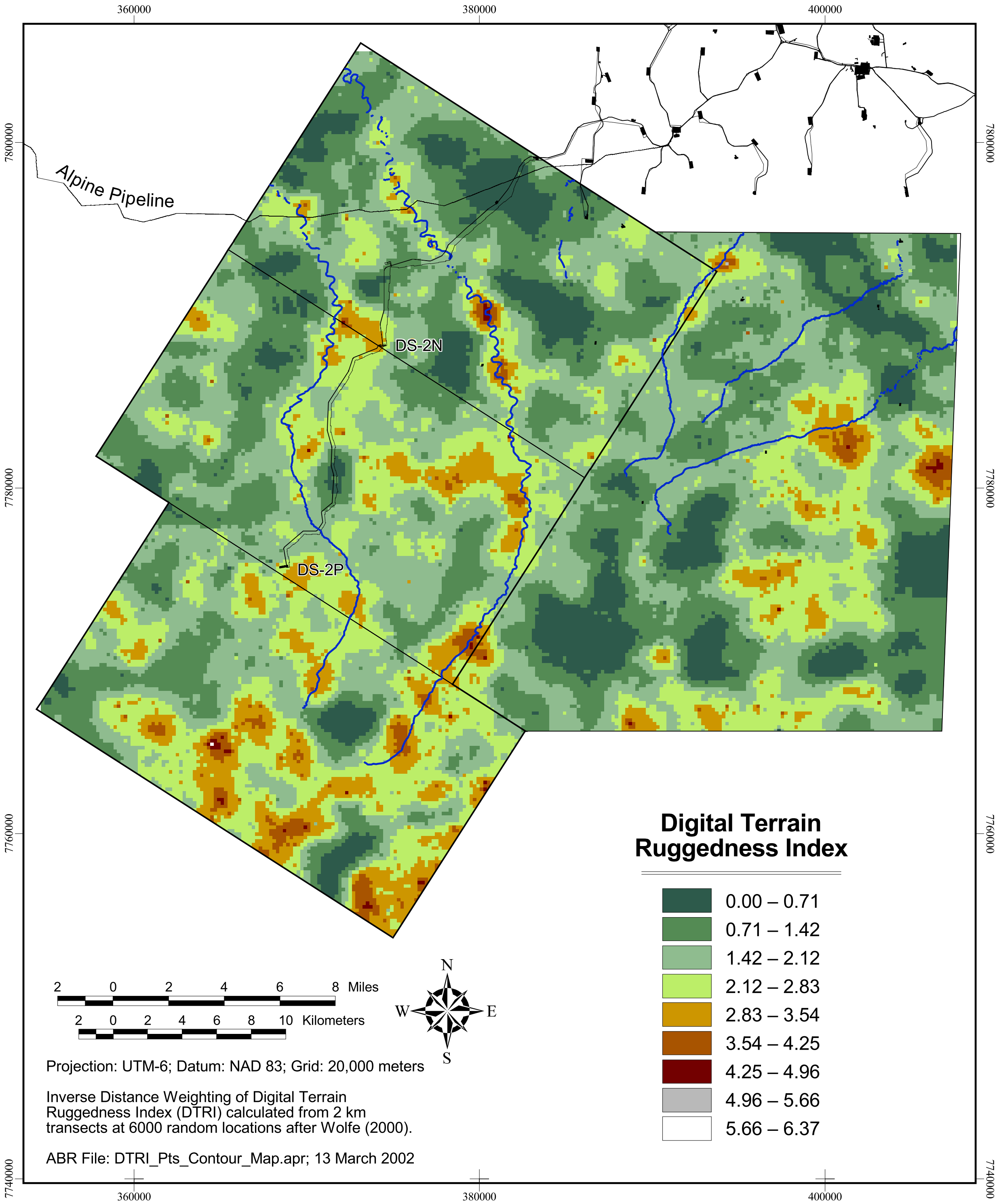


Figure 16. Estimated terrain ruggedness in the Meltwater study area and the Eastern area of concentrated calving, based on Digital Terrain Ruggedness Index (DTRI) calculated from 2-km transects at 5000 random points on Landsat TM image from 14 July 2001.

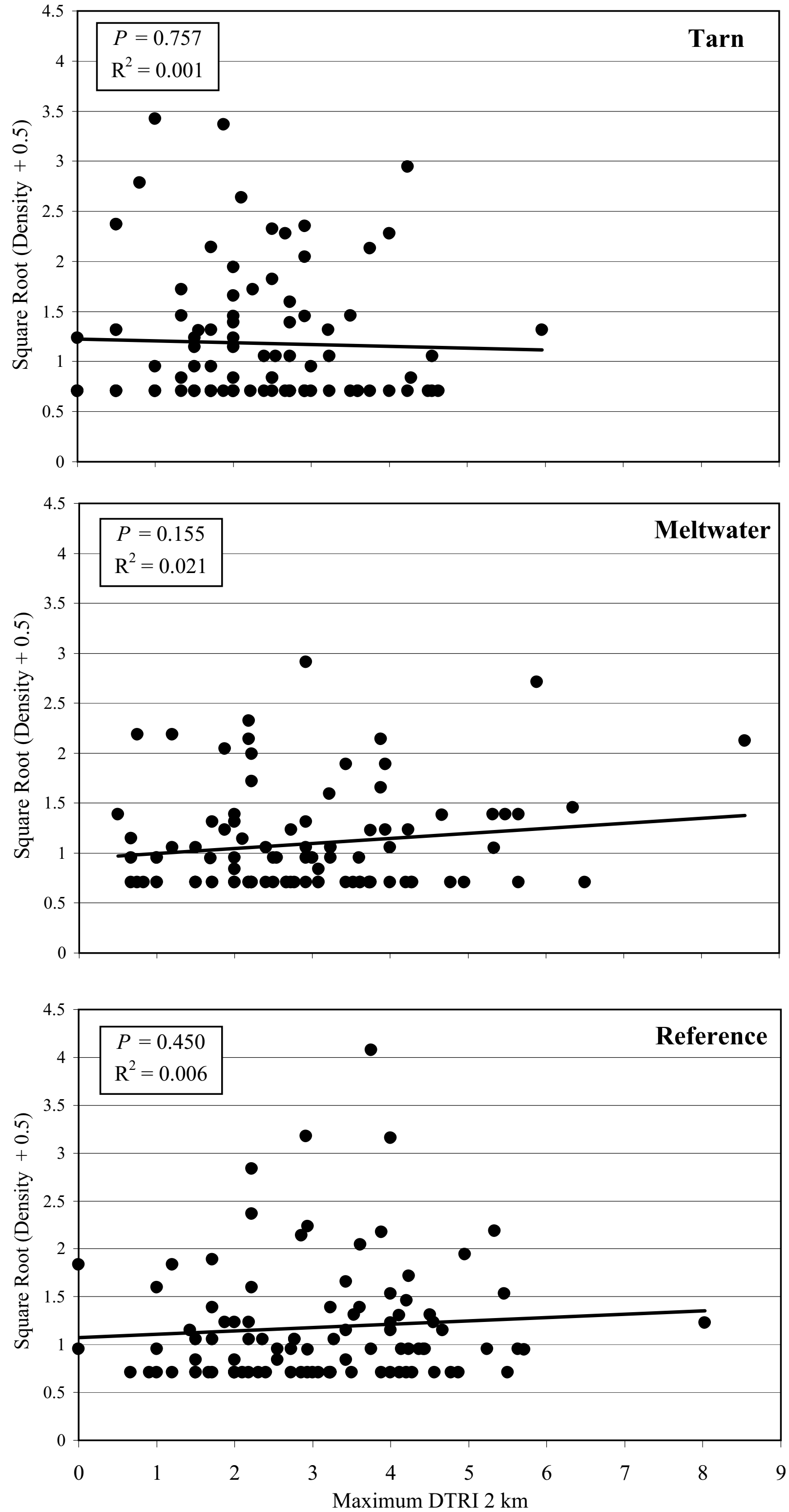


Figure 17. Caribou density (square-root-transformed means) during calving (4–13 June 2001) in relation to terrain ruggedness (maximum DTRI) in the Meltwater study area (96 quadrats, each 2 × 0.8 km, in each of 3 survey blocks).

Table 15. Terrain ruggedness (mean DTRI for 2-km transects) at locations of caribou groups and random points in the Meltwater study area (Tarn, Meltwater, and Reference survey blocks) during the pre-calving, calving, and post-calving periods, May–June 2001. The mean of 2000 random locations in the Eastern area was 1.56.

Dist. to Road	Period	Tarn *n*	Tarn Mean	Meltwater *n*	Meltwater Mean	Reference *n*	Reference Mean	Total *n*	Total Mean
< 4 km	Pre-calving	1	1.33	4	1.40	–	–	5	1.39
	Calving	35	1.27	26	1.82	1	0.89	62	1.49
	Post-calving	121	1.27^{-}	49	1.64	16	2.74	186	1.49^{-}
	All	157	1.27^{-}	79	1.69	17	2.60	253	1.49^{--}
	Random Points	429	1.46	368	1.82	78	2.14	875	1.67
> 4 km	Pre-calving	10	1.39	4	1.82	5	3.25	19	1.97
	Calving	86	1.50	64	1.86	109	2.27	259	1.92
	Post-calving	142	1.44	147	1.80	144	2.14	433	1.80
	All	238	1.46	215	1.82	258	2.22	711	1.84
	Random Points	571	1.43	632	1.75	922	2.15	2125	1.84
Total	Pre-calving	11	1.38	8	1.61	5	3.25	24	1.85
	Calving	121	1.44	90	1.85	110	2.26	321	1.83
	Post-calving	263	1.36	196	1.76	160	2.20	619	1.70
	All	395	1.38	294	1.79	275	2.24	964	1.75
	Random Points	1000	1.44	1000	1.78	1000	2.15	3000	1.79

$^{-}$ Significantly less than random points at P <0.05, based on 2000 Monte Carlo simulations.
$^{--}$ Significantly less than random points at P <0.01, based on 2000 Monte Carlo simulations.

Meltwater survey blocks (all P > 0.990) but was significantly higher in the Eastern concentration area (all P < 0.001; Figure 19, Table 16). NDVI621 was significantly higher in the Meltwater block than the other three areas (all P < 0.001). The Reference block and Eastern concentration area did not differ (P = 0.405), but NDVI621 was significantly lower in the Tarn block than the other areas (P < 0.001; Table 16, Figure 20). In general, the uplands near our study area had higher levels of biomass than did the more coastal areas around the Kuparuk Oilfield (Figures 18–20).

There was a strong correlation between NDVI611 and NDVIrate (r = – 0.541, P < 0.001; Figure 21). Areas with low biomass on 11 June tended to have high rates of growth between 11 June and 21 June, whereas areas with high levels of biomass on 11 June gained little additional biomass over the same period. The exception was the Tarn block, where overall levels of biomass were lower than in the other two blocks, but there was a strong correlation between NDVI611 and NDVI621 (R^2 = 0.490, P < 0.001) and the slope was not significantly different from one (slope = 0.972, 95% CI = 0.769–1.175).

We assessed caribou distribution in relation to the various biomass estimators using Monte Carlo simulations and found that the most pronounced selection occurred during the period between 11 and 21 June (Table 17). Specifically, caribou during this period used areas with high NDVIrate and high NDVI621 values, but appeared to select areas with low NDVI611 values.

NDVI values appeared to be related in part to habitat type. Based on the 288 2×0.8-km transects, NDVI611 was strongly and positively related to the proportion of tussock tundra in the grid cells (slope = 0.272, R^2 = 0.476, P < 0.001). Moist sedge/shrub tundra, on the other hand, was strongly correlated with NDVIrate (slope = 0.009, R^2 = 0.234, P < 0.001).

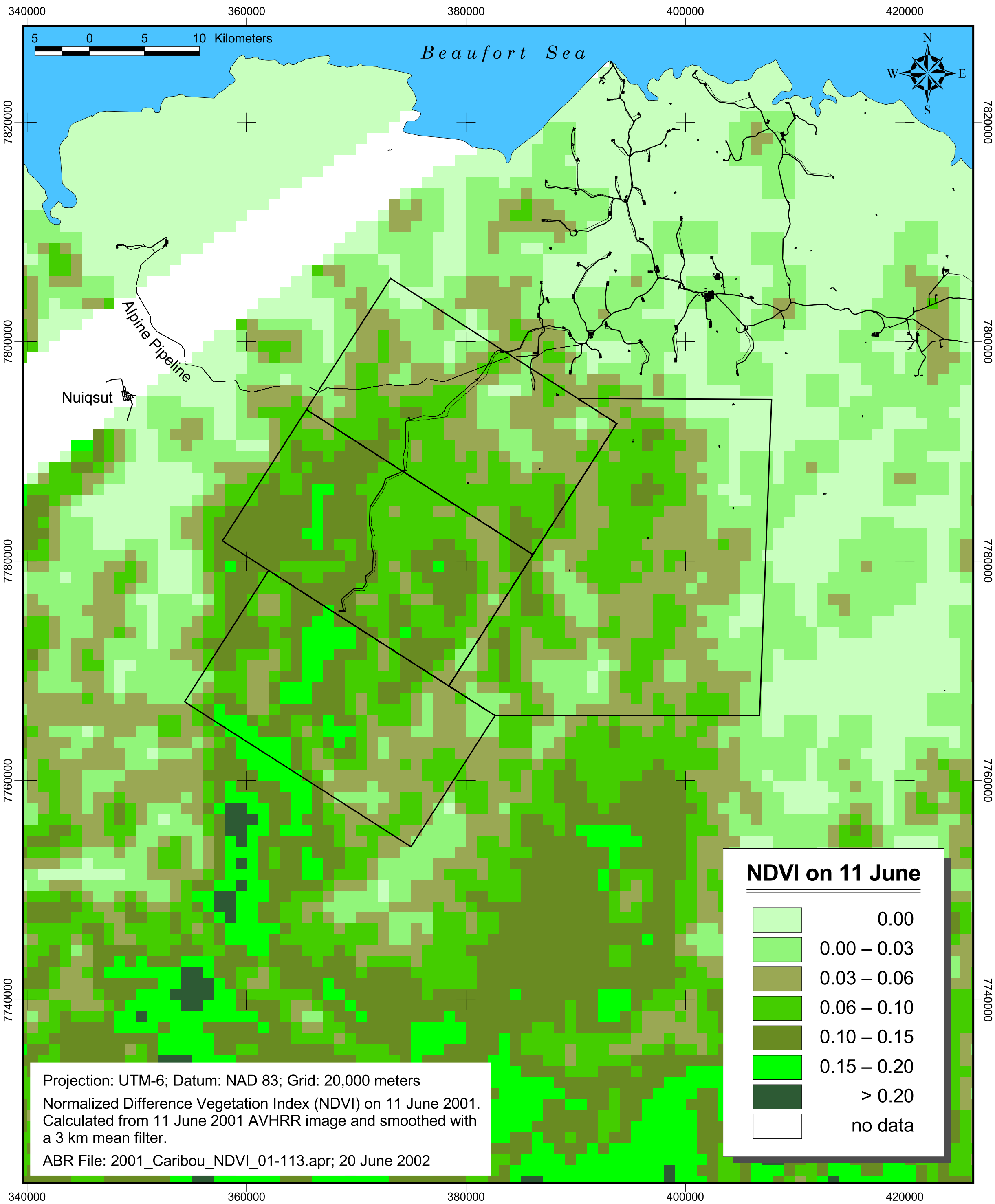


Figure 18. Estimated values of vegetative biomass in the Kuparuk–Colville region on 11 June 2001 (NDVI611), based on AVHRR satellite imagery (1-km pixel resolution).

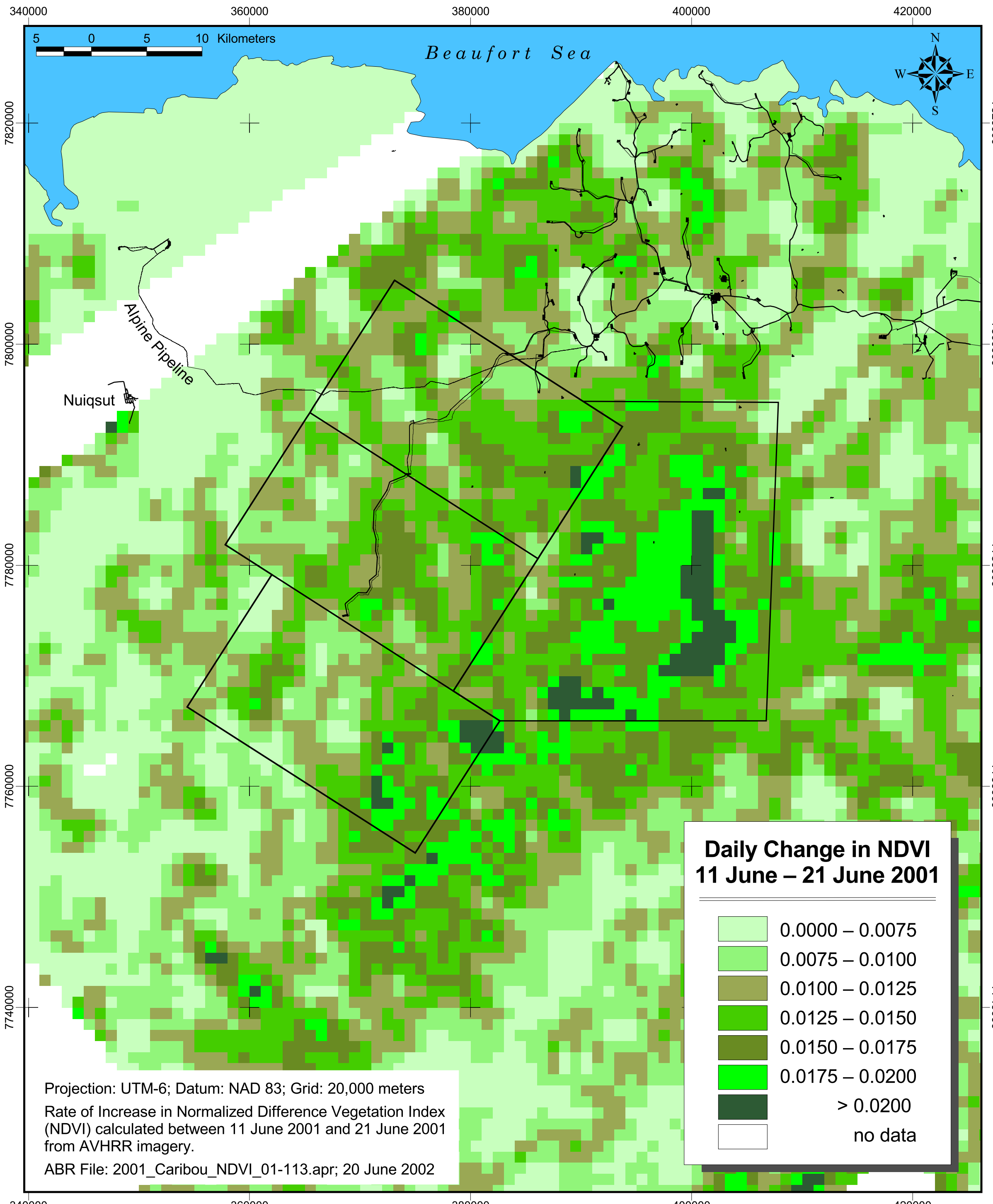


Figure 19. Average rate of daily change in estimated vegetative biomass (NDVIrate) in the Kuparuk–Colville region from 11 June to 21 June 2001, based on AVHRR satellite imagery (1-km pixel resolution).

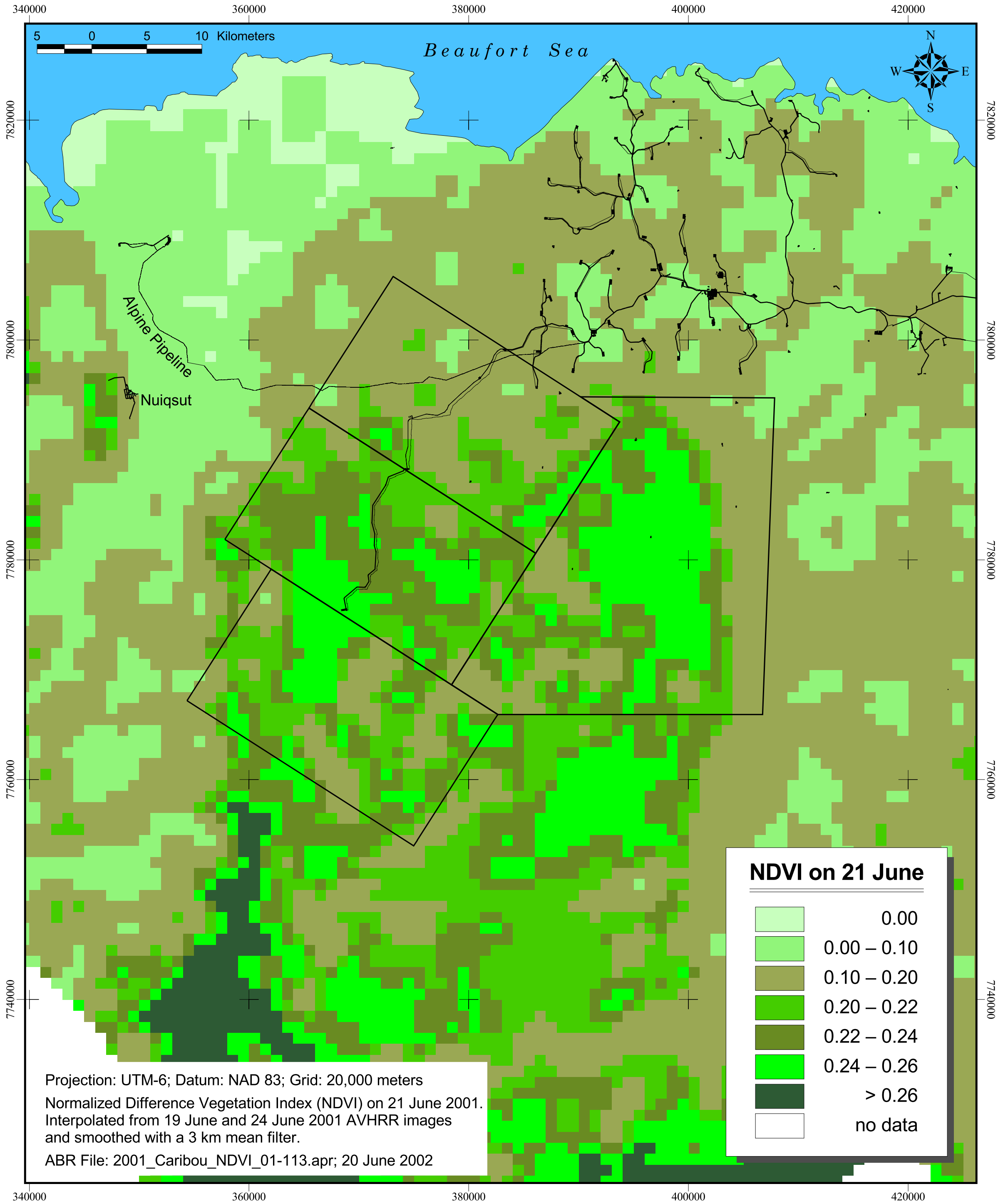


Figure 20. Estimated values of vegetative biomass in the Kuparuk–Colville region on 21 June 2001 (NDVI621), interpolated from AVHRR satellite images taken 19 June and 24 June 2001 (1-km pixel resolution).

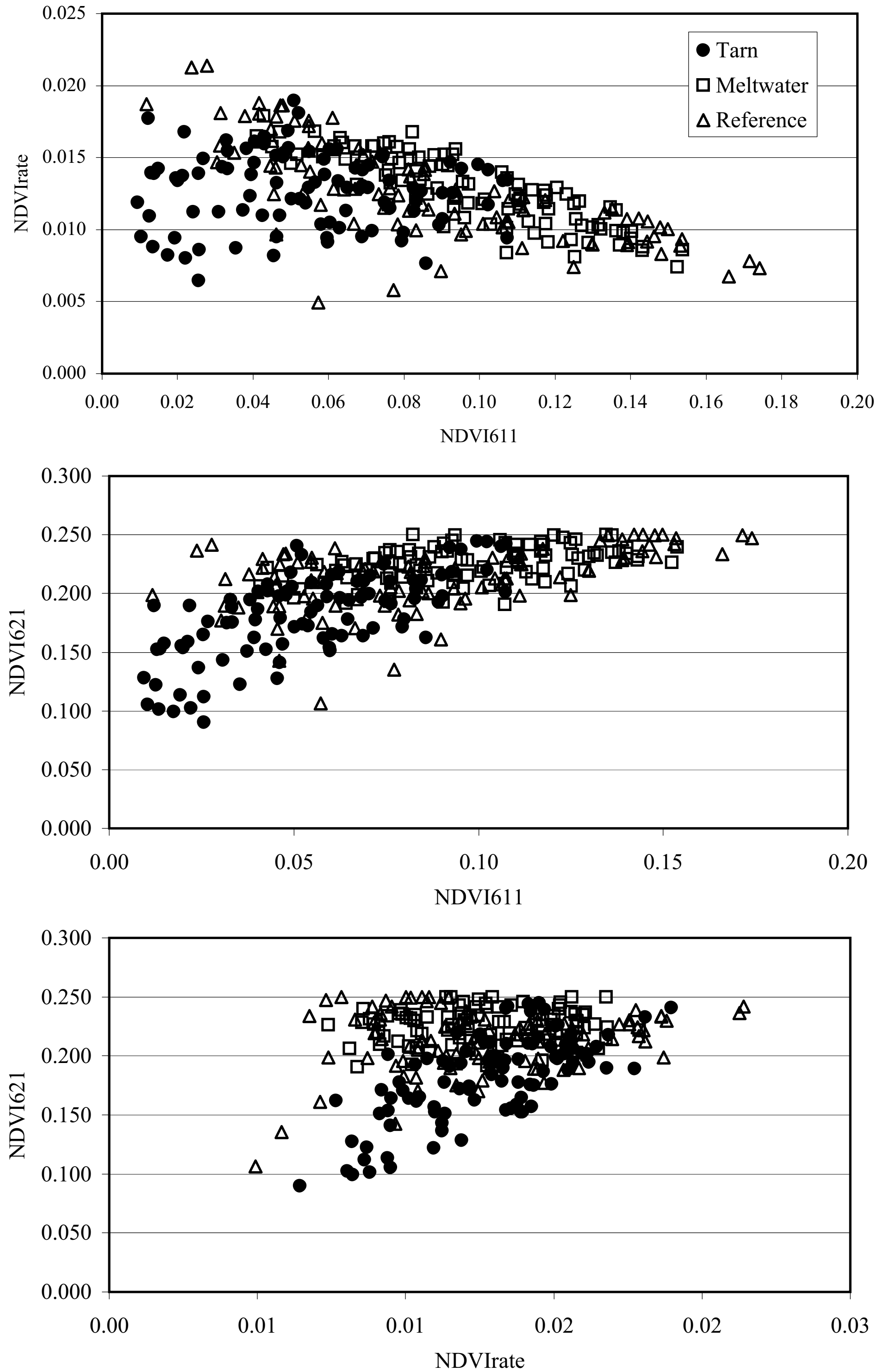


Figure 21. Relationships among estimated values of vegetative biomass (NDVI611, NDVI621, NDVIrate) in 288 quadrats (each 2 × 0.8 km) in the Meltwater study area, June 2001.

Table 16. Estimated biomass values (Normalized Difference Vegetation Index, or NDVI) on 11 June (NDVI611), 21 June (NDVI621), and the average daily rate of change (NDVIrate) during 11–21 June in the Meltwater study area (Tarn, Meltwater, and Reference survey blocks) and Eastern concentration area, 2001.

Area	Statistic	Mean	SD	Max.	Min.
Tarn	NDVI611	0.0542	0.0287	0.1300	0
	NDVIrate	0.0127	0.0028	0.0202	0.0046
	NDVI621	0.1810	0.0393	0.2500	0.0500
Meltwater	NDVI611	0.0979	0.0306	0.1700	0.0100
	NDVIrate	0.0127	0.0028	0.0198	0.0061
	NDVI621	0.2250	0.0171	0.2500	0.1200
Reference	NDVI611	0.0863	0.0428	0.1900	0.0100
	NDVIrate	0.0127	0.0037	0.0220	0.0034
	NDVI621	0.2130	0.0293	0.2500	0.0800
Eastern	NDVI611	0.0470	0.0290	0.1300	0
	NDVIrate	0.0163	0.0030	0.0230	0.0036
	NDVI621	0.2100	0.0398	0.2500	0.0400

DISTANCE TO ROAD

TARN ROAD COMPARISON, 1993–2001

Caribou densities in the Kuparuk–Colville region during the calving season generally were lower in the late springs of 2000 and 2001 than during most other years since 1993 (Figure 22, Table 7). Based on the IDW surface models calculated from eight years of regional surveys, calf densities were lower in the western half of the Tarn and Meltwater survey blocks than in the eastern half, reflecting the broad density gradient mentioned earlier. Near the Tarn road, calf densities were lower between 1 km east of the road and 4 km west of the road in all four years after construction than in all four years prior to construction (Figure 23).

An ANOVA of caribou density during mid-June regional calving surveys showed that caribou density varied among the five distance-to-road categories ($P < 0.001$) and was lower throughout the Tarn survey block after completion of the Tarn road (1998–2001) than prior to construction (1993, 1995–1997; $P < 0.001$). The interaction of distance to road and pre- and post-development was not significant ($P = 0.764$), however, indicating that the decline in caribou densities after 1997 was largely uniform over the entire Tarn block.

A similar result was found for calf density; that is, density varied by distance to road ($P < 0.001$) and was lower throughout the area after completion of the Tarn road ($P < 0.001$), but the interaction of distance to road and pre- and post-development was not significant ($P = 0.908$). In both cases, densities were highest at distances greater than 6 km east of the road and were not significantly different in all other distance categories ($P > 0.05$; Tukey's Multiple Comparison). However, calf densities dropped to close to zero within 2 km of the road in the post-construction years (Figure 24).

Table 17. Estimated biomass (NDVI) values at locations used by caribou groups compared with values for all pixels available within 400 m of aerial survey transects in the Meltwater study area and Eastern area of concentrated calving, May–June 2001.

Area	Period	*n*	NDVI611 Mean	NDVIrate Mean	NDVI621 Mean
Tarn	May 17–June 8	44	0.0598	0.0134	0.1941^{+}
	June 13–20	200	0.0596^{+}	0.0138^{++}	0.1978^{++}
	June 24–28	151	0.0532	0.0129	0.1825
	Available		0.0542	0.0127	0.1817
Meltwater	May 17–June 8	34	0.0991	0.0131	0.2302
	June 13–20	153	0.0928^{-}	0.0132	0.2245
	June 24–28	107	0.1024	0.0122^{-}	0.2244
	Available		0.0977	0.0127	0.2256
Reference	May 17–June 8	40	0.0846	0.0130	0.2149
	June 13–20	171	0.0753^{--}	0.0139^{++}	0.2147
	June 24–28	64	0.1034^{++}	0.0114^{--}	0.2172
	Available		0.0859	0.0127	0.2130
All 3 Survey Blocks	May 17–June 8	118	0.0795	0.0132	0.2115
	June 13–20	524	0.0744^{--}	0.0137^{++}	0.2111^{++}
	June 24–28	322	0.0795	0.0124^{-}	0.2033
	Available		0.0793	0.0127	0.2067
Eastern	June 5–7	81	0.0563^{++}	0.0165	0.2218^{++}
	June 11	240	0.0557^{++}	0.0164	0.2194^{++}
	Available		0.0471	0.0164	0.2107

$^{+}$ Significantly greater than availability at P <0.05, based on 2000 Monte Carlo simulations.
$^{++}$ Significantly greater than availability at P <0.01, based on 2000 Monte Carlo simulations.
$^{-}$ Significantly less than availability at P <0.05, based on 2000 Monte Carlo simulations.

In the four years prior to construction, 16 out of 56 quadrats within 2 km of the road had calves present, whereas in the four years after construction only 1 out of 56 quadrats had calves present (P = 0.001; Fisher's Exact Test; Bonferroni Correction). There were no significant differences in any of the other four distance categories ($P \geq$ 0.865; Fisher's Exact Test; Bonferroni Correction). For total caribou, there were no significant differences in the number of quadrats with caribou after development among distance-to-road categories ($P \geq$ 0.100).

TARN AND MELTWATER ROADS, 2001

As expected from previous years (Figure 9), there was a strong east-to-west gradient in caribou densities in 2001, with the highest densities of caribou occurring east of the Tarn and Meltwater roads. Based on the regional IDW density maps, the calving density near the road in both the Meltwater and Tarn survey blocks was the lowest recorded in all eight years of surveys (Figure 23). In the Tarn block during calving, only 4 out of 121 groups (1 out of 56 groups with calves) were observed west of the Tarn Road. In the Meltwater block, 24 out of 90 groups (12 out of 40 groups with calves) were observed west of the road (Figure 25; Appendix F).

In the Tarn block, the proportion of groups with calves within 2 km of the Tarn road was 40%, compared to an average of 46% for the entire Tarn block during calving; this was not a significant difference (P = 0.751; Fisher's Exact Test). The proportion of groups with calves within 2 km of the Meltwater road was only 18%, compared to an average of 44% for the entire Meltwater block during calving, but this difference was not significant either (P = 0.103; Fisher's Exact Test).

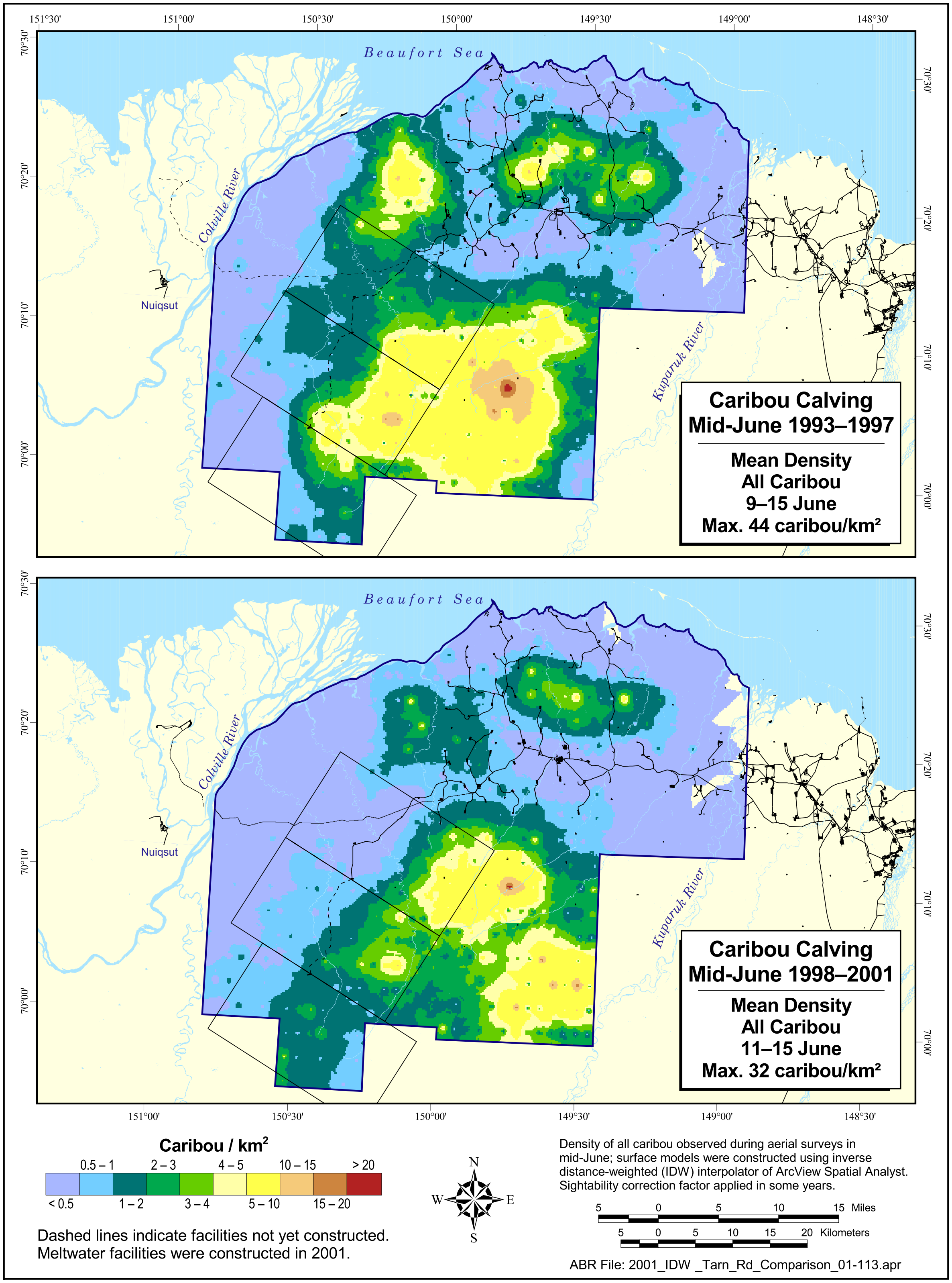


Figure 22. Mean density of caribou observed in regional aerial survey transect segments (3.2 × 0.8-km quadrats) in mid-June 1993 and 1995–1997 (before construction of Tarn road and pads; top), compared with 1998–2001 (post-construction; bottom).

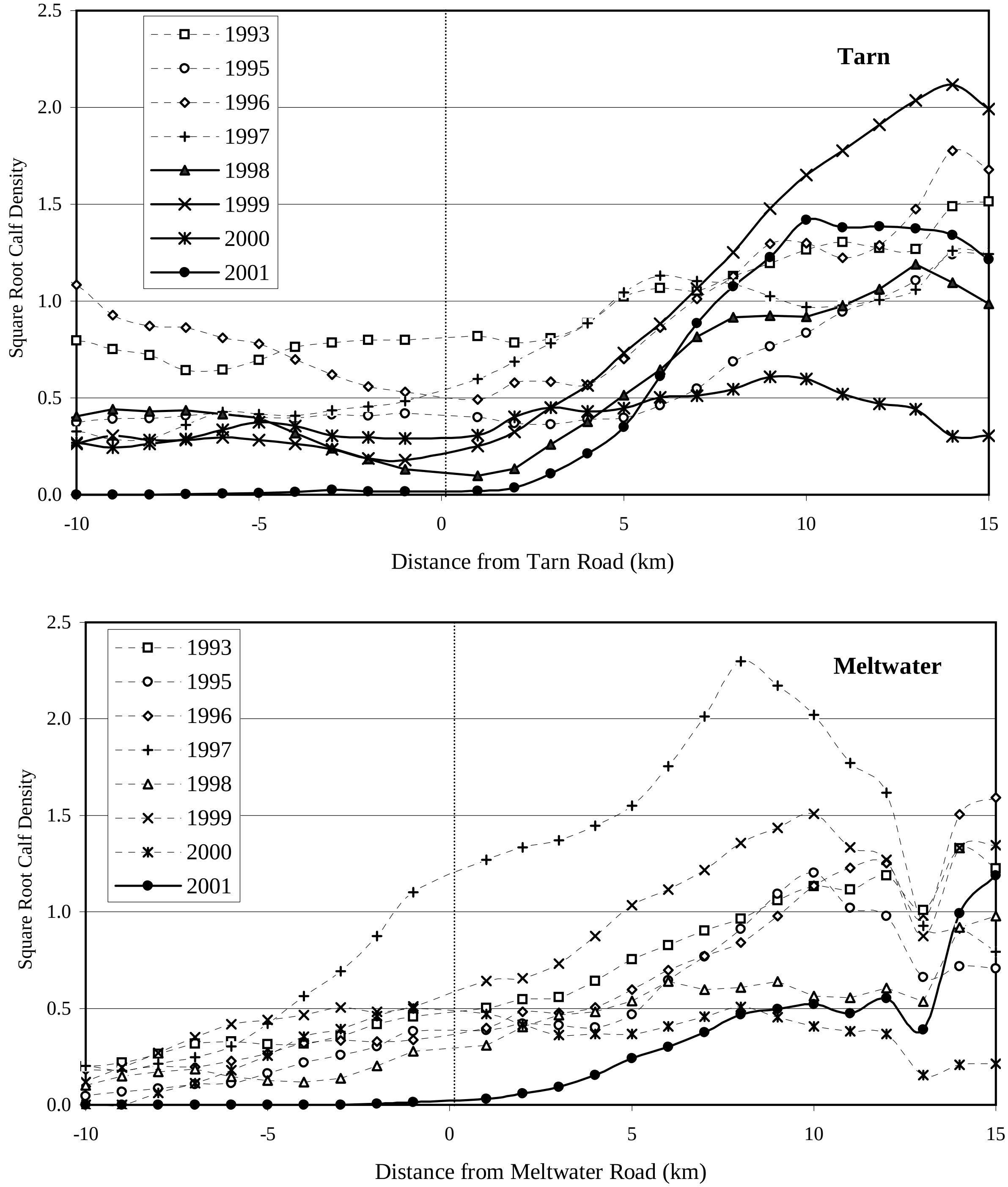


Figure 23. Density of caribou calves in relation to distance from roads during mid-June surveys in 1993 and 1995–2001 in the Tarn and Meltwater survey blocks (based on 3.2 × 0.8-km quadrats).

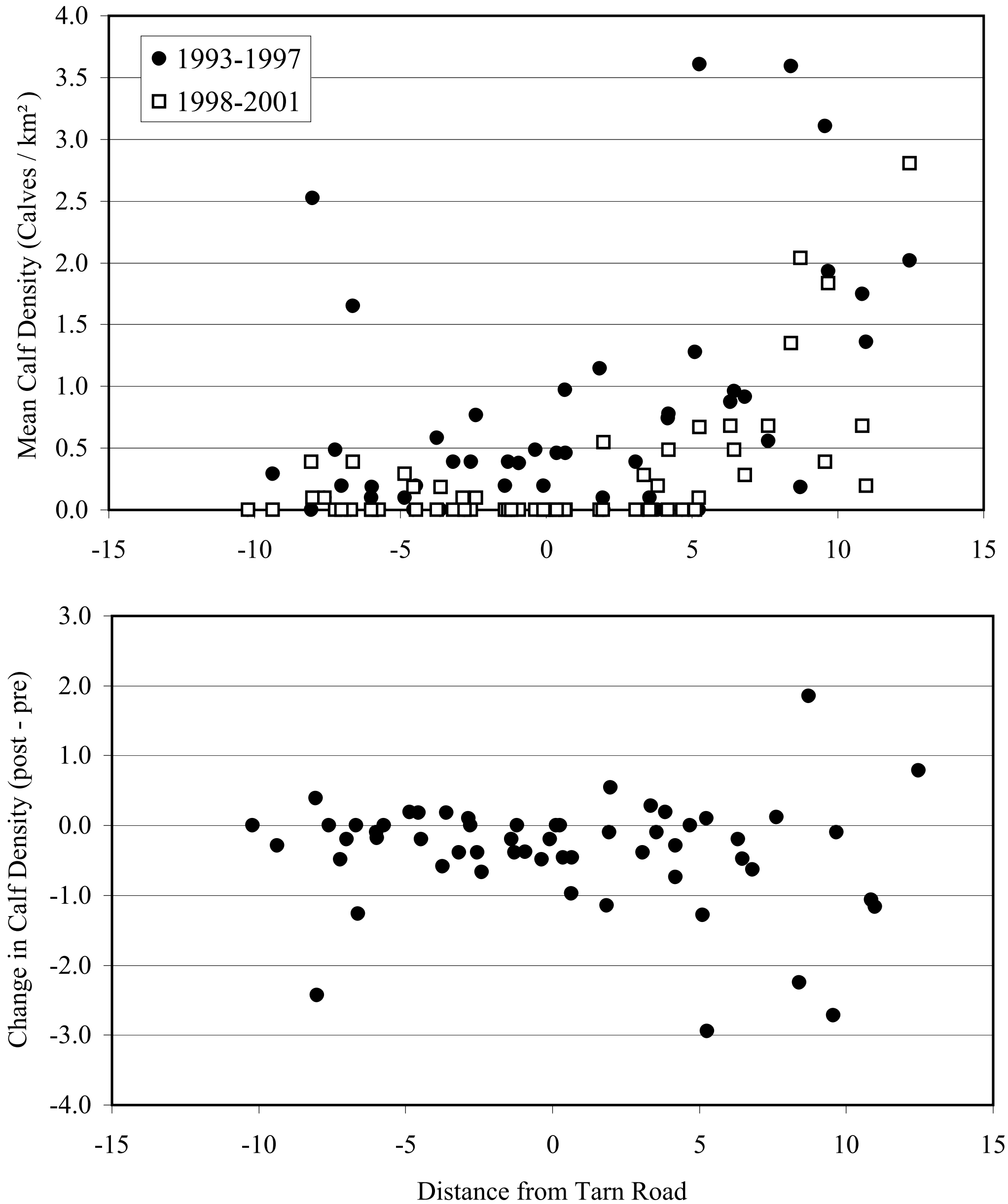


Figure 24. Mean calf density and change in mean calf density from mid-June 1993 and 1995–1997 (preconstruction) to 1998–2001 (post-construction) in relation to distance from the Tarn Road (based on 3.2 × 0.8-km quadrats).

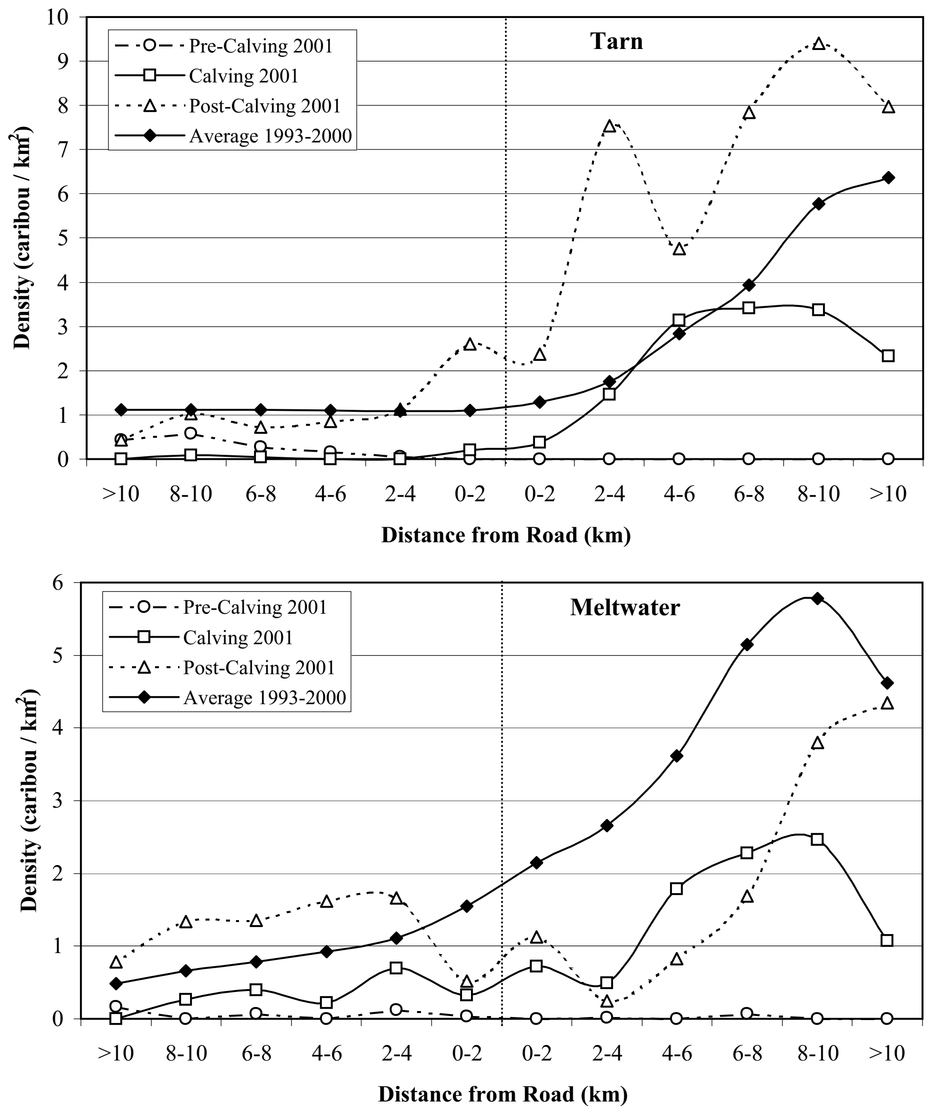


Figure 25. Caribou density in relation to distance from roads and pads in the Tarn and Meltwater survey blocks during the pre-calving, calving, and post-calving periods in 2001, in relation to the mean density for 1993–2000.

The proportion of groups containing calves during the post-calving period was much higher in the Tarn block than the Meltwater block, however (40% vs. 24%; P = 0.001; Fisher's Exact Test; Figure 26).

We used chi-square tests to compare the number of caribou groups observed to the number expected in five distance-to-road categories if distribution was equal to area (Table 18). In the Tarn block, the number of groups with calves, groups without calves, and total groups during calving were less than expected near the road and west of the road, but greater than expected east of the road. During post-calving, the number of calf groups observed was not different from expected, and the number of groups without calves was greater than expected near the road. In the Meltwater block during calving, the number of observed groups with calves was lower than expected near the road, but the number of groups

Table 18. Occurrence of caribou (number of groups) observed in various distance categories from roads in the Tarn and Meltwater survey blocks, 2001, compared with expected numbers (chi-square tests).

			Distance & Direction from Road (km)						
Survey Block	Period	Group Type	> 6 W	2–6 W	2 W–2 E	2–6 E	> 6 E	χ^2	*P*
Tarn	Pre-calving	No Calves	7 +	4	0	0	0	27.1	<0.001
	Calving	Calves	0 -	0 -	4 -	26 +	26 +	49.8	<0.001
		No Calves	2 -	0 -	6 -	31 +	26 +	47.6	<0.001
		Total	2 -	0 -	10 -	57 +	52 +	96.6	<0.001
	Post-Calving	Calves	7 -	5 -	18	36 +	38 +	29.3	<0.001
		No Calves	18	18 -	50 +	35	38	13.8	0.008
		Total	25 -	23 -	68	71	76	26.1	<0.001
	Area (km²)		23.47	28.58	33.04	35.58	37.65		
Meltwater	Pre-calving	No Calves	2	2	1	1	2	0.7	0.952
	Calving	Calves	4	8	2 -	7	19 +	12.0	0.017
		No Calves	5	3 -	9	11	22	11.8	0.019
		Total	9 -	11	11	18	41 +	19.9	<0.001
	Post-Calving	Calves	5	11	3 -	1 -	28 +	30.6	<0.001
		No Calves	36	23	22	22	45	4.7	0.323
		Total	41	34	25	23 -	73 +	15.3	0.004
	Area (km²)		30.43	27.66	29.26	28.10	42.85		

- Significantly less than expected ($P < 0.05$), based on area.
+ Significantly more than expected ($P < 0.05$), based on area.

without calves was not different from expected. During post-calving, the number of calf groups observed was lower than expected near the road and 2–6 km east of the road, whereas the number of groups without calves was not different from expected in any of the five categories (Table 18).

Using 192 2 × 0.8-km quadrats in the Tarn and Meltwater survey blocks, we compared caribou densities within five distance-to-road categories after adjusting for differences in percent moist sedge/shrub tundra, NDVIrate, and maximum DTRI. Significant differences in caribou density were found in relation to distance from road for each survey block during both calving and post-calving (all $P < 0.005$). In all four block/period combinations, the density in the area near the road was significantly lower than in the area ≥6 km east of the road, but not significantly different from the other three distance categories (Table 19).

DISCUSSION

CONVOY AND ROAD SURVEYS

Very few caribou were seen in the Meltwater study area before our 8 June survey, a late date compared with most previous years. For the second year in a row, the late arrival of numbers of caribou likely was due to late snowmelt (Appendix A). Aerial and road surveys in May indicated that a small number of caribou (<50) used the study area consistently, moving little until early June. Because traffic on the Meltwater road ended before caribou moved into the study area in large numbers, we were unable to record the reactions of many caribou to the convoys. Only three groups were seen within 1 km of the road during convoys (25 May–4 June) and three groups were seen in that zone during the period of intensive road maintenance (5–8 June). Of these six groups, one showed overt reactions to vehicles.

Table 19. Mean density (caribou/km²) in survey quadrats (2 km by 0.8 km) by period and distance to road in the Tarn and Meltwater survey blocks, 2001.

Period	Survey Block	Distance Category	Mean	SE	*n*
Calving	Tarn	<6 km W	0.06 [e]	0.02	14
		6–2 km W	0.10 [de]	0.02	18
		2 km W–2km E	0.22 [de]	0.05	18
		2–6 km E	1.25 [d]	0.30	17
		>6km E	3.45 [c]	0.64	29
	Meltwater	<6 km W	0.09 [b]	0.06	19
		6–2 km W	0.21 [ab]	0.12	17
		2 km W–2km E	0.14 [b]	0.09	17
		2–6 km E	0.67 [ab]	0.34	16
		>6km E	1.23 [a]	0.36	27
Post-calving	Tarn	<6 km W	0.65 [h]	0.17	14
		6–2 km W	1.18 [h]	0.28	18
		2 km W–2km E	2.26 [hg]	0.53	18
		2–6 km E	5.73 [fg]	1.39	17
		>6km E	8.21 [f]	1.53	29
	Meltwater	<6 km W	1.32 [ij]	0.30	19
		6–2 km W	1.56 [ij]	0.38	17
		2 km W–2km E	0.84 [j]	0.20	17
		2–6 km E	0.63 [j]	0.16	16
		>6km E	3.21 [i]	0.62	27

Different letters indicate significantly different densities at $\alpha < 0.05$ within a period and study block, based on Bonferroni multiple-comparison tests and GLM model including percent moist sedge–shrub tundra, NDVIrate, and maximum DTRI.

AERIAL SURVEYS

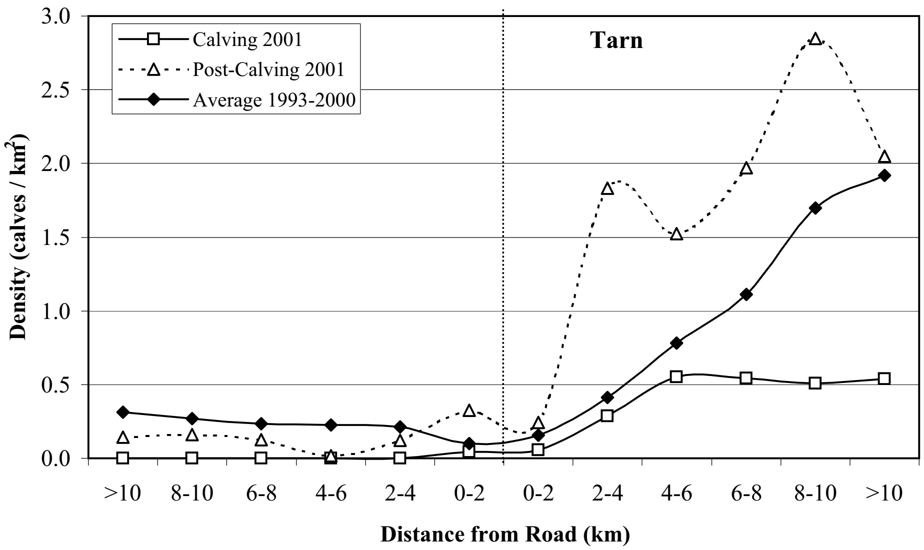
Aerial transect surveys and reconnaissance surveys indicated that most caribou were south of the Meltwater study area until late May when they began moving into the calving area. By mid-June, however, the regional calving distribution was generally similar to previous years (Figures 9–10). As in previous years, the most concentrated calving occurred east of the study area in the upper Ugnuravik and Sakonowyak river drainages. Caribou predominantly were located east of the Tarn and Meltwater roads during calving but were dispersed on both sides of the road during post-calving. Large post-calving nursery bands were observed predominantly in the eastern Tarn block.

Caribou densities in the study area during late summer and fall were low but use was consistent. The low densities agree with the few data available for this period from past years. The large-scale movement of CAH caribou west of the Colville River in July may have affected caribou distribution and movements later in the summer and fall by shifting large numbers of CAH caribou farther west than normal (Burgess et al. 2002).

Hunting opportunities for residents of Nuiqsut appeared to be fairly good in 2001. Large groups of caribou were accessible by boat in the Colville Delta during the large-scale movements in the third week of July, and high densities of caribou were present west of Nuiqsut in fall (Burgess et al. 2002) after enough snow was present to use snowmachines.

ROAD CROSSINGS

We observed a number of road crossings by caribou, particularly during the insect season. Few were observed during May and early June, however, due to fewer caribou being present around infrastructure and because caribou tended to move less at that time of year. Although calving



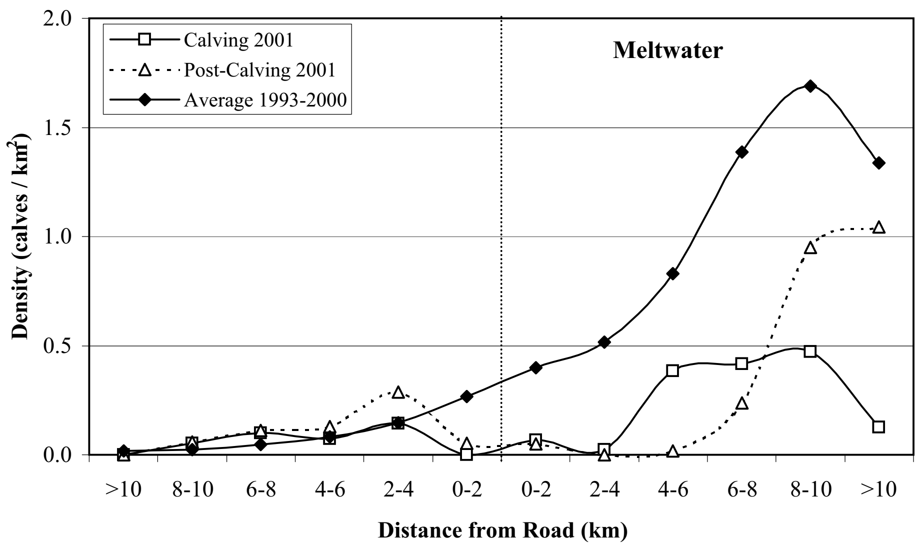


Figure 26. Density of caribou calves in relation to distance from roads and pads in the Tarn and Meltwater survey blocks during the pre-calving, calving, and post-calving periods in 2001, in relation to the mean calf density for 1993–2000.

caribou appeared to avoid areas close to roads, the continued use of calving habitat north of the Spine Road indicates that some caribou crossed roads prior to calving.

As in previous years, the herd used coastal areas for insect-relief habitat and returned inland during periods of low insect harassment. During these insect-induced movements, large groups crossed roads and pipelines. Along with the Kuparuk River, the area around the upper Miluveach and Kachemach rivers continued to be favored habitat during times of low insect activity. After the emergence of oestrid flies in mid-July, scattered small groups and individual caribou were seen on drill pads, under buildings and pipelines, and walking along roads.

VEGETATION TYPES

Similar to previous studies for the CAH (Wolfe 2000) and Teshekpuk and Western Arctic Herds (Kelleyhouse 2001), we found that caribou selected the dominant vegetation type. Caribou selected areas with high percentages of moist sedge/shrub tundra. This vegetation type was the dominant type in all four areas mapped, but was most prevalent in the Eastern concentration area where the highest density of calves was recorded. This vegetation type contains abundant *Eriophorum vaginatum*, which is an important forage species during calving (Kuropat 1984, Martell et al. 1986, Russell et al. 1993). The Eastern concentration area has the lowest percentage of tussock tundra, however, and this vegetation type is dominated by *E. vaginatum* (Appendix E). During post-calving, caribou typically select foraging areas with higher biomass and a higher proportions of *Salix* leaves (White et al. 1975, Martell et al. 1986, Russell et al. 1993).

Wolfe (2000) used the six-category vegetation classification of Muller et al. (1999) and reported that female CAH caribou selected wet graminoid tundra and moist graminoid, prostrate-shrub tundra during calving in 1980–1995. Moist graminoid, prostrate-shrub tundra corresponds to moist sedge/shrub tundra in our classification (Appendix G), and wet graminoid tundra corresponds to either shallow water/fresh sedge marsh or wet sedge/willow meadow (lowlands) in our classification. We also documented selection of moist sedge/shrub tundra, but found a tendency to avoid lowland types in our study area (Table 14); this difference may have been due to the scales of the different studies or to a difference in the classifications.

We tested for selection of vegetation types by caribou using two methods: comparing use versus availability for all vegetation types, and comparing caribou density on transect quadrats to the percentage of moist sedge/shrub tundra in that quadrat. While these methods produced generally similar results, the quadrat method was able to identify significantly higher densities of caribou on moist sedge/shrub tundra-dominated quadrats in all three study blocks, perhaps because the quadrat method takes group size into account.

Even where significant differences were found, the relationships were not strong (Figure 15). Thus, it appears that vegetation type is not a strong predictor of caribou location at this scale of analysis. Habitat selection by caribou likely involves other criteria also, such as snow cover, terrain features, vegetation phenology and biomass, and the presence of specific forage species, rather than vegetation type alone. In addition, caribou distribution during and immediately calving may be partly determined by the risk of predation.

TERRAIN RUGGEDNESS

Caribou showed no selection for rugged terrain within any of the survey blocks. Over all three blocks combined, caribou used significantly more rugged terrain during calving than during post-calving. This corresponds to a general movement of caribou from the more rugged areas in the south to the less rugged Tarn block to the north after calving.

Our analyses showed little indication of selection or avoidance of rugged terrain by caribou. When studying habitat selection, the scale of interest must be identified (Johnson 1980), and habitat selection by caribou can be considered at several scales. At the broadest scale, caribou are avoiding rugged terrain by selecting the coastal plain over the foothills of the Brooks Range. On the coastal plain, however, calving in the uplands south of the Kuparuk Field rather than closer to the coast indicates that caribou are selecting relatively rugged terrain.

We looked for selection at two smaller scales, within each of the three 24.5 × 13.6-km survey blocks (Tarn, Meltwater, and Reference) and within all three blocks combined. In both cases, there was no selection for rugged terrain during calving. In a study area closer to the coast, Nellemann and Cameron (1996, 1998) concluded that caribou selected rugged terrain to utilize the higher quantities of graminoid species and *Eriophorum vaginatum* flowers they found on quadrats with a higher ruggedness index (Nellemann and Thomsen 1994).

Wolfe (2000) compared annual concentrated calving areas used by radio-collared cows in 1980–1995 to the total calving grounds (over all years, not the annual extent of calving) and concluded that CAH caribou calving to the west of the Sagavanirktok River selected rugged terrain, whereas caribou calving east of the Sagavanirktok River avoided rugged terrain. Unfortunately, Wolfe (2000) used habitats on both sides of the river to calculate availability while constraining habitats used to one side or the other. Therefore, his results may reflect inherent differences in terrain ruggedness between east and west rather than selection by caribou.

Kelleyhouse (2001) found that the Western Arctic and Teshekpuk Lake herds neither selected nor avoided rugged terrain during calving but that concentrated calving areas had less rugged terrain than was available. Both Kelleyhouse (2001) and Wolfe (2000) tested for selection of rugged terrain at a much larger scale than this study.

NDVI

NDVI in June is strongly influenced by the timing of snowmelt and plant phenology, and 2001 was a year of late snowmelt. Due to persistent cloud cover, our first NDVI values were calculated on 11 June, a day later than the calving period used in previous studies (1–10 June; Wolfe 2000, Kelleyhouse 2001). Even so, because of the late snowmelt in 2001, 11 June corresponded closely to the period immediately after snowmelt over much of the study area. Differences in snowmelt among areas likely contributed to differences in NDVI611, which in turn affected NDVIrate. The fact that there was a significant negative correlation between NDVI611 and NDVIrate suggests that the rate of plant emergence is not constant and that there is an initial flush of biomass immediately after snowmelt, after which the rate of increase in NDVI slows. This initial flush of green plant growth likely provides forage that is high in protein and digestibility. Our results indicate that NDVI may be a useful tool to identify the emergence of new vegetation but the timing of the imagery in relation to the disappearance of snow cover must be considered when interpreting the results.

Differences were apparent in the rate of green-up among vegetation types. NDVI611 increased with an increasing proportion of tussock tundra, indicating that tussock vegetation was among the first to grow after snowmelt or that snow in areas dominated by tussock tundra had melted earlier. The relationship between vegetation type and NDVI611, NDVI621, and NDVIrate likely would be different in a year of early snowmelt.

Caribou appeared to calve in areas of high NDVIrate (e.g., calving densities were highest in the Eastern concentration area and in the eastern portions of the three survey blocks), especially during the period between 11 June and 21 June (Table 17). After 21 June, caribou generally used areas of lower NDVIrate, consistent with selection for areas of newly emerging vegetation. Areas with low NDVIrate before 21 June are more likely to have a flush of new growth after 21 June.

Wolfe (2000) found that NDVIrate was higher near the coast where concentrated calving occurred in the 1980s and early 1990s, and therefore concluded that habitat quality was lower in the concentrated calving areas used in recent years. Our results indicate that the highest rates of NDVI increase were in the Eastern concentration area where concentrated calving has occurred in recent years. This difference is likely due to the large difference in standing water between the uplands and the wetter coastal areas. Wolfe (2000) applied a water correction factor, whereas we concluded (following Kelleyhouse 2001) that a reliable water correction was not available and so we did not correct for differences in percent standing water. Therefore, our results likely underestimate the true biomass levels in areas with large amounts of standing water; Wolfe's water correction may have overestimated biomass levels (S. Wolfe, pers. comm.). The values of NDVI621 show that the lowest values often correspond to the areas with large lakes. In the absence of an accepted water correction factor and due to differences in phenology among vegetation types, it is difficult to compare habitat quality among locations within a year solely on the basis of NDVIrate.

DISTANCE TO ROAD

TARN ROAD COMPARISON 1993–2001

Densities of caribou calves appeared to be depressed close to the Tarn road after road construction based on IDW maps (Figure 23), and the proportion of quadrats with calves was lower within 2 km of the road. This corresponds to earlier studies that show that calving caribou avoid roads even with low levels of traffic (Dau and Cameron 1986).

TARN AND MELTWATER ROADS, 2001

Because the Tarn and Meltwater roads are at the western periphery of the most concentrated calving activity and calving distributions fluctuate among years (Lawhead and Prichard 2001), it is difficult to definitively identify the cause of lower calving densities around the Meltwater and Tarn roads from one year's data. The late snowmelt in 2001 confounded our assessment by depressing the numbers of caribou in the study area. Surveys in subsequent years of this study will elucidate the relationship between the effects of snow conditions and human activities on calving distribution.

The distribution of caribou relative to the road could not be explained by vegetation type, NDVIrate, or terrain ruggedness. Even after adjusting for differing proportions of moist sedge/shrub tundra, NDVIrate, and terrain ruggedness, caribou densities were still higher >6 km east of the road than near the road or west of the Tarn road during calving and post-calving and the Meltwater road during post-calving (Table 19). However densities within 2 km of the road did not differ significantly from densities 2–6 km east of the road after correcting for these variables.

Calving occurred west of the Meltwater road in greater numbers than within 2 km of the road (Figures 6, 26). It is not known how many of these caribou crossed the road from east to west or moved north from southwest of the Meltwater pad (DS-2P). The higher number of caribou west of the Meltwater road than west of the Tarn road may reflect an increased crossing rate of the Meltwater road due to limited traffic. Again, surveys in future years when the road is in better condition will allow a better assessment of the potential effects of convoy traffic on use of the area near the road.

CONCLUSIONS AND EVALUATION OF MITIGATION EFFECTIVENESS

Few caribou were present in and around the Kuparuk survey areas (including Meltwater) during early road and aerial surveys in May and early June. Large numbers of caribou were not observed in the study area until 8 June, which was later than normal, presumably due to the cold, late spring in 2001.

Because the structural condition of the Meltwater road deteriorated and traffic ceased before large numbers of caribou migrated into the area, we were unable to assess the effectiveness of convoying on calving caribou during 2001. However, the data collected in 2001 while the road had little or no traffic will provide a useful comparison for future years.

The distribution of caribou during calving was similar to recent years. As expected, the highest densities of calving caribou occurred east of the study area and densities decreased in the western half of the study area. Because of this pre-existing density gradient, it is challenging to evaluate the potential displacement of caribou by the road. Based on aerial surveys conducted in four years preceding and four years following construction of the Tarn road, it appears that there has been moderate displacement of cows and calves caribou near the road, consistent with previous studies in the region.

It also appears that caribou groups with calves avoided an area ~2 km away from both the Tarn and Meltwater roads. Caribou densities were lower near the road than east of the road but the quadrat analysis did not show a definitive decrease in caribou numbers due to the presence of the road. Calf densities appeared to be more strongly affected by the road than adult densities. Both the Tarn and Meltwater roads are located on the western edge of concentrated calving, although there were more caribou west of the Meltwater road than the more heavily trafficked Tarn road.

Caribou movements during the insect season were similar to previous years, with the exception of an unprecedented large movement of the western segment of the herd onto and west of the Colville Delta following prolonged westerly winds in the third week of July. The highest numbers of caribou in the Meltwater study area in the insect season occurred when insect activity was suppressed by cool weather. Caribou appeared to prefer areas near the Kachemach and Miluveach rivers, as well as the bluffs along the Itkillik River, at such times. We detected no indications of caribou movements changing due to the Meltwater road or pipeline during the insect season. The Meltwater study area had very low densities of caribou during August–October. The fall densities during 2001 may have been unusually low due to the large numbers of CAH caribou that had moved west of the Colville River in July.

The naturally occurring gradient of higher calving densities to the east of the Meltwater study area, the shutdown of the Meltwater road, and the late spring in 2001 posed challenges for the interpretation of calving data and effectiveness of mitigation. As more data are collected in future years of varying weather conditions and after the Meltwater road becomes serviceable, we will be better able to evaluate the effectiveness of the current mitigation measures.

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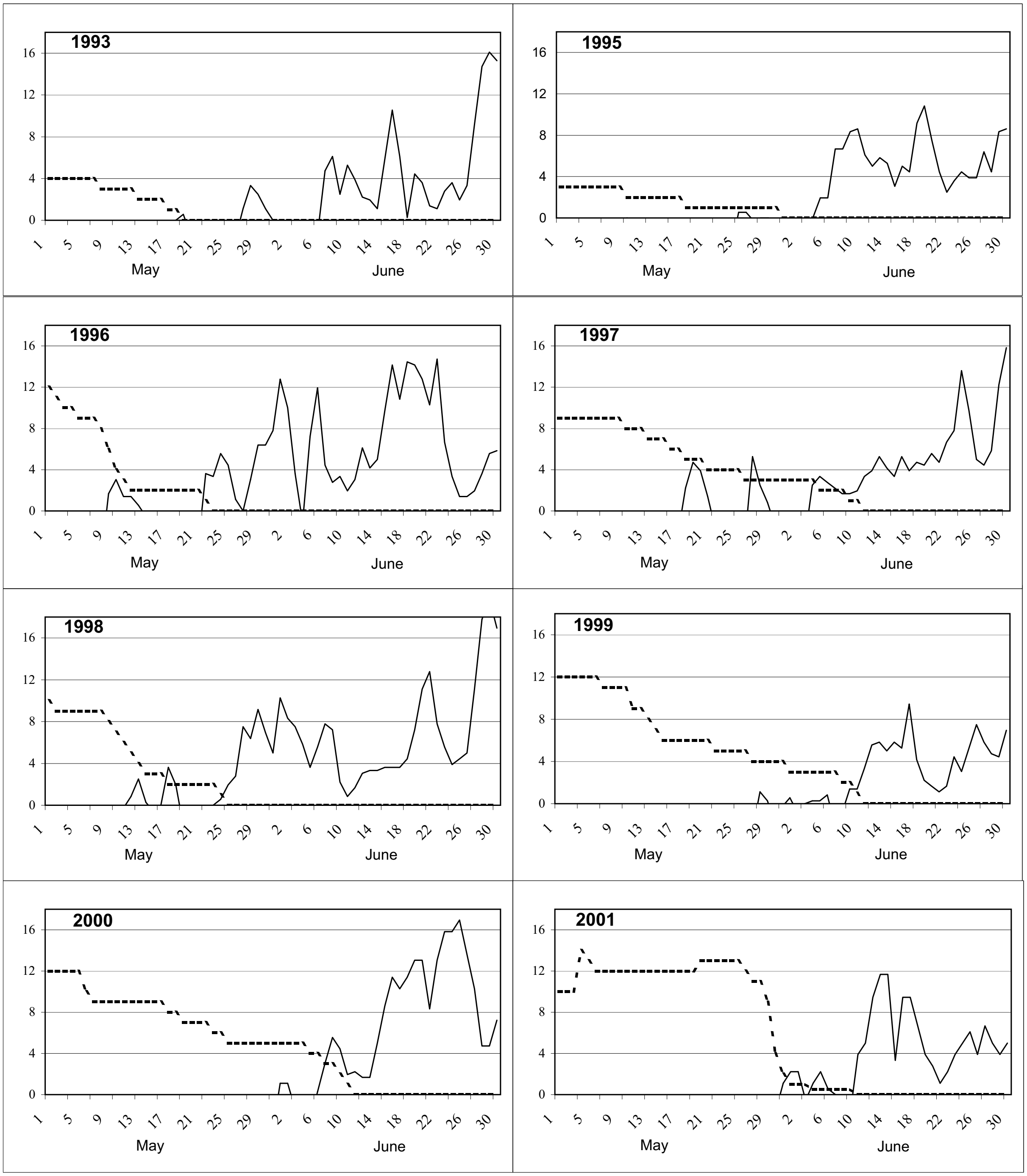
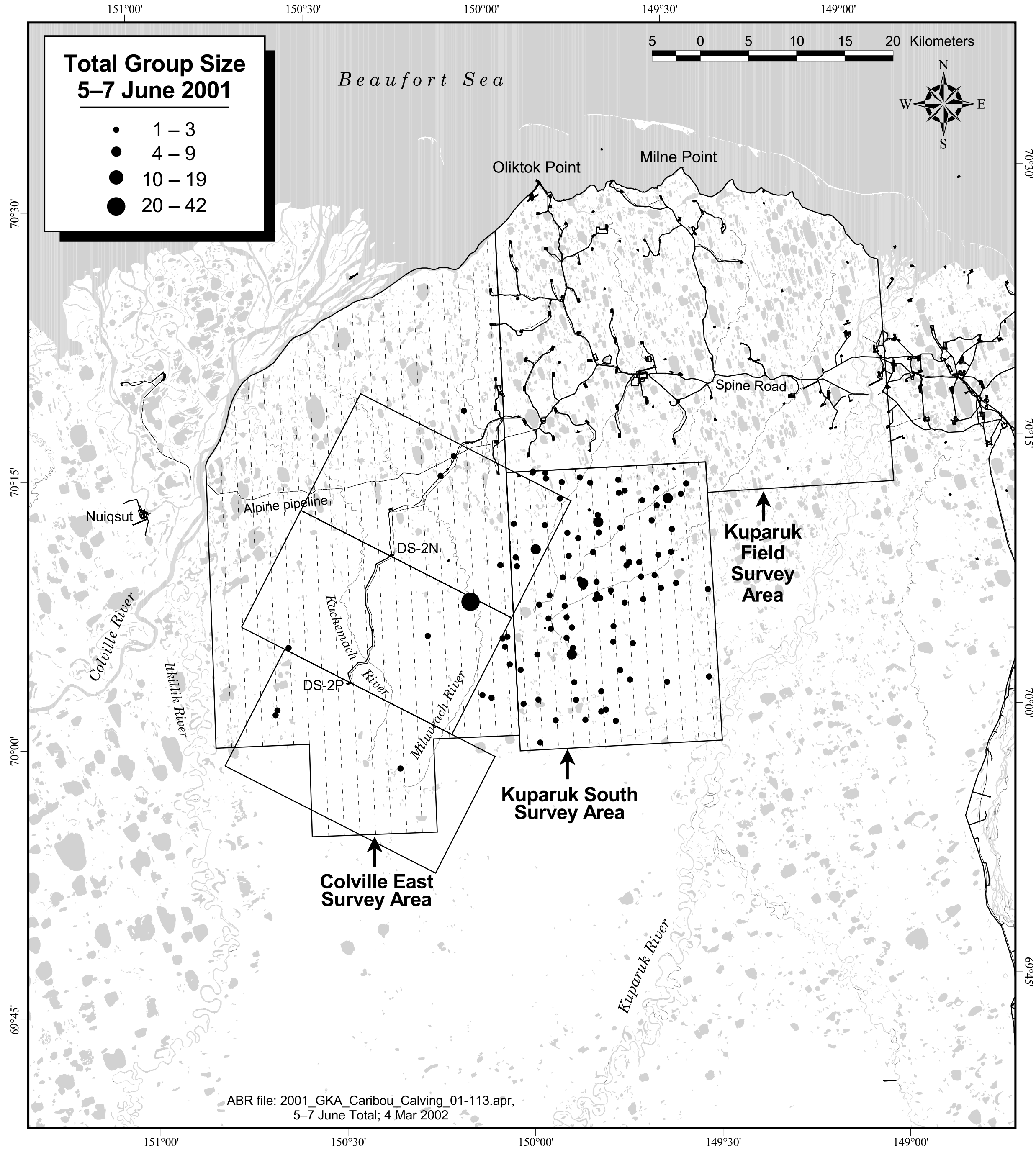
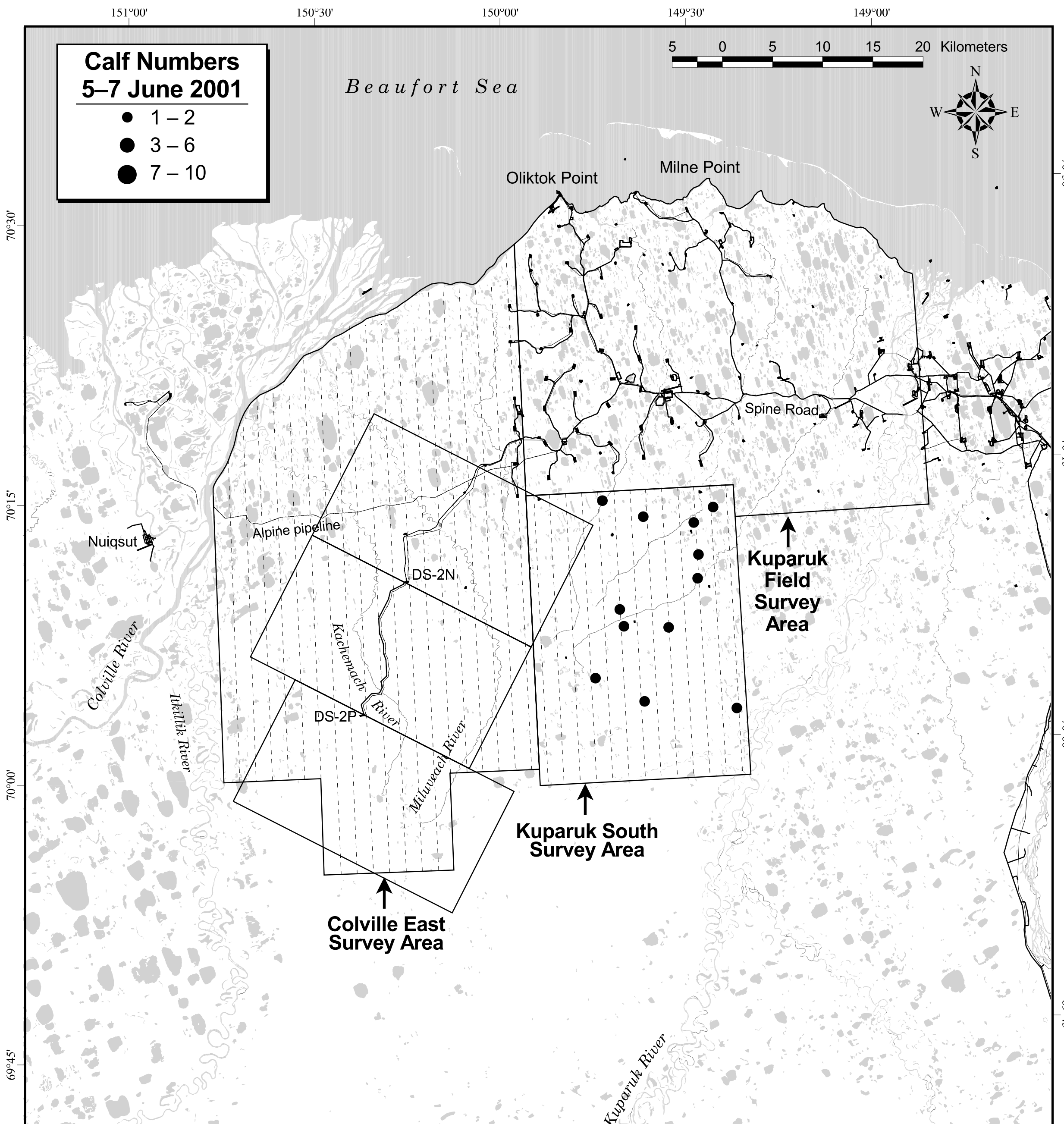


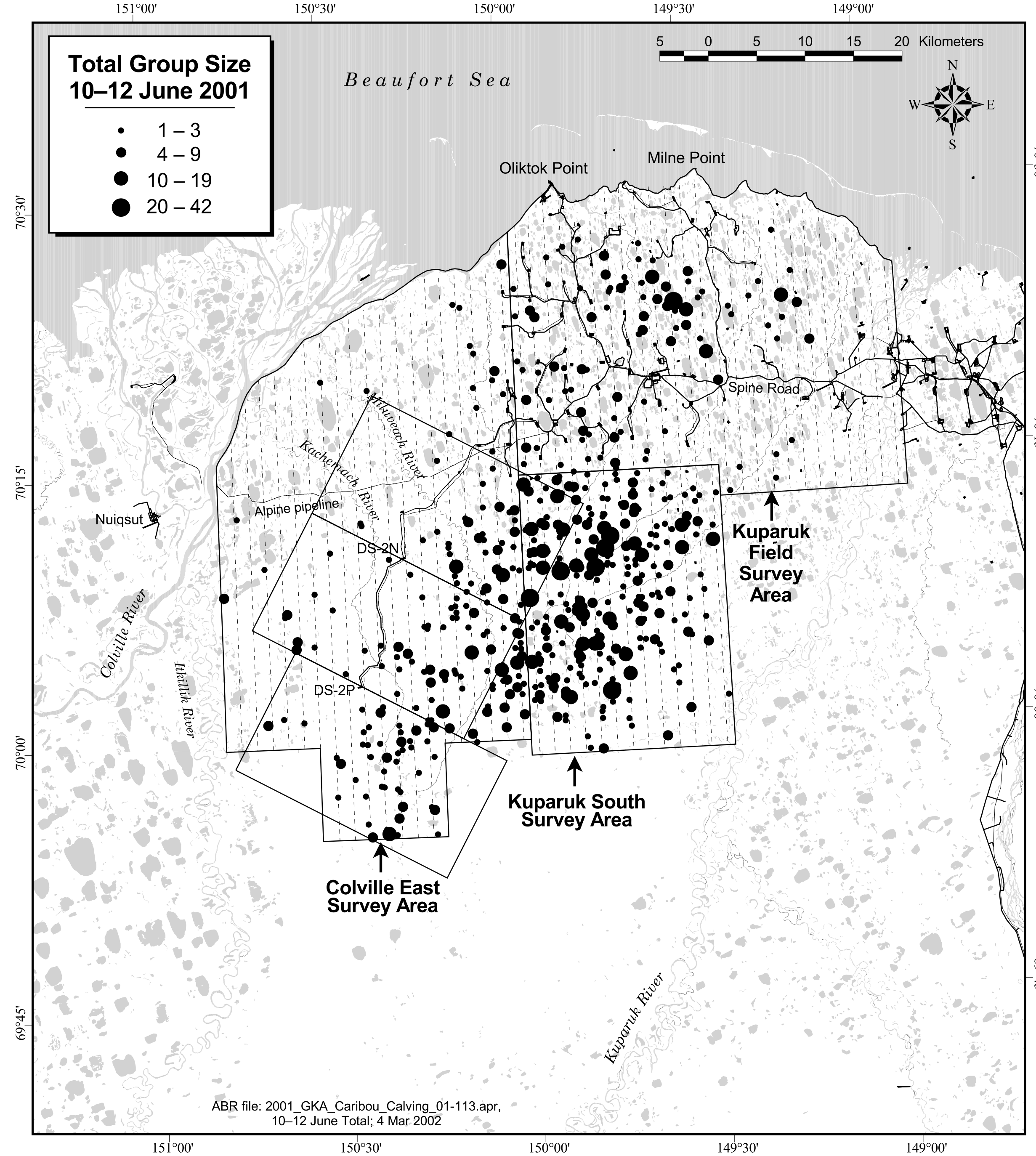
Appendix A. Snow depth (inches; dashed lines) and average daily temperature (º C; solidlines) at the Kuparuk airstrip, May–June 1993–2001.



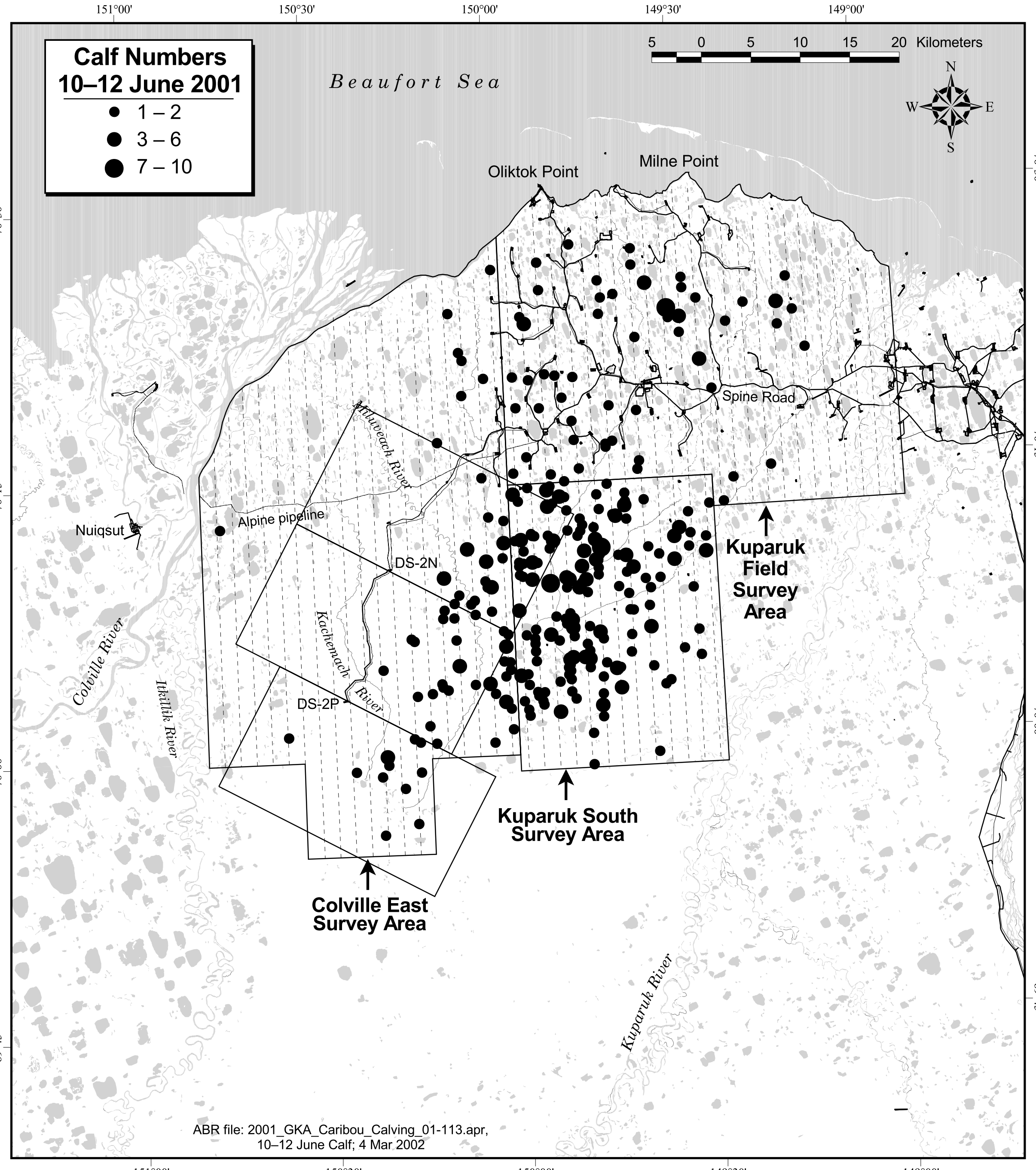
Appendix B. Distribution and abundance of caribou during regional calving surveys in early and mid-June 2001.



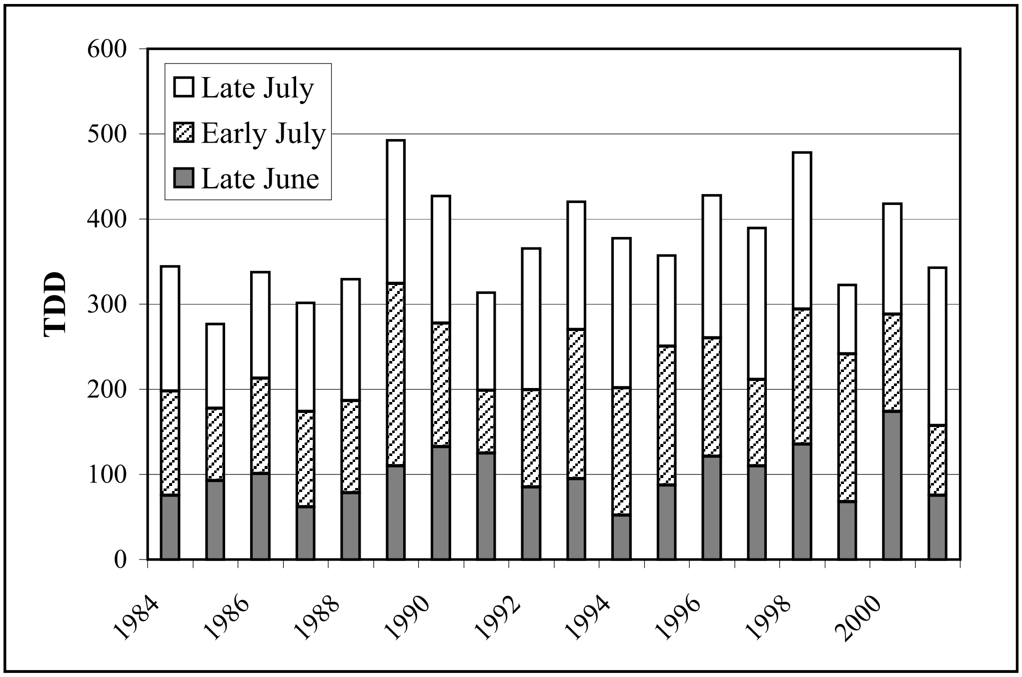
Appendix B. (Continued).



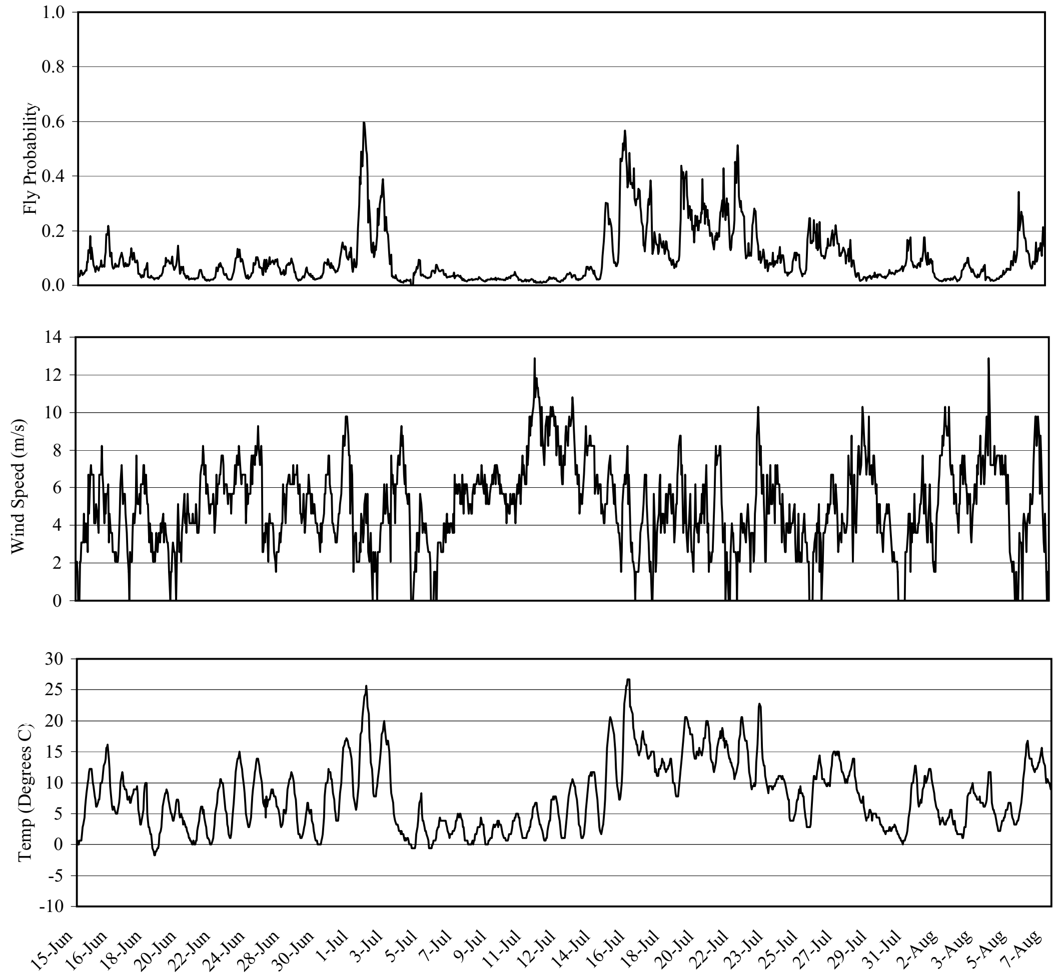
Appendix B. (Continued).



Appendix B. (Continued).



Appendix C. Index of annual insect-season severity (expressed as cumulative thawing degree-days in º C above freezing) from mid-June through July 1983–2001



Appendix D. Probability of oestrid fly activity (index from Mörschel and Klein 1999) in summer 2001, based on wind speed and air temperature recorded at Nuiqsut.

Appendix E. Classification and description of vegetation types mapped in the Meltwater study area, 2001.

Class	Description
Water	Areas covered by permanent water. Small inclusions of Fresh Grass or Sedge Marsh may be present.
Shallow Water/Fresh Sedge Marsh	Permanently flooded shallow waterbodies that may be vegetated or unvevegetated. Where present, vegetation is dominated by *Carex aquatilis.*
Fresh Grass Marsh	Ponds and lake margins with emergent *Arctophylla fulva*.
Wet Sedge–Willow Meadow (Lowlands)	Vegetation is dominated by sedges, usually *Carex aquatilis* and *Eriophorum angustifolium,* although other sedges may be present, including *C. rotundata, C. saxatilis, C. membranacea, C. chordorriza,* and *E. russeolum*. Willows, including *Salix lanata*, *S. arctica,* and *S. pulchra*, may be co-dominant on better-drained sites and nearly absent in recently drained lake basins and non-patterned meadows. This class usually is associated with low-centered polygons, Disjunct Polygons, Strang, and Nonpatterned Ground. The surface generally is flooded during early summer (depth < 0.3 m) and drains later, but remains saturated within 15 cm of the surface throughout the growing season. Soils usually have a moderately thick (10-50 cm) organic layer over silt loam. This map class may also include small inclusions of Fresh Sedge Marsh and Moist Sedge–Shrub Tundra.
Wet Sedge–Willow Meadow (Watertrack)	Vegetation is dominated by sedges, usually *Carex aquatilis* and *Eriophorum angustifolium.* This type usually occurs in drainage tracks on gentle slopes and other areas with a deeper active layer and higher productivity compared with Wet Sedge–Willow Meadow found in lowlands and thaw basins. Drainage tracks flood in spring and some surface water remains throughout the summer. Willows (e.g. *Salix pulchra*) may be co-dominant in areas outside of water tracks, this map class has inclusions of low shrub.
Moist Sedge–Shrub Tundra	Vegetation is dominated by *Carex aquatilis, C. bigelowii, Eriophorum angustifolium, Salix pulchra*, and *Dryas integrifolia*. Other common vascular species include *S. reticulata, Vaccinium vitis-idaea, Cassiope tetragona, Chrysanthemum integrifolia, Senecio atropurpureus, Pedicularis lanata, P. capitata, Polygonum viviparum,* and *Papaver macounii;* small quantities of *E*. vaginatum often are present. The ground is covered with a nearly continuous carpet of mosses usually including *Tomenthypnum nitens, Hylocomium splendens, Aulacomnium turgidum,* and *Dicranum* spp. This class combines Sedge–Willow and Sedge–*Dryas* Tundra. In the Meltwater study area this class is most common on better-drained uplands between thaw basins, lower slopes of pingos, thaw-lake plains, and foothill slopes. Usually associated with high-centered, low-relief polygons, this class can also be found on Nonpatterned Ground, with Frost Scars or in mixed polygon areas. In high-relief areas (especially high-centered polygons) vegetation communities are more complex, including wet and aquatic sedge vegetation in flooded troughs. Generally, soils are saturated at intermediate depths (> 15 cm) and free of surface water during summer; some sites may be inundated briefly during break-up. This type shares many plant species with Tussock Tundra and Dwarf Shrub Tundra and transition types among the three classes are common.

Appendix E. (Continued).

Class	Description
Moist Tussock Tundra	The vegetation is dominated by the tussock-forming sedge *Eriophorum vaginatum*; associated species include *Carex bigelowii*, *Dryas integrifolia*, *Cassiope tetragona*, and *Salix reticulata*. Many of the associated species are similar to those listed for Moist Sedge–Shrub Tundra. Found on broad upper slopes of ridges on coastal plain deposits and within ice-rich basins. Water generally is absent from the active layer during midsummer but occasionally can be found near the surface (>15 cm depth). Areas of transition between this class and Moist Sedge–Shrub Tundra are common.
Dwarf Shrub Tundra	This type is a compilation of three dwarf shrub classes: *Dryas* Tundra, *Cassiope* Tundra, and Dwarf Willow Tundra. *Dryas* Tundra is dominated by *Dryas integrifolia* which forms an open to closed cover. Other common species include *Salix reticulata, S. phlebophylla, Carex bigelowii, and C. scirpodea.* Forbs (e.g. Silene acaulis, Papaver spp.) are found on moister sites, and lichens (e.g. *Cladonia* spp*., Cladina* spp.) on drier sites. *Tomenthypnum nitens* is a common moss in this class. *Dryas* Tundra is found on well drained sites, usually ridges, pingos and occassionally stream terraces. *Cassiope* tundra typically occurs in snowbeds at the base of shallow slopes and on colluvium. The class is dominated by an open to closed cover of *Cassiope tetragona.* Other common species include *Vaccinium uliginosum, Salix reticulata, S. phlebophylla, Carex bigelowii*, *Festuca altaica, Boykinia richardsonii* and *Lupinus arcticus*. *Tomenthypnum nitens* is a common moss. Dwarf Willow Tundra often is dominated by an assembledge of dwarf willows including *Salix polaris, S. rotundifolia, S. reticulata, S. phlebophylla, and S. arctica*. Other common species include *Equisetum arvense, Astragalus alpinus, Anemone richardsonii, Carex aquatilis, Trisetum spicatum,* and *Arctagrostis latifolia.* In the Meltwater area*,* This class most often is found along the banks of small streams. Soils are well drained, lack an organic horizon and show indications of frequent sedimentation.
Low Shrub Tundra	This class is most common in the southern portions of the Meltwater area where it is predominantly composed of closed low willow (>75% cover) on shallow to moderate slopes and in creek drainages. *Salix pulchra* and *S.* glauca are the most common willows. Also included in this class are stands of open low willow (25-75% cover) on floodplains and uplands. On better-drained stable sand dunes, *S. glauca* is dominant; associated species include *Dryas integrifolia, S. reticulata, Cassiope tetragona, Arctostaphylos rubra,* and *Astragalus umbellatus*. On wetter sites such as floodplains and drained lake basins, *S. lanata* and *S. planifolia* are more common and sedges also are important. Associates include *Carex aquatilis*, *C. bigelowii*, *Eriophorum angustifolium*, *Arctagrostis latifolia*, *Dryas integrifolia*, *S. reticulata*, *Lupinus arcticus*, and mosses such as *Tomenthypnum nitens.* This class may include some Wet Sedge–Willow Watertrack or more highly productive areas of Dwarf Shrub Tundra, e.g. *Dryas* Tundra with a high forb component.
Barren	Barren flats on river floodplains, sand sheets, and recently drained lake bottoms that are recently exposed or too unstable to support more than a few pioneering plants (<30% cover). Typical pioneer plants include *Salix alaxensis, Elymus arenarius,* and *Deschamspia caespitosa.* Riverine Barrens include river flats and bars. These areas are flooded seasonally and are underlain by fine-grained sediments (primarily silt) overlying sandy gravel. Lacustrine Barrens include newly drained lake basins as well as unvegetated margins of lakes and ponds in which water level fluctuations inhibit vegetation growth. These areas are flooded seasonally and are underlain by clay and silt. This class also includes gravel pads, gravel pits and roads and could include some areas covered by snow.

Appendix F. Number and density (caribou/km2) of caribou groups at various distances from the Meltwater and Tarn roads during pre-calving, calving, and post-calving 2001..

				Calf Groups		Total Groups			Calf Density		Adult Density		
Area		Distance (km)	Area (km²)	Calving	Post Calving	Pre Calving	Calving	Post Calving	Calving	Post Calving	Pre Calving	Calving	Post Calving
water	West	>10	4.49	0	0	1	0	5	0.00	0.00	0.17	0.00	0.78
		8-10	12.51	1	2	0	2	22	0.05	0.06	0.00	0.21	1.28
		6-8	13.44	3	3	1	7	14	0.10	0.11	0.07	0.30	1.25
		4-6	13.71	3	5	0	4	19	0.07	0.13	0.00	0.15	1.50
		2-4	13.95	5	6	2	7	15	0.14	0.29	0.13	0.55	1.38
		0-2	14.39	0	2	1	4	11	0.00	0.05	0.03	0.32	0.47
	East	0-2	14.87	2	1	0	7	14	0.07	0.05	0.00	0.65	1.08
		2-4	14.25	1	0	1	8	9	0.02	0.00	0.02	0.47	0.25
		4-6	13.85	6	1	0	10	14	0.39	0.02	0.00	1.40	0.81
		6-8	13.62	8	6	2	17	17	0.42	0.24	0.07	1.86	1.45
		8-10	13.41	8	13	0	15	22	0.47	0.95	0.00	1.99	2.85
		>10	15.83	3	9	0	9	34	0.13	1.04	0.00	0.95	3.30
		total	158.30	40	48	8	90	196	0.16	0.27	0.03	0.78	1.41
	West	>10	1.75	0	1	1	0	2	0.00	0.14	0.43	0.00	0.29
		8-10	7.77	0	2	3	1	10	0.00	0.16	0.58	0.09	0.87
		6-8	13.95	0	4	3	1	13	0.00	0.13	0.27	0.05	0.59
		4-6	14.16	0	1	3	0	12	0.00	0.02	0.16	0.00	0.83
		2-4	14.42	0	4	1	0	11	0.00	0.12	0.05	0.00	1.01
		0-2	14.66	1	8	0	2	32	0.05	0.32	0.00	0.16	2.29
	East	0-2	18.38	3	10	0	8	36	0.05	0.24	0.00	0.33	2.12
		2-4	18.71	11	18	0	25	42	0.29	1.83	0.00	1.18	5.71
		4-6	16.88	15	18	0	32	29	0.55	1.53	0.00	2.59	3.23
		6-8	16.00	9	18	0	20	34	0.54	1.97	0.00	2.88	5.88
		8-10	11.77	8	13	0	17	26	0.51	2.85	0.00	2.86	6.56
		>10	9.88	9	7	0	15	16	0.54	2.05	0.00	1.79	5.92
		total	158.33	56	104	11	121	263	0.23	1.01	0.08	1.09	3.19

Appendix G. Comparison of vegetation classes derived from Landsat TM classification (this study) with Multispectral Scanner-derived landcover types (Muller et al. 1999).

Landsat TM Vegetation Classes	Multispectral Scanner Landcover Types
Water	Water
Fresh Grass Marsh	Water
Shallow Water/Fresh Sedge Marsh	Water; Wet Graminoid Tundra
Wet Sedge–Willow Meadow (Lowlands)	Wet Graminoid Tundra; Moist Low-shrub Tundra
Wet Sedge–Willow Meadow (Watertrack)	Moist Low-shrub Tundra
Moist Sedge–Shrub Tundra	Moist Graminoid, Prostrate-shrub Tundra
Moist Tussock Tundra	Moist Tussock-graminoid, Dwarf-shrub Tundra
Dwarf Shrub Tundra	Dry Prostrate-shrub Tundra and Barrens
Low Shrub Tundra	Moist Low-Shrub Tundra
Barren	Dry Prostrate-Shrub Tundra and Barrens
Snow	Clouds and Ice

Moist Sedge–Shrub Tundra

Moist Tussock Tundra

Wet Sedge–Willow Meadow, watertrack
(with Moist Tussock Tundra)

Wet Sedge–Willow Meadow, lowland

Low Shrub Tundra

Dwarf Shrub Tundra

Appendix H. Photographs of representative vegetation classes mapped in the Meltwater study area, northern Alaska.